BSEFS

Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995–2023

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Key Message

Annual water flow in 2023 to the Baltic Sea was approximately 16,800 m^3 s^{-1} (9,7 l s^{-1} km^{-2}) which is 7.6% higher than the average of 1995-2022. This is markedly higher flow than average to four sub-basins, 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 689,000 tonnes in 2023 or about 19% higher than the average of 2013-2022. Compared to 2022 the flow in 2023 was 2,300 m^3 s^{-1} (16%) higher and the waterborne TN inputs were 126,000 tonnes (or 22%) higher. The annual waterborne total phosphorus inputs (TP) in 2023 amounted to approximately 21,400 tonnes, which is about 5% (1,300 tonnes) lower than the average of 2013-2022, but about 3,900 tonnes (or 22%) higher than in 2022.

Inputs of nitrogen and phosphorus from direct point sources have decreased with approximately 57% and 83% since 1995, respectively. In 2023, inputs from direct point sources constituted 3.8% TN and 5.0% TP of the corresponding total waterborne input to the Baltic Sea. In 1995, the proportions of direct inputs were 7.8% for TN and 15% for TP, respectively. Annual inputs from direct point sources are rather small compared with inputs from diffuse sources via rivers.

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, 9% and 45% respectively (compared with 15% for TN and 48% for TP, respectively in 2022).

Annual precipitation in 2023 was higher than normal (1991-2020) in most of the Baltic Sea catchment areas: Denmark, Germany, biggest part of Estonia, Finland, Latvia and Poland, Southern half of Sweden. In the northern half of Sweden, northern part of Finland, northern part of Poland and Lithuania annual precipitation was below or close to average. Particularly Denmark, Germany and the southwestern part of Sweden had very high precipitation, with Denmark having highest precipitation on record (more that 7 % higher than former highest on record).

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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 1995-2023. 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 1995-2022) (Svendsen et al, 2025), 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 as direct point source discharges. The main sources of waterborne input are diffuse anthropogenic sources (agriculture, managed forestry, scattered dwellings, storm overflows etc.), natural background sources and point sources (such as wastewater 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 89% of TP inputs in 2022 (Svendsen et al, 2025).

Time series with information on annual nutrient inputs are needed in order 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 pollutant 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, TP and total flow during 1995-2023 are included in tables 2-8 per Baltic Sea sub-basin and for the Baltic Sea as a whole.

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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 2023 data, Finland has updated flow for direct point sources during 1995-2022 making the dataset more complete (direct flow higher than reported earlier). Otherwise only very minor revisions have been provided on former reported 1995-2022 data.

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 2023 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 parts of the catchment, and thereby on inputs of nitrogen and phosphorus. Overall rainfall in amounts exceeding 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 rainfall can result in high flow and nutrient loads in rivers and surface erosion.

While precipitation can infiltrate dry soils without or with only minor fractions entering inland surface waters as surface runoff during spring and summer, soils tend to be saturated in autumn and winter and a bigger fraction of the participation will enter inland surface waters as surface runoff. 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.

Maps on 2023 precipitation deviation from the reference period 1991-2020 in Europe 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 2023 was higher than normal (long term average of 1991-2020) in most of the Baltic Sea catchment areas. Particularly in Denmark with highest precipitation on record (+28 % compared with normal), Germany, biggest part of Estonia, Finland, Latvia and Poland, Southern half of Sweden had higher (typical +5-15 %) than average 1991-2020 precipitation. Northern half of Sweden, northern part of Finland, northern part of Poland and Lithuania where below (5-15%) or close to average. Particularly Denmark, western part of German catchment to the Baltic Sea and southwestern part of Sweden, southern part of Finland and parts of Latvia had precipitation described by Copernicus as either much above or exceptionally much above (average figure A.3), with Denmark having highest precipitation on record (more that 7 % higher than former highest on record).

Winter (December 2022-February 2023) was 5-20 % wetter than average in most part of the Baltic Sea catchment areas, and particularly in Denmark and southwestern part of Russia. Spring was drier (10- 40 %) for most of the catchment in the Baltic States, Germany, northern part of Finland, most of Poland, Russia and Sweden, but wetter (5-15%) in Denmark, part of southern and mid-Finland and southwestern Sweden. Summer 2023 precipitation was drier or close to normal (5-20%) in most parts of Estonia, southern part of Lavia, parts of Lithuania, Germany, main part of Poland, Russia and in the northern parts of Sweden. Precipitation was higher or very much higher (up to more than 40% over the long-term average) in Denmark, southern part of Sweden, southwestern and central part of Finland, northern part of Lativa and some central part of Poland. Autumn was wetter or a lot wetter (10-35%) than normal in Denmark, Estonia, most of Germany, Finland, Poland Russia and some parts of central and northern part of Sweden, but close to normal or drier (5-20%) in southern part of Latvia, parts of Lithuania and southern and some central parts of Sweden.

Annual average temperature was higher that the long-term average for the Baltic Sea catchment. It was particularly high for Estonian, German, Latvian, Lithuanian and Russian part of the Baltic Sea catchment area ranking among top 1 to top 6 warmest years since 1950 (figure A.5).

Denmark had record January and July, and highest annual precipitation on record and 28% higher than long-term average (1991-2020). High rain falls resulted in high flows from Denmark: to Kattegat 27% higher (precipitation 26% higher) than long term average, 20% higher (precipitation 24% higher) to Danish Straits but only 7% higher to Baltic Proper (precipitation 15% higher). The very rainy condition led to widespread flooding in river valleys and further on agricultural areas in many months, and it affected harvest in late summer and autumn 2023. It also affected runoff conditions and nitrogen loads in 2024.

In Estonia annual flow was 6% higher that the long-term average (defined for Estonia as 1992-2022. For Narva River only flow from the monitoring point at the border is reported. No estimates on total flow are available.

For Finland the higher than long-term average precipitation on the most of Finnish catchment to the Baltic Sea was also reflected in the flow: It was higher than long-term average to Bothnian Bay (11%), Bothnian Sea (30%), Archipelago Sea (23%) and Gulf of Finland (17%).

Despite precipitation higher to much higher than long-term average Germany estimates runoff about 24% lower than the long-term average (1994-2022), which partly can be contributed to low precipitation that were 15 % lower compared with the reference period 1991-2020.

Latvia had higher than long term-average precipitation and temperature in January and February 2023 resulting in high flow and nitrogen leaching from most catchments.

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

Overall, the flow to Baltic Proper from Lithuania in 2023 was close to average of 1995-2020 while it was 37% higher than the average to Gulf of Riga.

In Poland annual flow was 2023 about 7 % below long-term average (1995-2022) but nearly 16% higher than the preceding 5 years (2018-2022).

The rainfall in Sweden was much above long-term average in the southern parts, but close to it in the northern part. The Early part of 2023, and early late summer and autumn was wetter than the long- term average, but May and June were very dry. Early autumn snow stayed for the remainder of 2023.

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, 2024, 2025), 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) provide 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 2023. Flows are compared with the long-term average (1995-2022), but as there have been marked reductions in TN and TP input in the early part of the timeseries, TN and TP inputs in 2023 are compared with the corresponding latest ten years average (2013-22). Table 1a and b also include 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 for 2023 from averages in percentages. Flow to the Baltic Sea in 2023 was about 16,800 m^3 s^{-1} or 7.6% higher than the 1995-2022 average. The flow was 27% higher than average to Gulf of Riga and 24 % higher to Kattegat and between 7.7 and nearly 17 % higher to Bothnian Bay, Bothnian Sea and Danish Straits. Flow to Gulf of Finland (+1.4%) and Baltic Proper (- 2.5%%) was close to the 1995-2022 average. The flow is closely related to the precipitation, which was high to very high in Denmark, (precipitation highest on record), Germany, southern part of Sweden, parts of Poland, catchment to Gulf of Riga and southern part of Finland, and for the remaining part of the catchment to the Baltic Sea close to the long-term average.

Waterborne 2023 TN inputs to the Baltic Sea amounted more than 689,000 tons or 19% higher than average TN inputs during 2013-2022. The corresponding TP inputs were 21,400 tons or 5.7% lower than average 2013-2023 TP inputs. Compared with 2022 the flow in 2023 was nearly 2,300 m^3 s^{-1} higher (+16%), TN waterborne inputs were about 126,000 tonnes higher (+22%), and TP waterborne inputs was nearly 3,900 tonnes higher (+22%). With flow on average nearly 8.0% higher than long term average, and to some basins nearly 30% higher, should imply waterborne nutrient inputs higher than 2013-2022 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 +19% higher total nitrogen inputs in 2023 are partly a result of higher flow than long term average in the part of the Baltic Sea catchment area with high agricultural activity such as Denmark, part of Germany, parts of Poland, southern parts of Finland and Sweden, and the catchment to Gulf of Riga, while the northern part of Finland and Sweden with low agricultural activity had flow/precipitation conditions close to the long-term average. The four basins with flows between 13% to 27% higher than the long-term average (Bothnian Sea, Gulf of Riga, Danish Straits and Kattegat) provided nearly 39% of total waterborne nitrogen inputs in 2023 compared with nearly 34% during 2013-2022. Total nitrogen inputs to Baltic Proper were nearly 19% higher than the 2013-2022 average but flow was 2.5% lower than long-term average. But most of the southwestern part of the catchment to Baltic Proper with the highest agricultural activities, had higher than average flow, leading to higher nitrogen inputs from diffuse sources. In addition, we have indications of significantly increasing total nitrogen inputs from these areas to Baltic Proper in the latest 10 to 15 years.

For total phosphorus the importance of inputs from point sources/wastewater are higher than for nitrogen, but stormwater effluents are important to some Baltic Sea sub-basins, and the importance of higher 2023 flow than long-term average ended up with higher than 2013-2022 average total phosphorus inputs to Gulf of Riga (+39%), Kattegat (+22%), Bothnian Sea (+18%), and Danish Straits (+13%) which also indicates the importance of diffuse phosphorus inputs to the sea. Approximately 35% of the total phosphorus inputs to the Baltic Sea in 2023 entered from the four sub-basins with high flows in 2023 compared with long-term average in average of 2013-2022 with 26%. For Baltic Proper and Gulf of Finland with 2023 flow close to long-term average total phosphorus inputs was markedly lower than 2013-2022 average, 21% and 18%, respectively, which among other factors indicate effects of improved treatment of wastewater. It should be noted that particularly for phosphorus the sampling frequency and whether samples also are taken under high flows have an impact on the estimated inputs. Finland indicates in the annual report that they to some basins might have to low sampling frequency and not being sampling under some important high flow/high load episodes in 2023, leading to an underestimation of the particle bound phosphorus inputs. The situation might be similar for some other countries.

While waterborne phosphorus inputs have been decreasing overall 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.

Annual flow-weighted riverine concentration (calculated by dividing annual riverine nutrient input with the corresponding water flow[3]) to the Baltic Sea in 2023 was 1.27 mg N l^{-1} or 0,09 mg N l^{-1} (9.2%) higher than the corresponding concentration during 2013-2022. For TP it was 0.039 mg P l^{-1} or 0,006 mg P l^{-1} (14%) lower than the corresponding average of 2013-2022. Flow-weighted TN concentrations were

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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.

lower than the 2013-2022 average for only two basins, Gulf of Finland (7.2%) and Kattegat (4.0%), and higher to four basins: Bothnian Sea (+14%), Gulf of Riga (10%), Baltic Proper (8.0%) and Bothnian Bay (3.8%) (table 1.c). For Danish Straits the concentrations in 2023 were close to the average of the last 10 years. It seems like the significant increase in (flow-normalized) waterborne TN inputs in recent years to some basins is affecting the discharge weighted concentrations. It is remarkable that the flow to Gulf of Riga in 2023 was 27% higher than the long-term average, leading to 61% higher waterborne total nitrogen inputs but “only” 10% higher flow weighted TN concentrations compared to 2013-2022 average. For Kattegat the 2023 flow was 24% higher than long-term average, waterborne inputs 26% higher than the 2013-2022 average but the flow-weighted concentration was 4% lower. Nutrient inputs to Kattegat are highly impacted by inputs from Göta Älv, and the catchment to this river includes some very big lakes, and flow and loads are regulated by dams and channels.

Flow-weighted TP concentration was lower than the 2013-2022 average to five sub-basins: Baltic Proper (29%), Gulf of Finland (16%), Kattegat (5.2%), Gulf of Riga (3.4%) and Danish Straits (2.8%), For two basins it was higher: Bothnian Sea (7.6%) and Bothnian Bay (6.0%) (table 1.c).

On page 3 and 4 and on the annex is information on the overall weather conditions on other circumstances to consider when evaluating the flow, waterborne TN and TN in 2023 to the Baltic Sea and the distribution between sub-basins.

Area specific waterborne catchment nutrient inputs in 2023 were highest to the Danish Straits (1.444 kg N km^{-2}, 44 kg P km^{-2}) (table 1.a), reflecting high population density and high proportion of agricultural land-use. The lowest area specific inputs are for the Bothnian Bay and the Bothnian Sea (196-250 kg N km^{-2} and 9.4-9.7 kg P km^{-2}) (table 1.b), 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. 396 kg N km^{-2} and 12 kg P km^{-2}. On the other hand, specific waterborne inputs per sea area are highest to the Gulf of Riga (1,857 kg N km^{-2}, 133 kg P km^{-2}) but lowest to the Bothnian Sea (722 kg N km^{-2}, 27 kg P km^{-2}). Average for the Baltic Sea is approx. 1,650 kg N km^{-2} and 51 kg P km^{-2}).

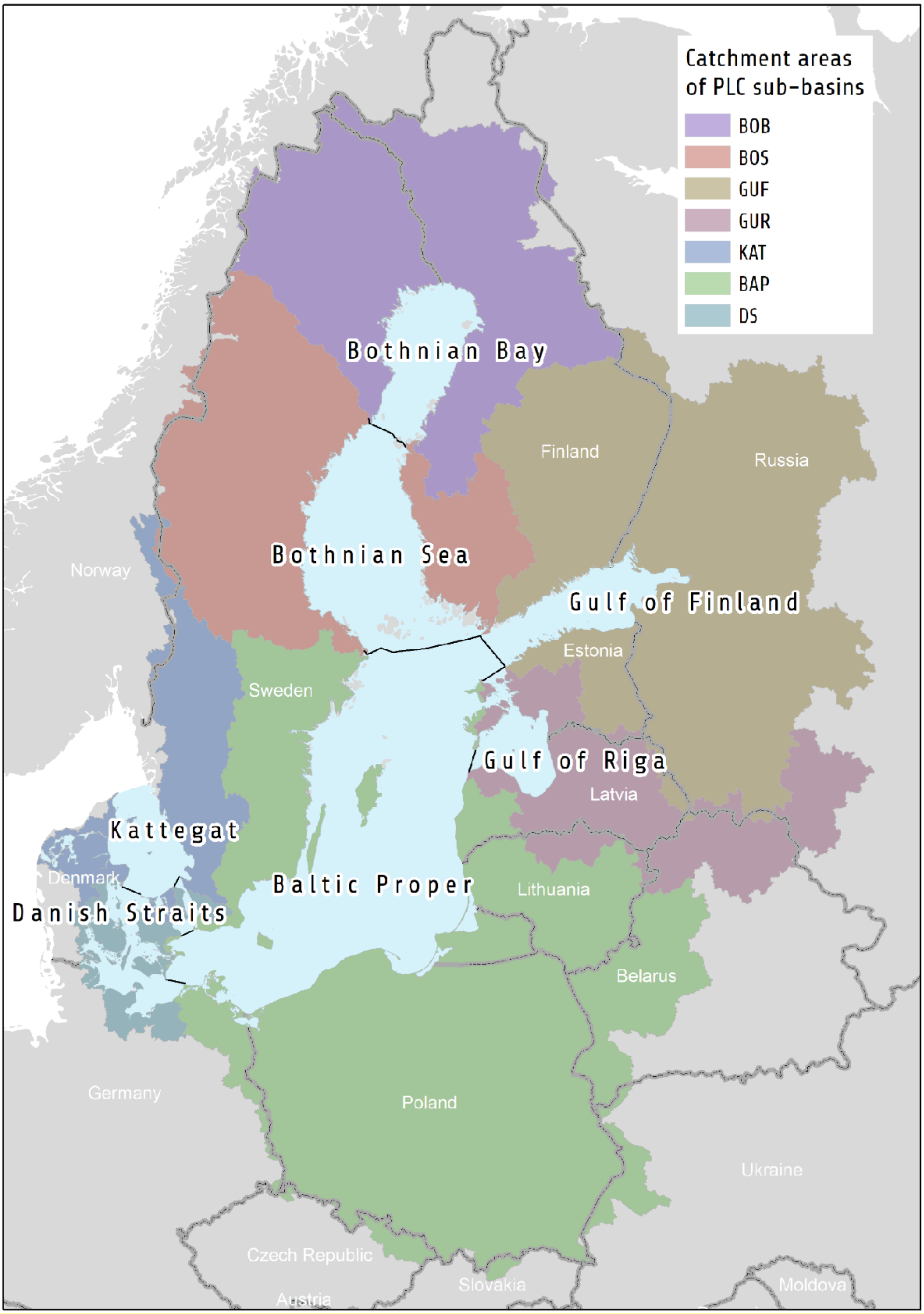


Figure 1. The catchment of the Baltic Sea is shared by nine HELCOM Contracting Parties - Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Latvia (LV), Lithuania (LT), Poland (PL), Russia (RU) and Sweden (SE) and 5 transboundary countries (Belarus, Czech Republic, Slovakia, Norway and Ukraine). 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 2023 and on average of 1995-2022 for flow and 2013-2022 for TN. Flow weighted TN concentrations (mg l^{-1}) of annual riverine inputs in 2023 and on average of 2013-2022. 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	**Sub-basin sea area**	**Flow**	**Flow**	**Flow**	**Flow**	**TN water-borne**	**TN water-borne**	**TN flow-weight. river conc.**	**TN flow-weight. river conc.**	**TN water-borne/ catch.area**	**TN water-borne / sea area**
			2023	**1995-2022**	**2023**	**1995-2022**	**2023**	**2013-2022**	**2023**	**2013-2022**	**2023**	**2023**
	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}**
BOB	263,000	36,000	3,737	3,470	14.2	13.2	51,646	49,217	0.42	0.40	196	1,435
BOS	228,000	79,000	3,308	2.,925	14.5	12.8	57,066	45,582	0.54	0.47	250	722
BAP	576,000	209,000	3,280	3,364	5.7	5.8	278,745	235,122	2.66	2.46	484	1,334
GUF	423,000	30,000	3,592	3,541	8.5	8.4	91,904	100,205	0.74	0.80	217	3,063
GUR	138,000	19,000	1,340	1.055	9.7	7.6	113,419	70,326	2.68	2.42	822	5,969
DS	27,000	21,000	251	215	9.3	8.0	39,000	32,253	4.75	4.77	1,444	1,857
KAT	87,000	24,000	1,329	1,073	15.3	12.3	57,643	45,637	1.33	1.39	663	2,402
BAS	**1,742,000**	**418,000**	**16,837**	**15,643**	**9.7**	**9.0**	**689,424**	**578,342**	**1.27**	**1.16**	**396**	**1,649**

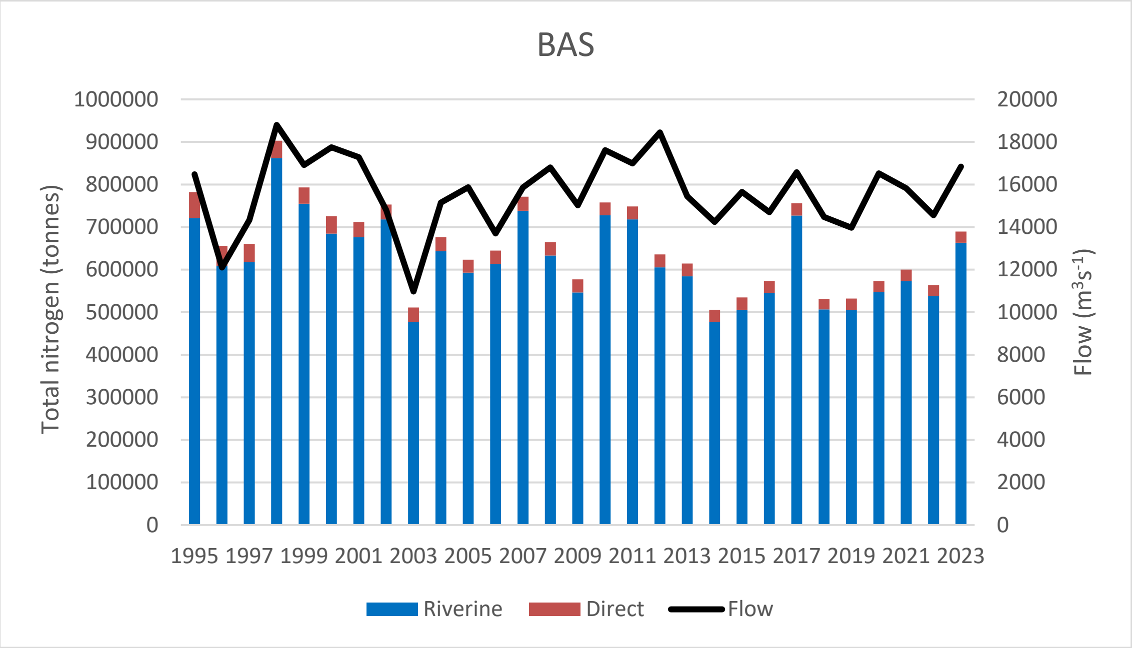
Table 1.b Catchment area to and sea area of the seven sub-basins of the Baltic Sea (km^2). Annual waterborne flow (m^3 s^{-1}), area specific flow (l s^{-1} km^{-2}), waterborne total phosphorus inputs TP (tonnes) in 2023 and on average of 1995-2022 for flow and 2013-2022 for TP. Flow weighted TP concentrations (mg l^{-1}) of annual riverine inputs in 2023 and on average of 2013-2022. 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.

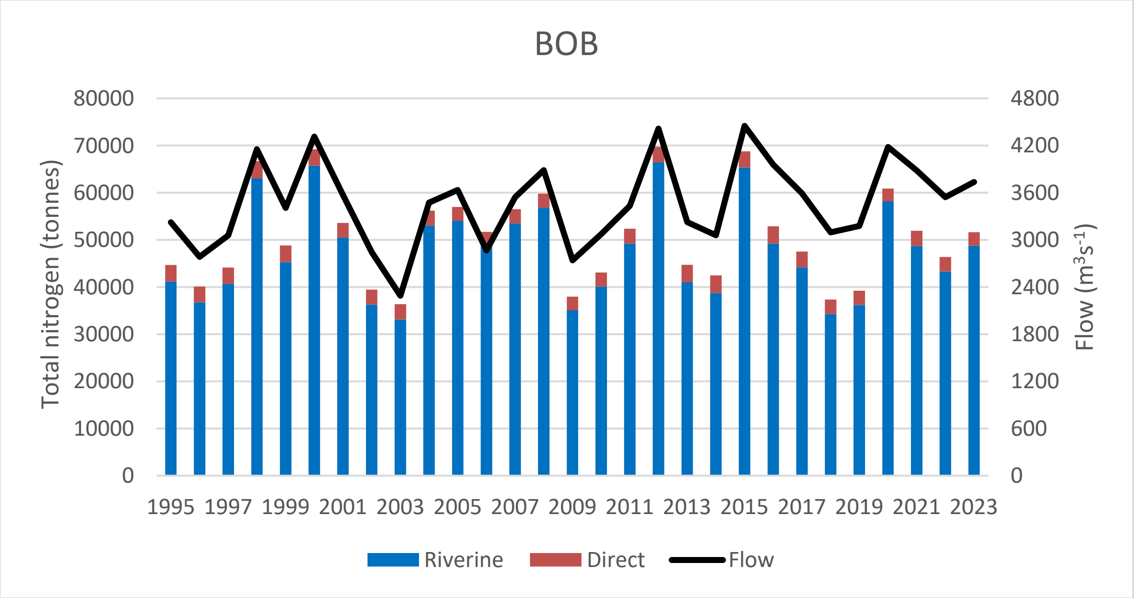
	Catchment area	**Sub-basin sea area**	**Flow 2023**	**Flow 1995-2022**	**Flow 2023**	**Flow 1995-2022**	**TP water-borne 2023**	**TP water-borne 2013-2022**	**TP flow-weight. river conc. 2023**	**TP flow-weight. river conc. 2013-2022**	**TP water-borne/ catch.area 2023**	**TP water-borne / sea area 2023**
	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}**
BOB	263,000	36,000	3,737	3,470	14.2	13.2	2,545	2,377	0,021	0,020	9.7	71
BOS	228,000	79,000	3,308	2,925	14.5	12.8	2,152	1,829	0,020	0,019	9.4	27
BAP	576,000	209,000	3,280	3,364	5.7	5.8	8,099	10,296	0,077	0,108	14	39
GUF	423,000	30,000	3,592	3,541	8.5	8.4	3,289	4,016	0,027	0,032	7.8	110
GUR	138,000	19,000	1,340	1,055	9.7	7.6	2,525	1,816	0,059	0,061	18	133
DS	27,000	21,000	251	215	9.3	8.0	1,189	1,056	0,128	0,132	44	57
KAT	87,000	24,000	1,329	1,073	15.3	12.3	1,599	1,299	0,036	0,038	18	67
BAS	**1,742,000**	**418,000**	**16,837**	**15,643**	**9.7**	**9.0**	**21,399**	**22,689**	**0,039**	**0,045**	**12**	**51**

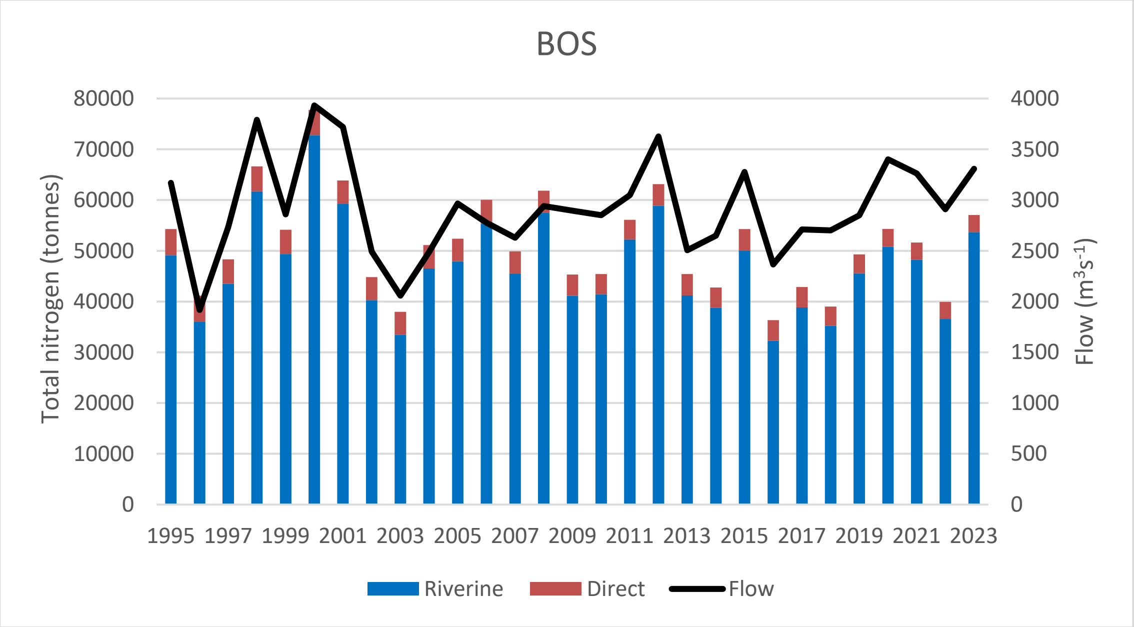
Table 1.c Deviation in 2023 in percentages from average flow during 1995-2022, and for TN and TP flow weighted riverine concentration and total TN and TP waterborne input in 2023 from corresponding averages during 2013- 2022.

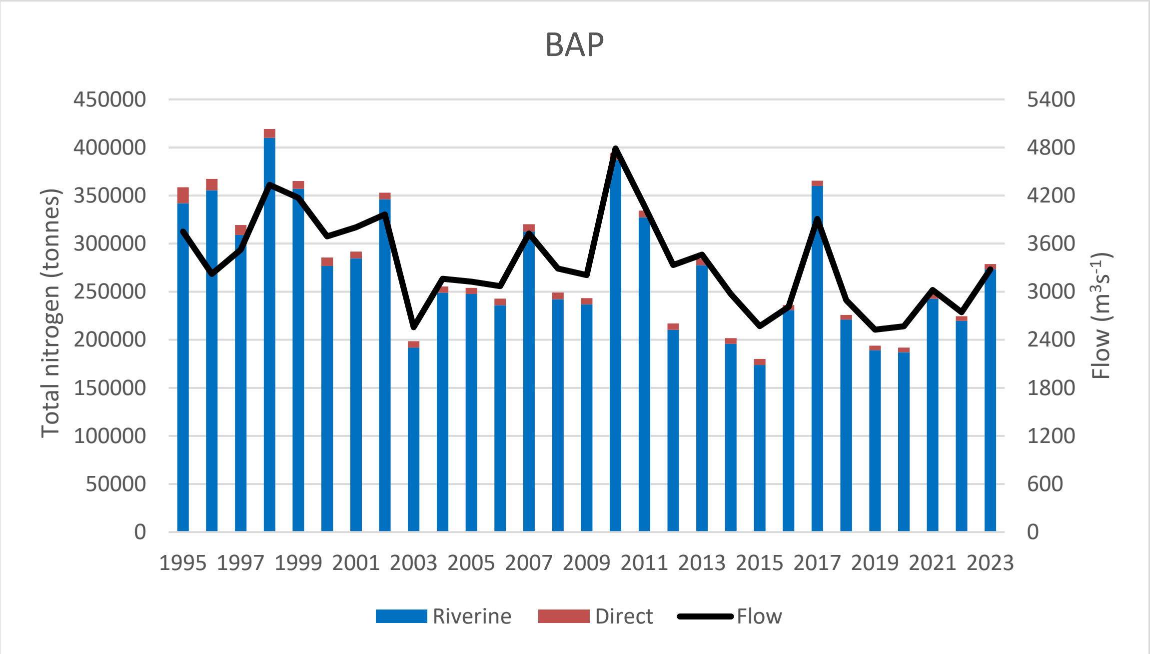
	Flow Deviation % From 1995-2022	**TN flowconc. Deviation % From 2013-2022**	**Total N Deviation % From 2013-2022**	**TP flowconc. Deviation % From 2013-2022**	**Total P Deviation % From 2013-2022**
BOB	7.7	3.6	4.9	6.0	7.1
BOS	13.1	13.8	25.2	7.6	17.7
BAP	-2.5	8.0	18.6	-28.7	-21.3
GUF	1.4	-7.2	-8.3	-16.0	-18.1
GUR	27.0	10.4	61.3	-3.4	39.0
DS	16.7	-0.5	20.9	-2.8	12.5
KAT	23.9	-4.0	26.3	-5.2	23.1
BAS	7.6	9.2	19.2	-13.8	-5.7

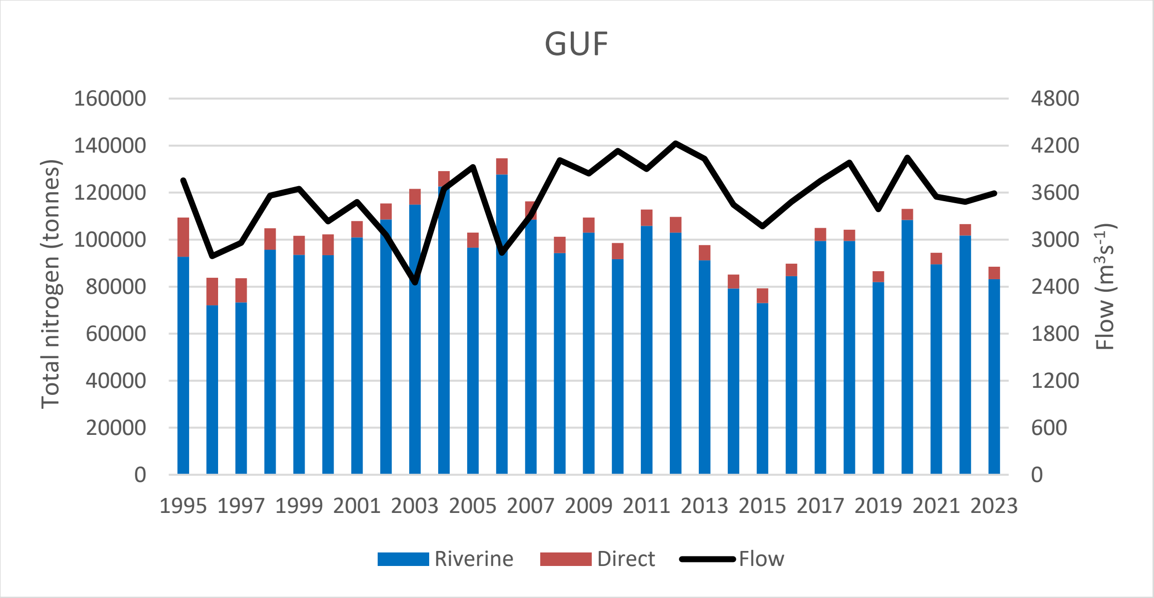
The annual water flow, direct - and riverine inputs of TN and TP during 1995-2023 to the Baltic Sea basins and to the Baltic Sea are shown in Figure 2a and b as well as in Tables 2-8 in the “Data” section. There are significant reductions in total direct nitrogen inputs from 1995 to 2022 to the Baltic Sea (57%). 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 (72%), Baltic Proper (68%) and to Gulf of Riga (63%). There are significant reductions of direct TP inputs to all basins, the highest Gulf of Finland (91%), Gulf of Riga (88%), Baltic proper (86%), and resulting in a total reduction of 83% to the Baltic Sea from these sources, although data on direct inputs are more uncertain in the beginning of the time series, and there have been some updates in the reported data by Finland. The reduction by 2022 in TN and TP from direct point sources since 1995 to Baltic Sea was 58% for total nitrogen and 84% for total phosphorus. The high flows to some of the sub- basins in 2023 compared with 2022 where flow overall was lower than long-term average are affecting reductions since 1995: reduction in direct nitrogen inputs 1995-2022 was 68% but for 1995 to 2023 only 63%. The corresponding numbers for Danish Straits was 76% versus 72% and for Kattegat 69% versus 50%. For Bothnian Bay where flow in 2022 and 2023 was almost the same direct nitrogen inputs was reduced with 12% from 1995 tom 2022 and 18% from 1995 to 2023 and corresponding number for total phosphorus was 57% versus 59 %. For Danish Strait (77% versus 74%), Kattegat (69% versus 61%) and Bothnian Sea (64% versus 61%) the higher flows in 2023 compared to 2022 have affected the decrease of phosphorus in percentage since 1995. Direct inputs to the Baltic Sea in 2023 constitute only a minor share of the total waterborne TN and TP inputs (3.8% and 5.0%, respectively), but they provide large proportions of the nutrient inputs to some sub-basins e.g., the Danish Straits (9.1%) and Gulf of Finland (9.5%) for TN, and the Danish Straits (20%) and Bothnian Sea and Baltic Proper (7.3% and 7.7%, respectively) for TP, and the importance is highest in years with low flow as 2022, and of lower importance in years with high flows as 2023.

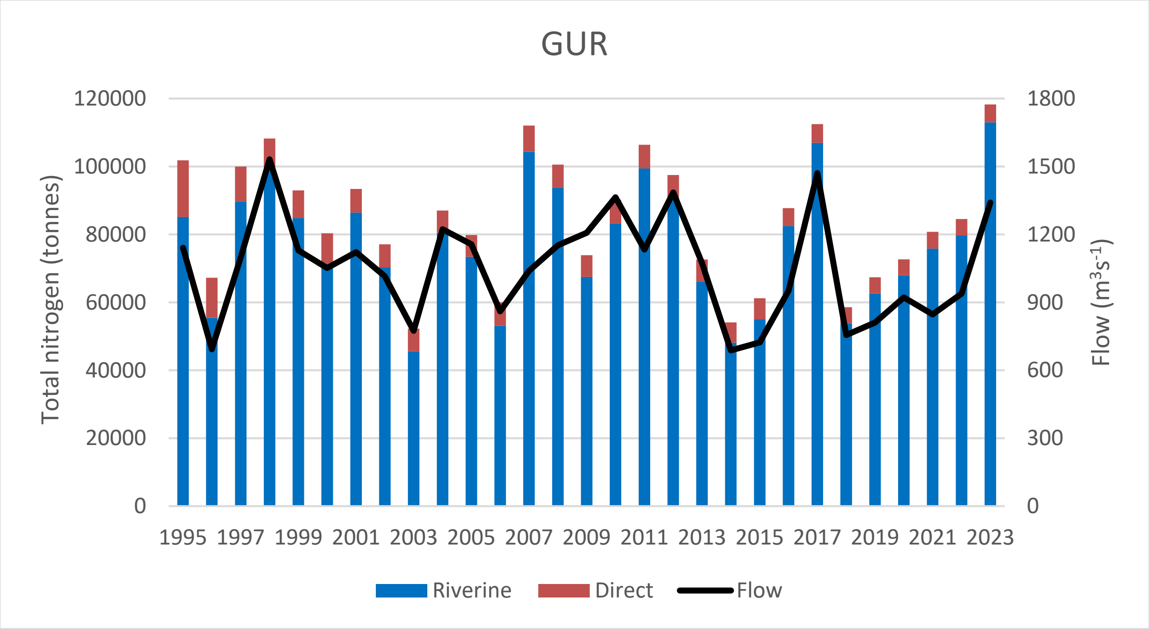

BAS
Total nitrogen (tonnes)
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Flow (m³s⁻¹)
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023
Riverine
Direct
Flow

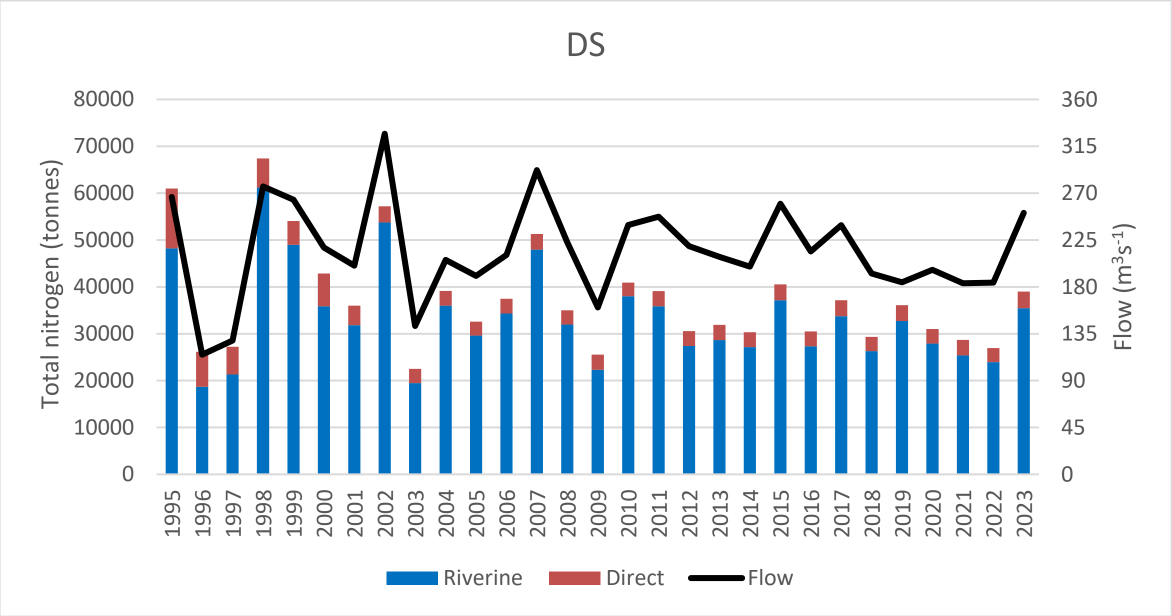

BOB
Total nitrogen (tonnes)
80000
70000
60000
50000
40000
30000
20000
10000
0
4800
4200
3600
3000
2400
1800
1200
600
0
Flow (m³s⁻¹)
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023
Riverine
Direct
Flow


BOS
Total nitrogen (tonnes)
80000
70000
60000
50000
40000
30000
20000
10000
0
4000
3500
3000
2500
2000
1500
1000
500
0
Flow (m³s⁻¹)
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023
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 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023
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 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023
Riverine
Direct
Flow


GUR
Total nitrogen (tonnes)
120000
100000
80000
60000
40000
20000
0
Flow (m^3s^{-1})
1800
1500
1200
900
600
300
0
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023
Riverine
Direct
Flow



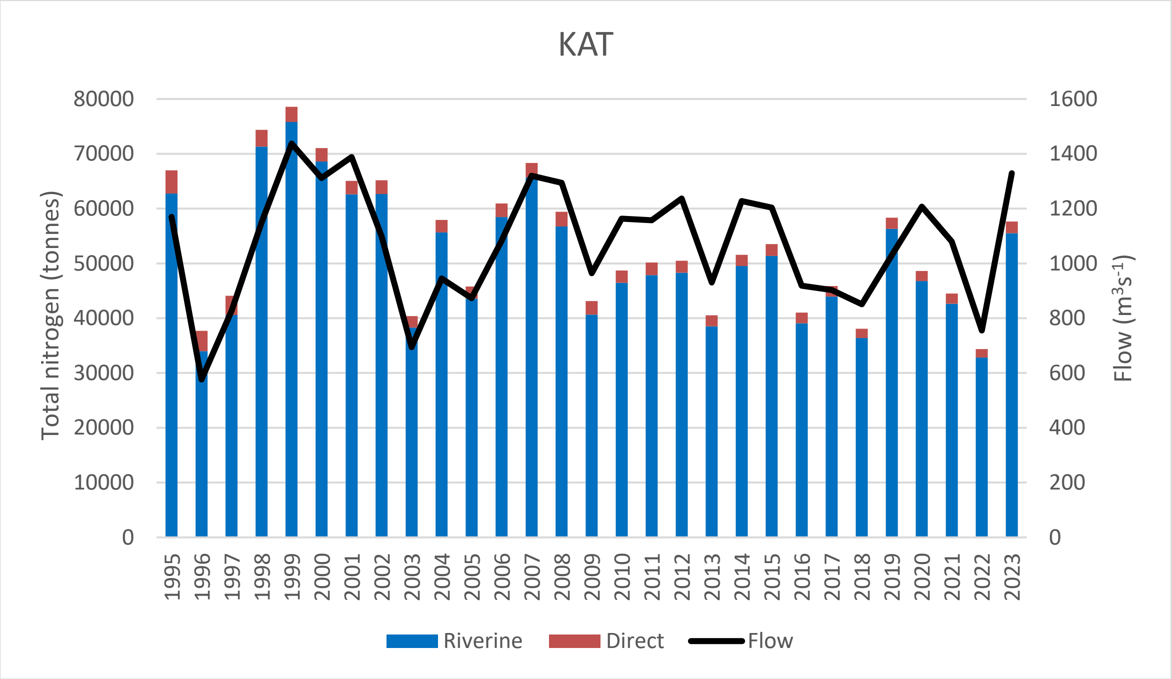
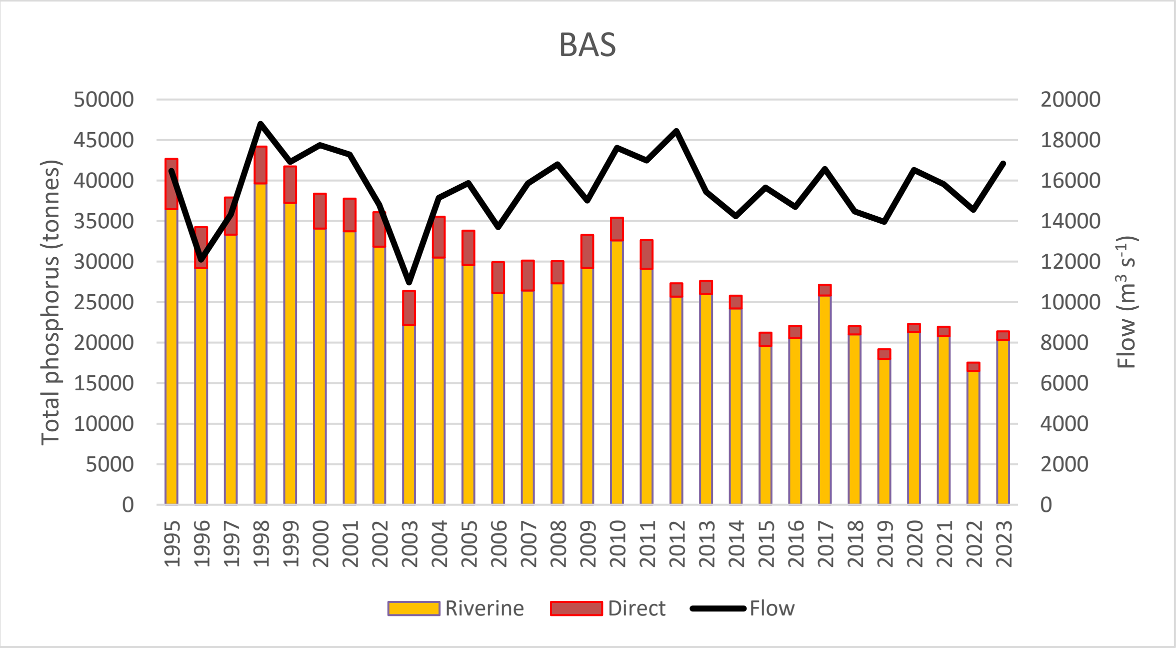
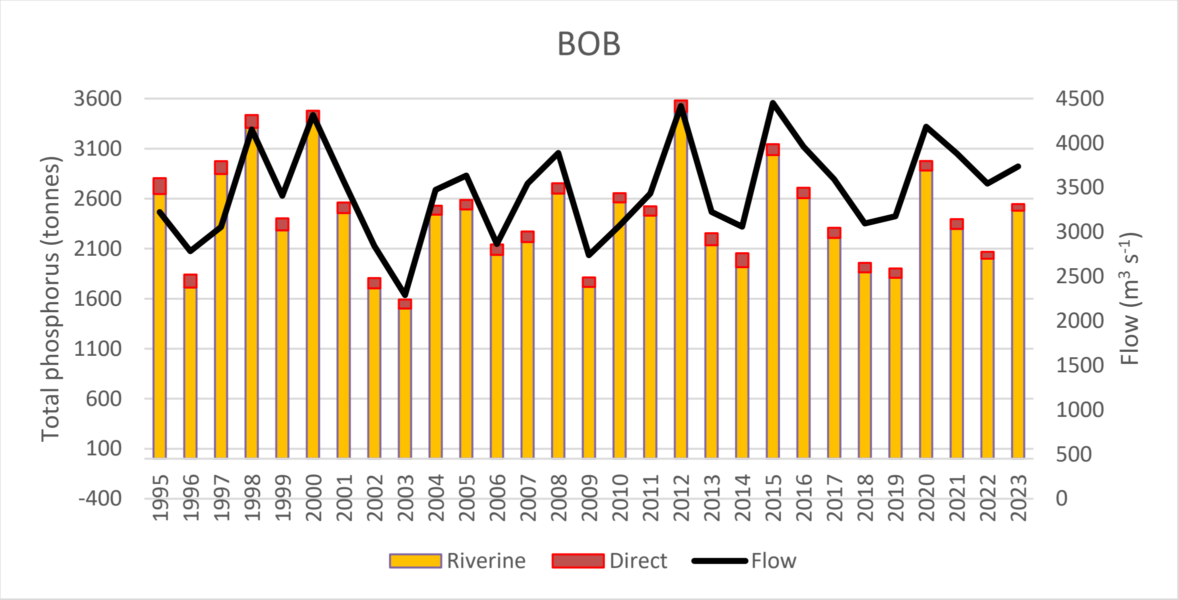
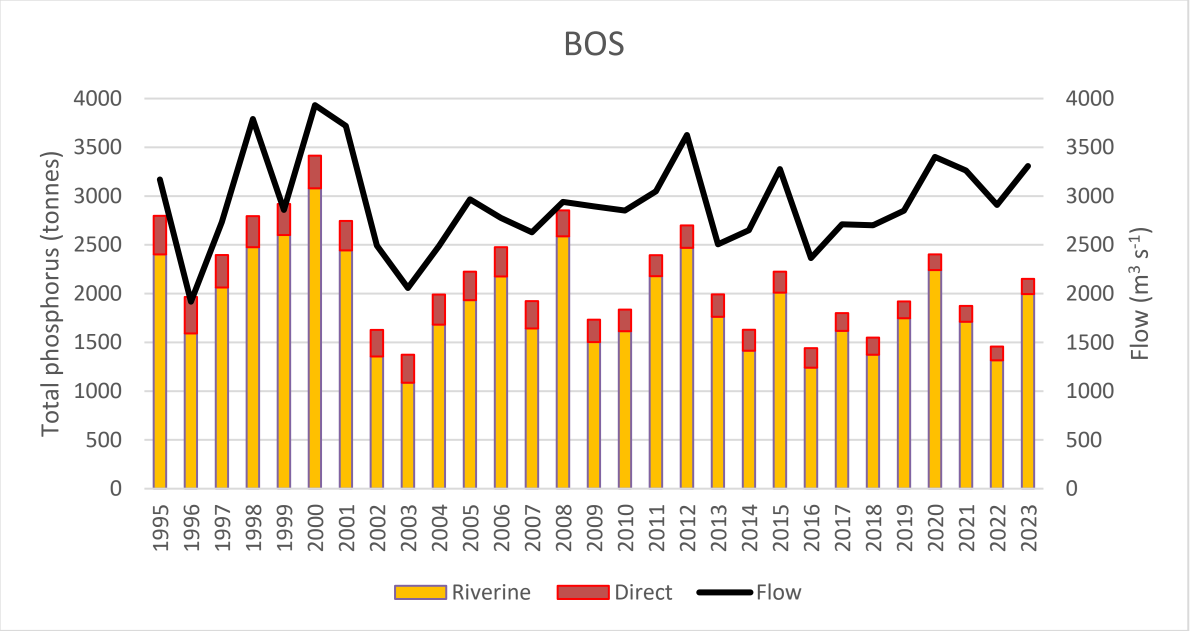
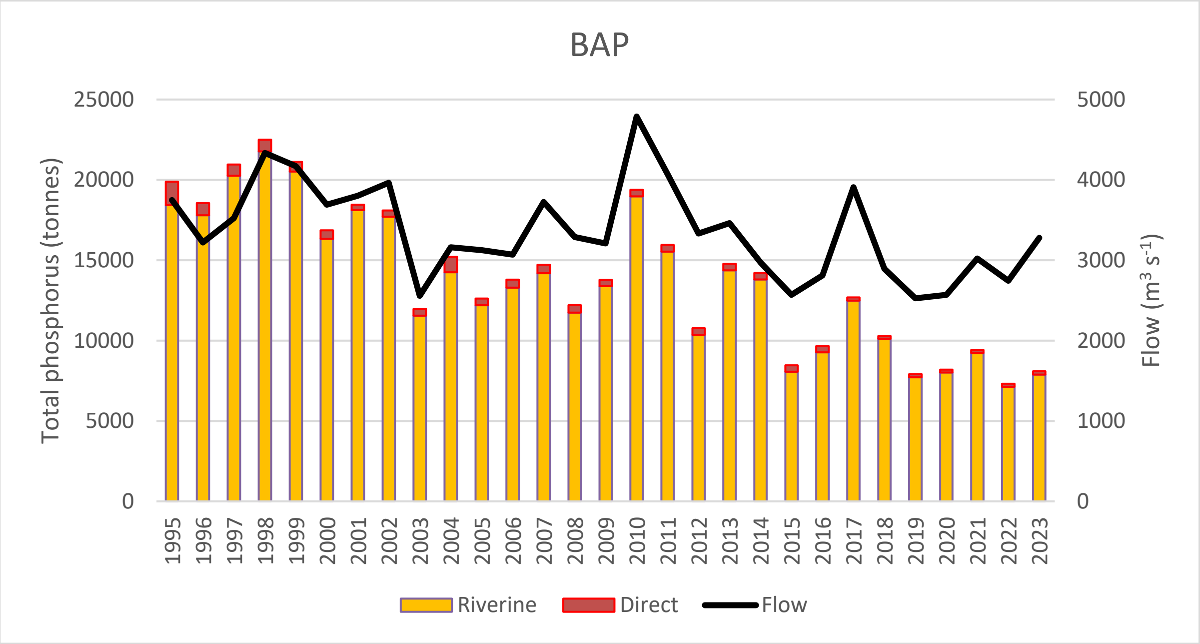


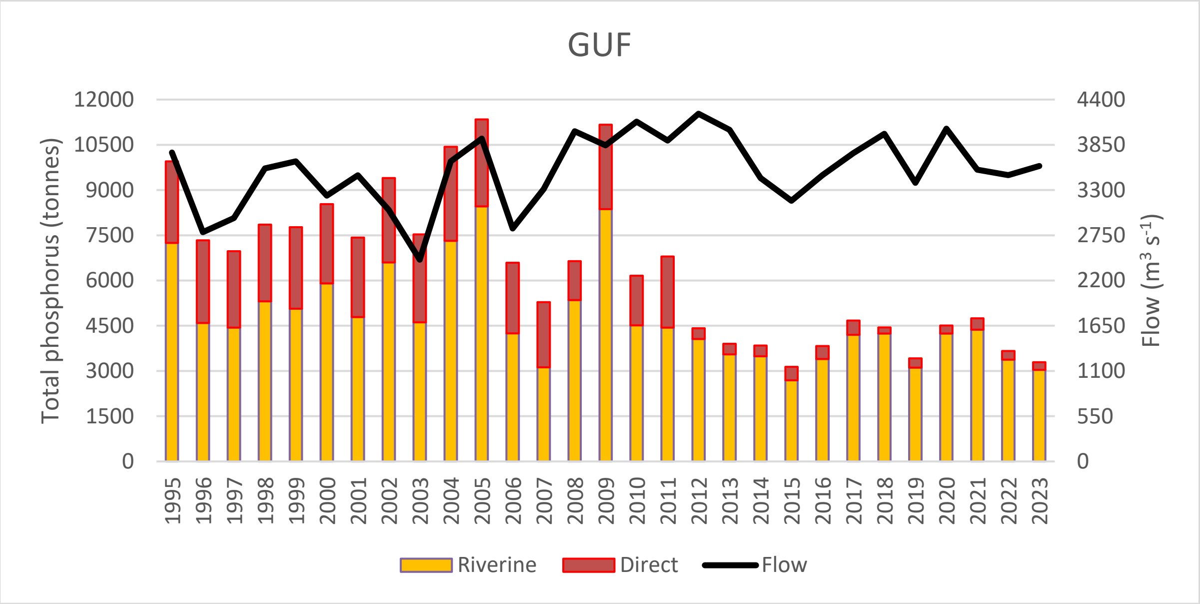
Figure 2A: Annual riverine and direct inputs of total nitrogen in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2023. Data behind the figures are shown in Tables 2-5. For an explanation of the basin abbreviations, see the caption to Figure 1.

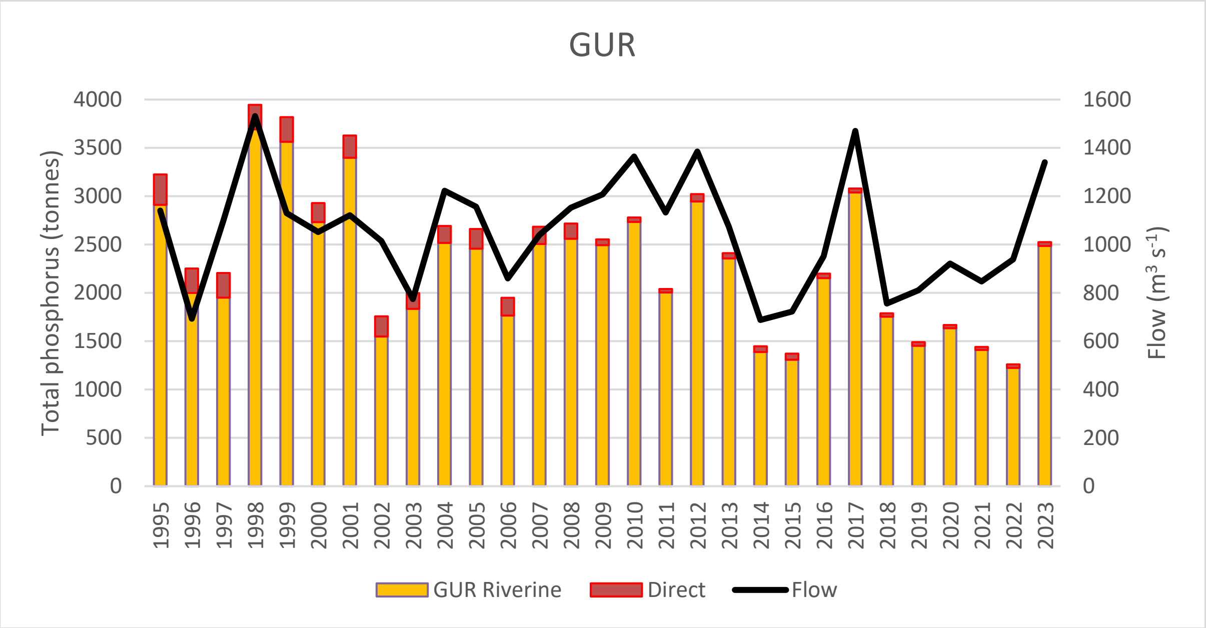

BAS
Total phosphorus (tonnes)
Flow (m^3 s^{-1})
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
Riverine
Direct
Flow


BOB
Total phosphorus (tonnes)
Flow (m^3 s^{-1})
3600
3100
2600
2100
1600
1100
600
100
-400
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
2023
Riverine
Direct
Flow


BOS
Total phosphorus (tonnes)
Flow (m^3 s^{-1})
4000
3500
3000
2500
2000
1500
1000
500
0
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
2023
Riverine
Direct
Flow


BAP
25000
20000
15000
10000
5000
0
Total phosphorus (tonnes)
5000
4000
3000
2000
1000
0
Flow (m3 s-1)
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 2023
Riverine
Direct
Flow


GUF
12000
10500
9000
7500
6000
4500
3000
1500
0
Total phosphorus (tonnes)
4400
3850
3300
2750
2200
1650
1100
550
0
Flow (m3 s-1)
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 2023
Riverine
Direct
Flow


GUR
4000
3500
3000
2500
2000
1500
1000
500
0
Total phosphorus (tonnes)
1600
1400
1200
1000
800
600
400
200
0
Flow (m3 s-1)
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 2023
GUR Riverine
Direct
Flow

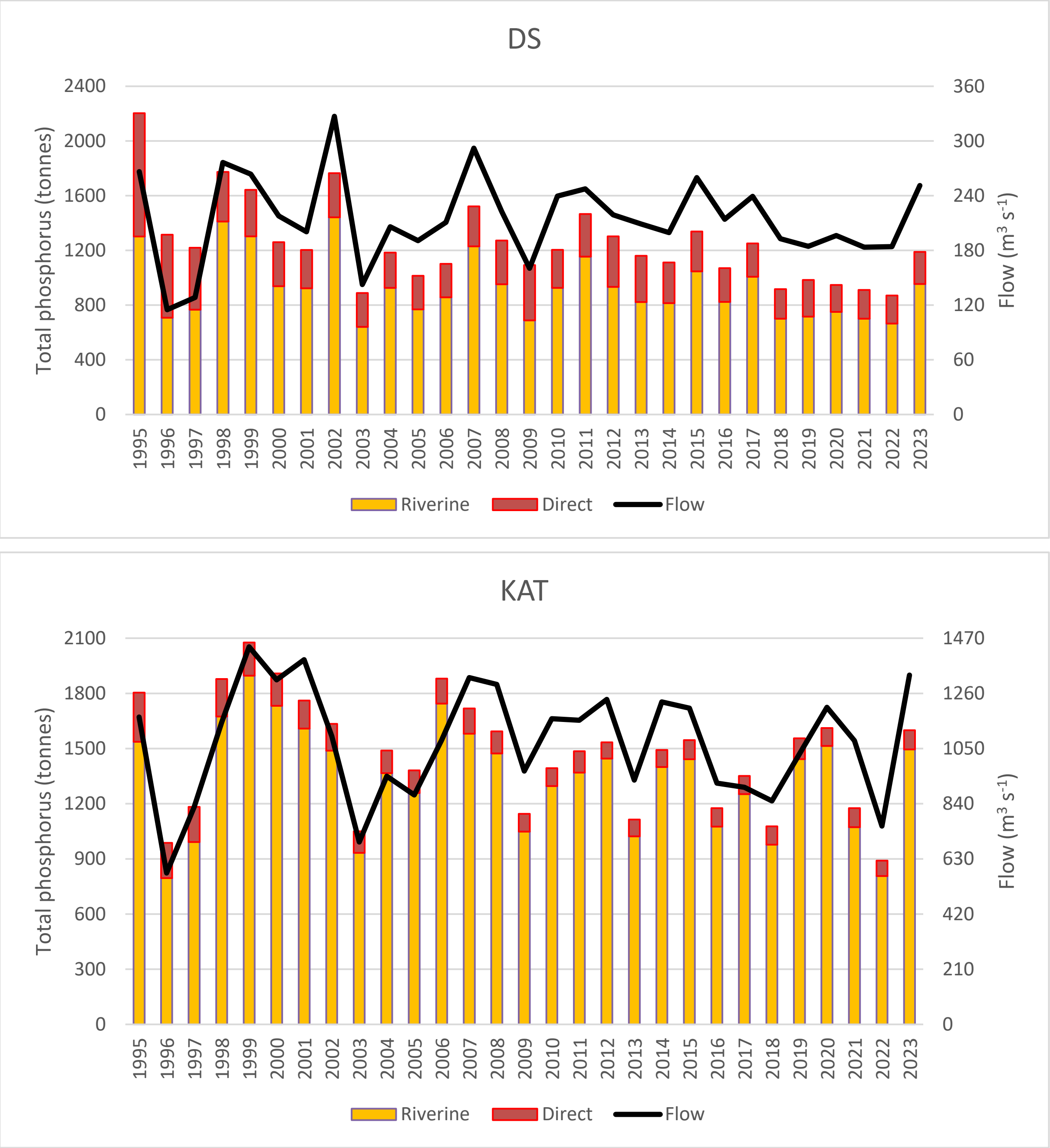


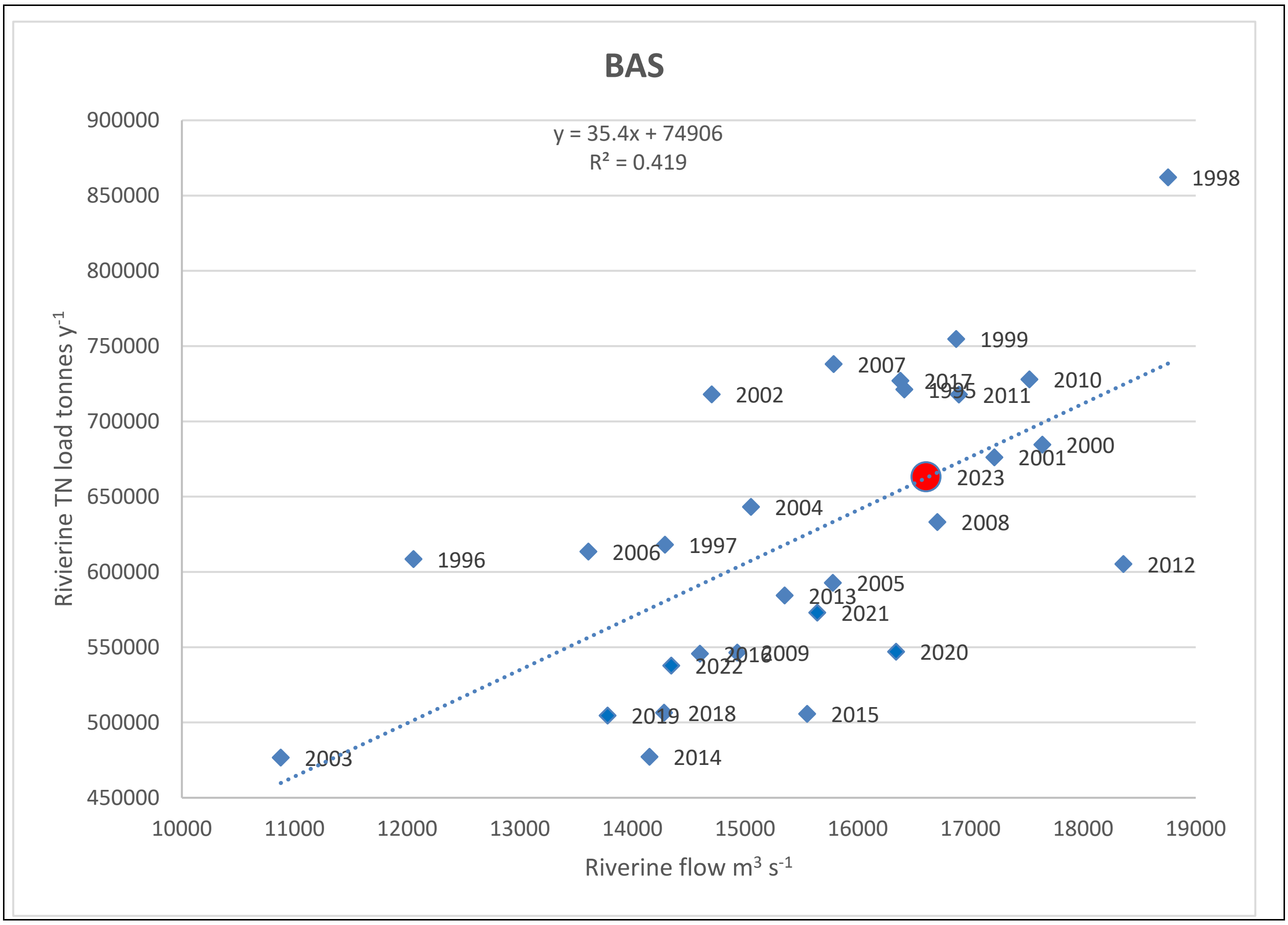
Figure 2B: Annual riverine and direct inputs of total phosphorus in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2023. Data behind the figures are shown in Tables 2 and 6-8. For an explanation of the basin abbreviations, see the caption to Figure 1.

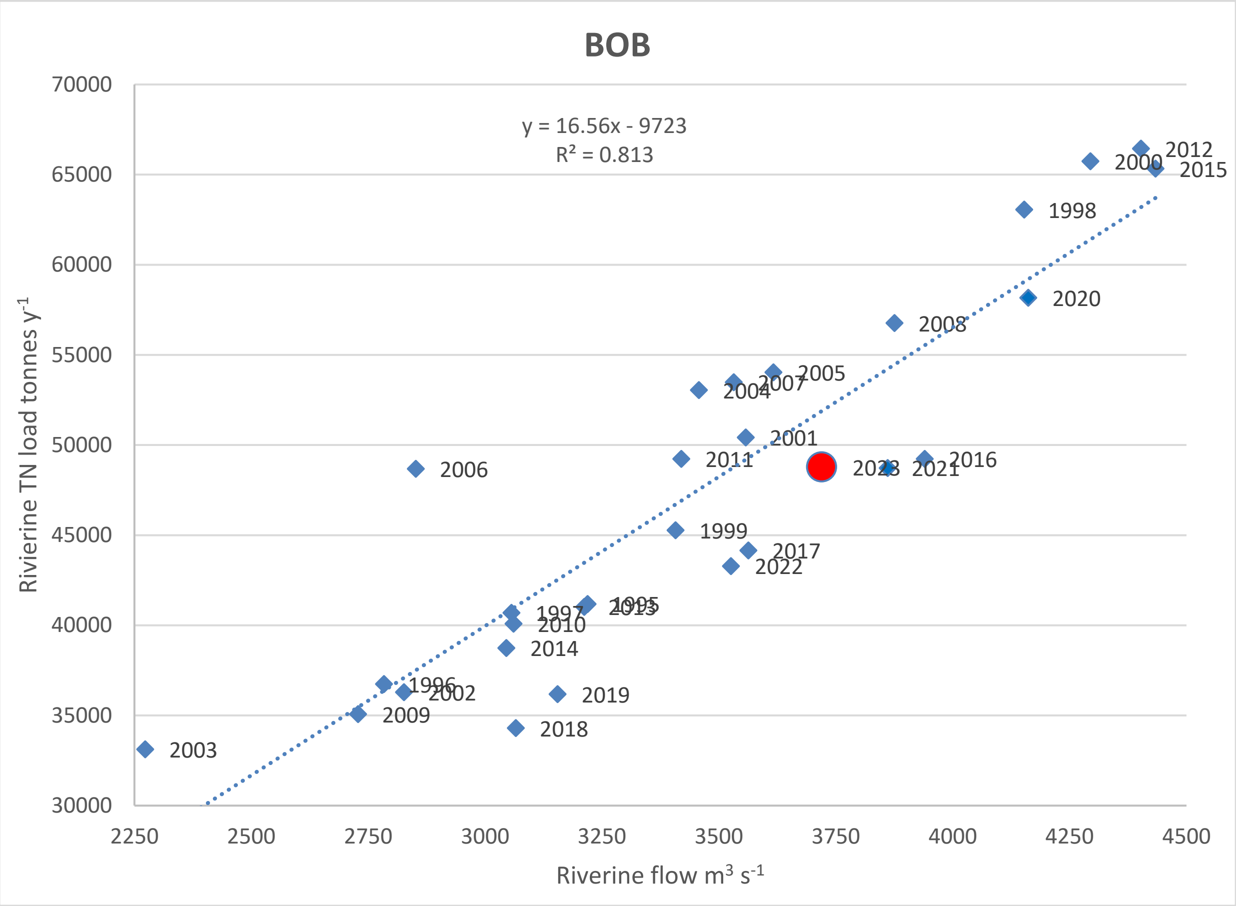
The correlation between the annual riverine TN and TP inputs, respectively, and water flow during 1995-2023 are shown as scatter and linear regression plots in Figure 3. The significance of the linear regression is tested statistically (see caption to Figure 3). The plots allow for characterization and evaluation of the TN and TP riverine inputs 1995-2023 specifically the inputs in 2023. 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.

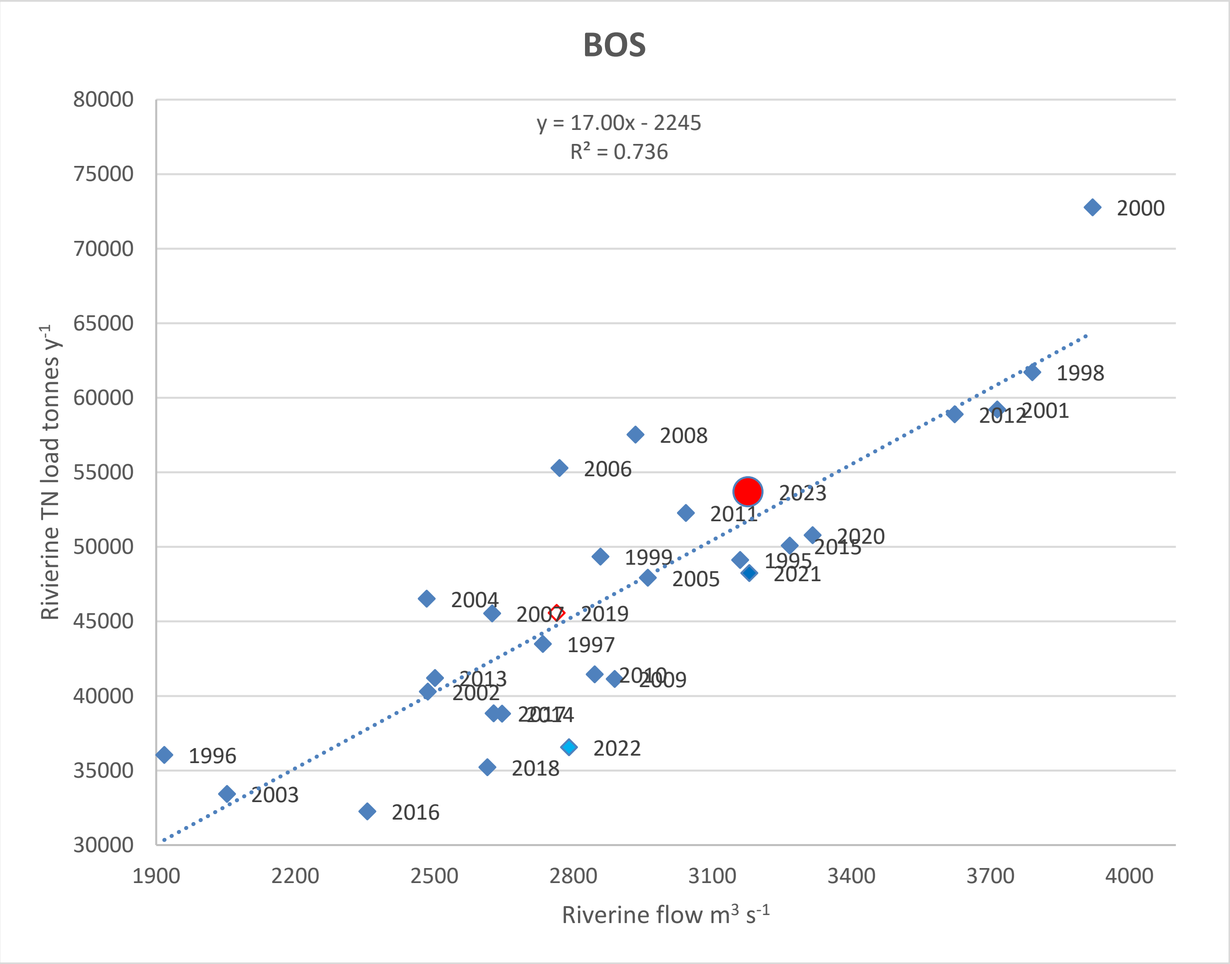
Riverine total nitrogen inputs in 2023 were on the regression line between riverine flow and riverine total nitrogen inputs for 1995-2023. For Bothnian Bay, Gulf of Finland, Danish Straits and Kattegat riverine total nitrogen inputs were under the regression line, for the remaining sub-basin they were over the regression line. For TP riverine inputs were much below the regression line for all basins. Total riverine nitrogen input in 2023 to Gulf of Riga was the highest during the 1995-2023. For TN to Gulf of Riga the 27% higher flow than average (1995-2022) has resulted in 61% higher TN inputs than average (2013-22) and a 10% higher flow-weighted TN concentration than average of 2013-2022 (see table 1c). The situation might indicate the significant increase of nitrogen inputs to Gulf of Riga shown in Svendsen et al, 2023 and an increase in nitrogen losses from agricultural areas in the catchment to Gulf of Riga.

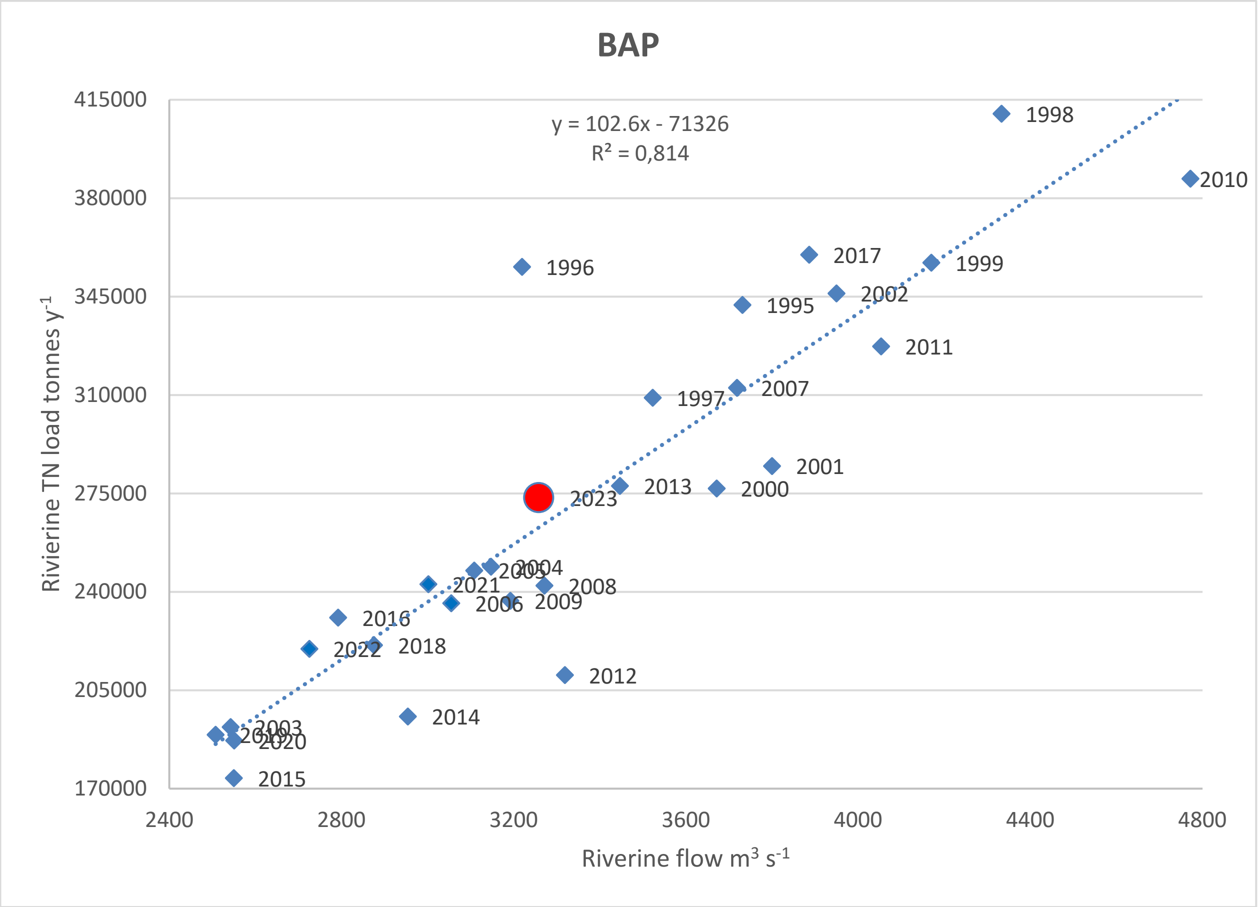
Total riverine phosphorus was among the lowest during 1995-2023 to Baltic Proper. Overall, the Figures 3A and 3B indicate a rather considerable range of nutrient inputs for any particular flow.

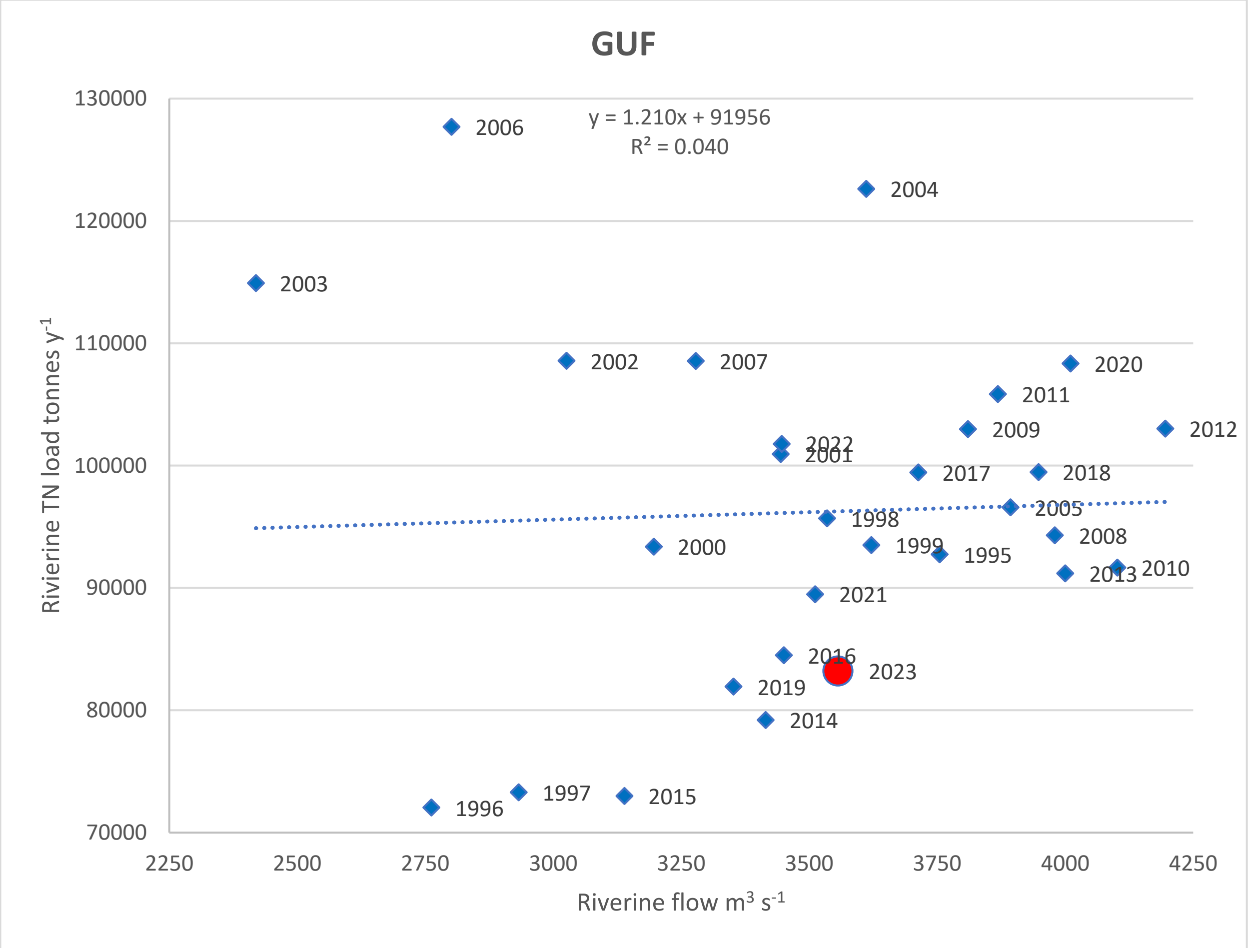
As a rule of thumb, a decrease in riverine TN and/or TP inputs during 1995 to 2023 is significant if most of the inputs of the latest 13-14 years fall below the dotted lines in Figure 3A and 3B. This is true for many basins for particularly phosphorus. If nutrient inputs from sources with low dependency 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 R² compared with time series with low share of inputs from point sources in the catchment.

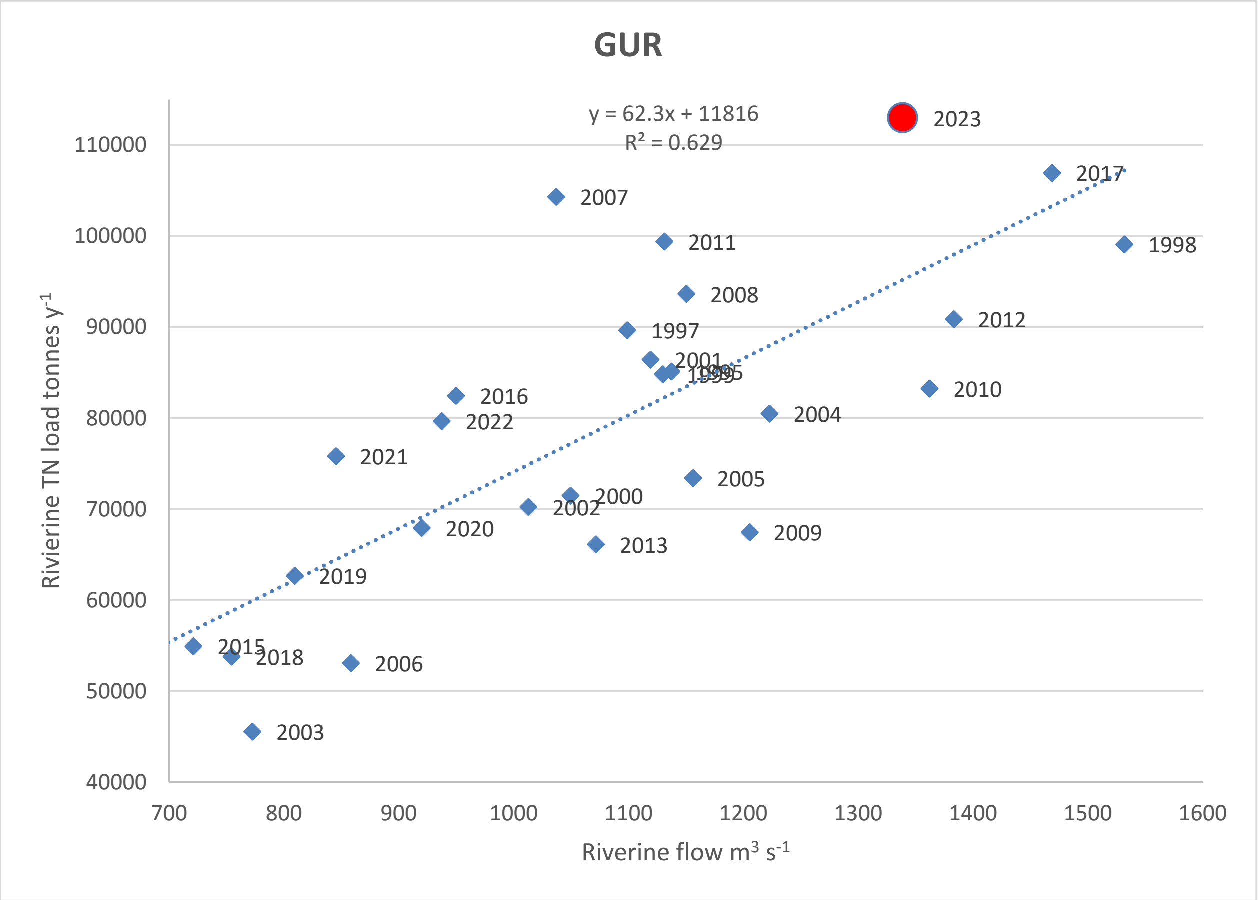


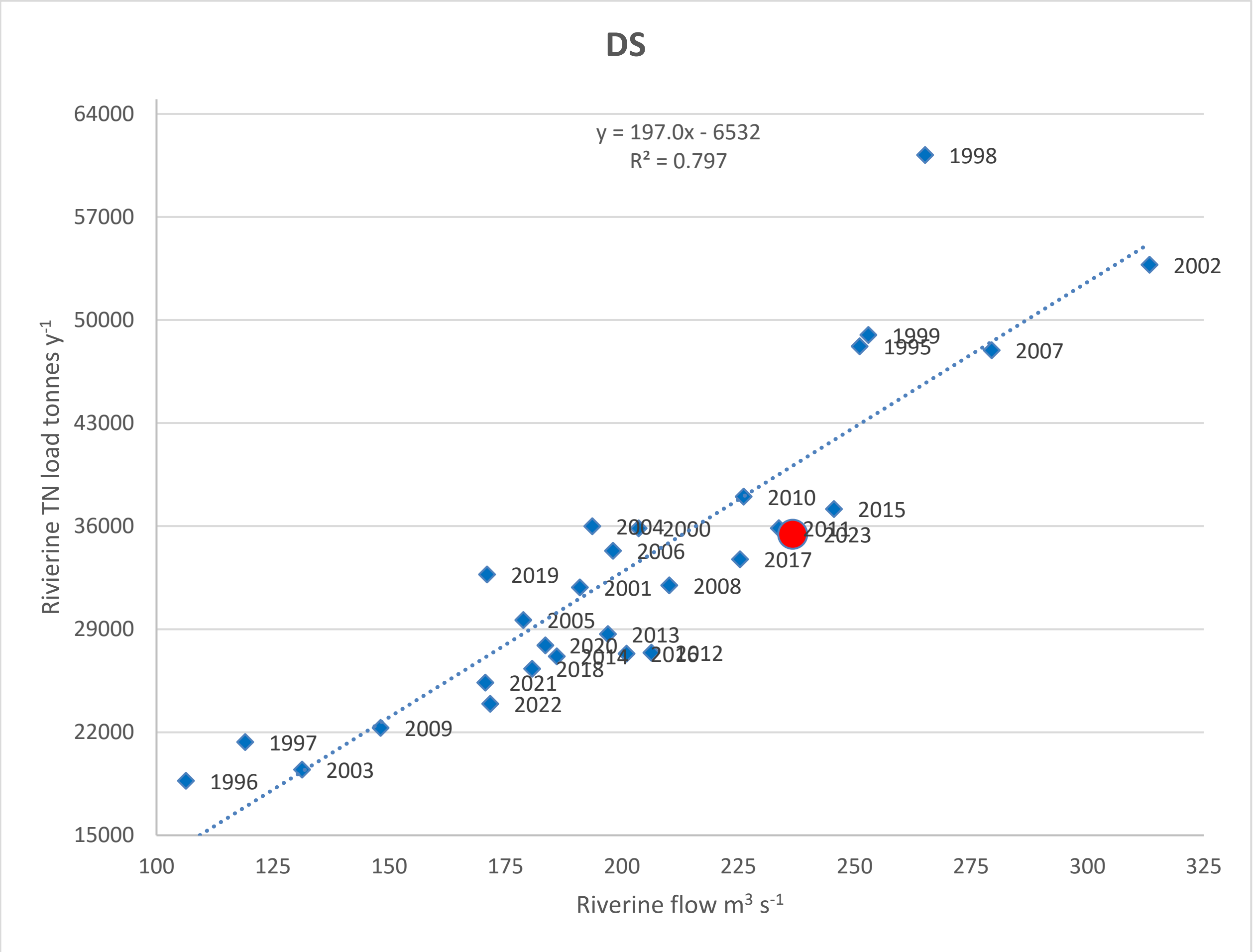

BOB
y = 16.56x - 9723
R² = 0.813
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
70000
65000
60000
55000
50000
45000
40000
35000
30000
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
2012
2000
2015
1998
2020
2008
2007
2005
2004
2001
2011
2006
2023
2021
2016
1999
2017
2022
1997
2010
1995
2013
2014
1996
2002
2019
2009
2018
2003


BOS
y = 17.00x - 2245
R² = 0.736
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
2023
2011
2020
2015
1995
2021
1999
2005
2004
2007
2019
1997
2013
2002
2010
2009
2017
2014
2022
1996
2018
2003
2016


BAP
y = 102.6x - 71326
R² = 0,814
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
415000
380000
345000
310000
275000
240000
205000
170000
2400
2800
3200
3600
4000
4400
4800
1998
2010
1996
2017
1999
1995
2002
2011
1997
2007
2001
2023
2013
2000
2004
2005
2021
2008
2006
2009
2016
2022
2018
2012
2014
2003
2019
2020
2015


GUF
y = 1.210x + 91956
R² = 0.040
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
2022
2001
2017
2018
2005
1998
2000
1999
1995
2008
2013
2010
2021
2016
2023
2019
2014
1996
1997
2015


GUR
y = 62.3x + 11816
R² = 0.629
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
2023
2017
2007
1998
2011
2008
2012
1997
2001
1999
1995
2010
2016
2022
2004
2021
2005
2002
2000
2020
2009
2013
2019
2015
2018
2006
2003


DS
y = 197.0x - 6532
R² = 0.797
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
2023
2006
2017
2019
2001
2008
2005
2013
2020
2014
2016
2012
2018
2021
2022
1997
2009
2003
1996

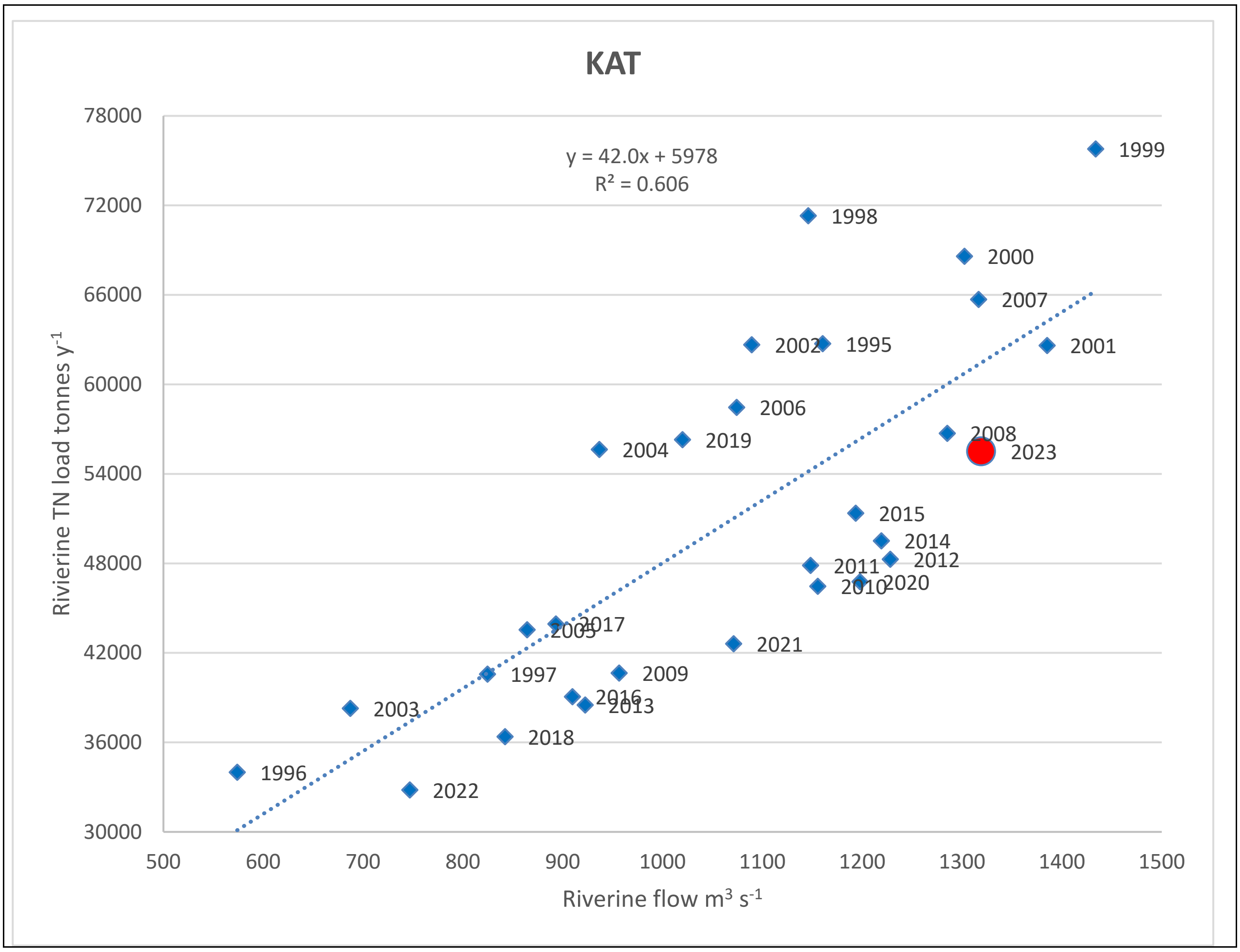
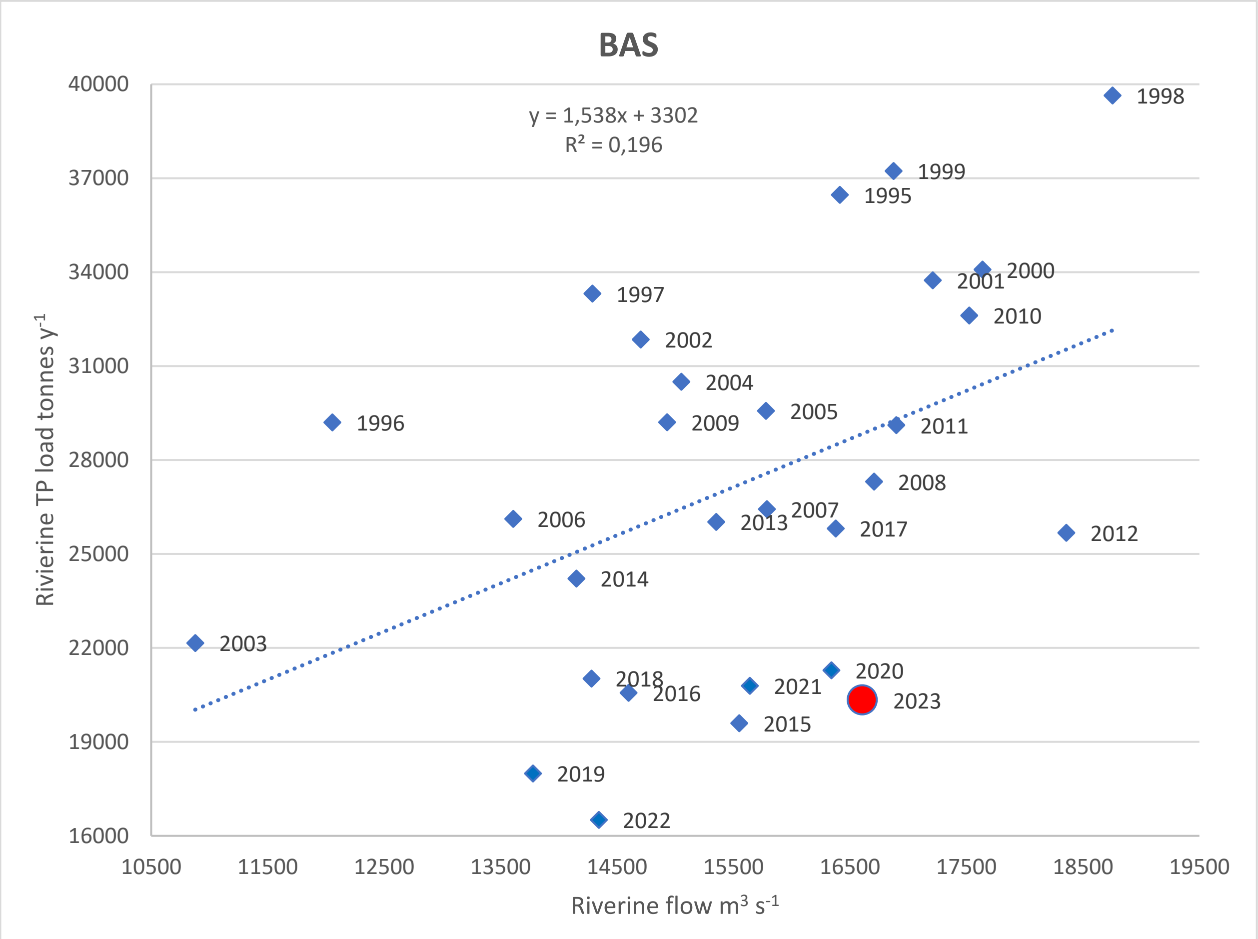


Figure 3A. Linear regression plots of annual riverine flows ($m^3 s^{-1}$) against annual riverine total nitrogen inputs (TN) to the seven Baltic Sea sub-basins and to the Baltic Sea during 1995-2023. Most recent year (2023) is marked with a big red dot and “2023” to the right of the dot. The linear 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 =0.813 say that about 81 % of the variation is explained (good correlation) by the regression. The statistical test calculates an F-value and analyses if the linear relation is significant (95 % confidence). All relations besides TN to GUF are significant. For an explanation of abbreviations, see the caption to Figure 1.


BAS
y = 1,538x + 3302
R² = 0,196
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
40000
37000
34000
31000
28000
25000
22000
19000
16000
10500
11500
12500
13500
14500
15500
16500
17500
18500
19500
1998
1999
1995
2000
2001
2010
1997
2002
2004
2005
2009
1996
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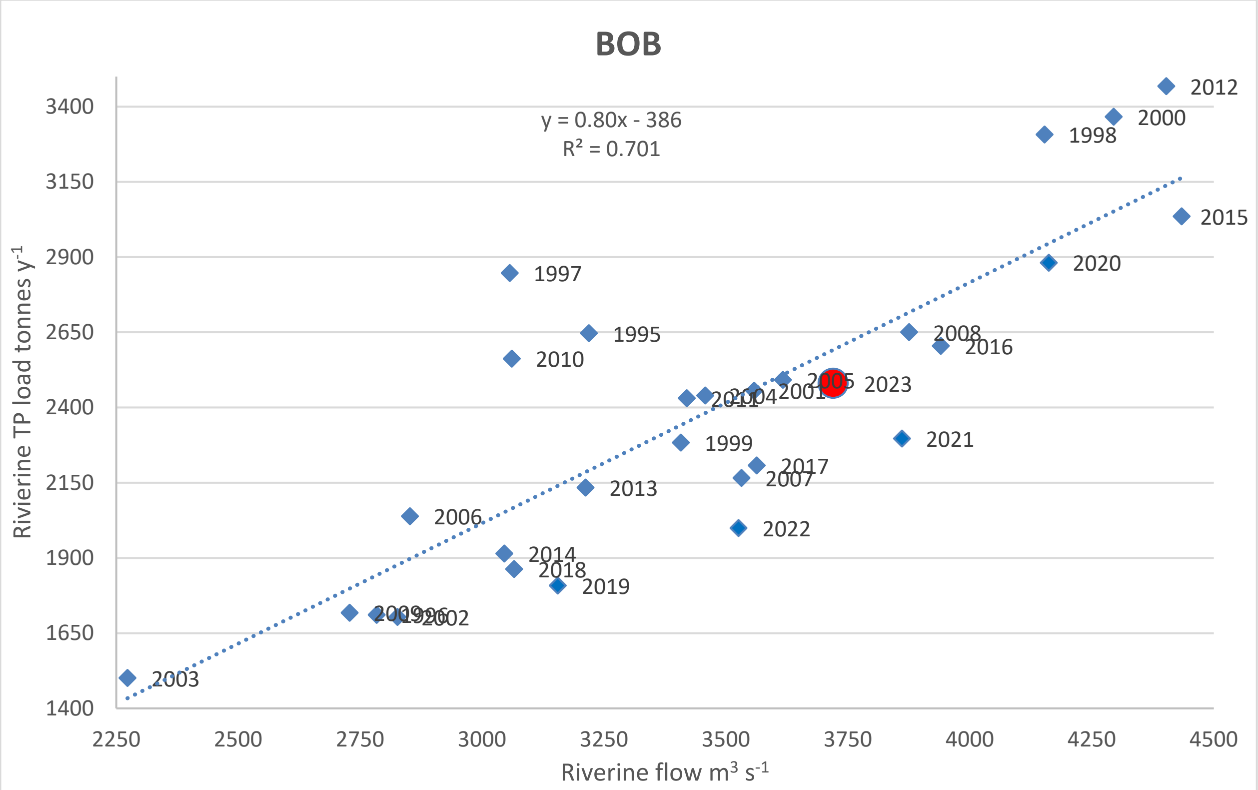
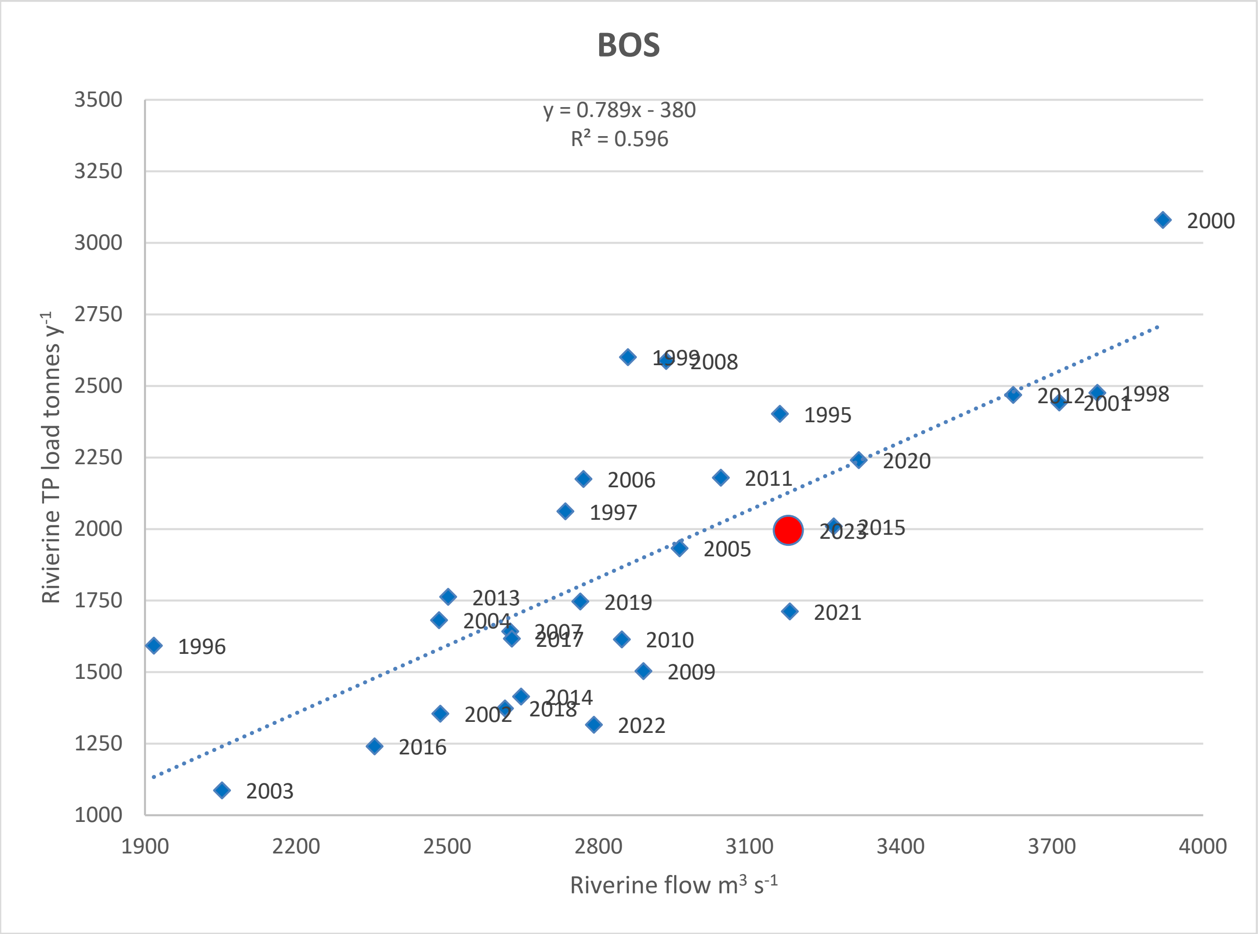
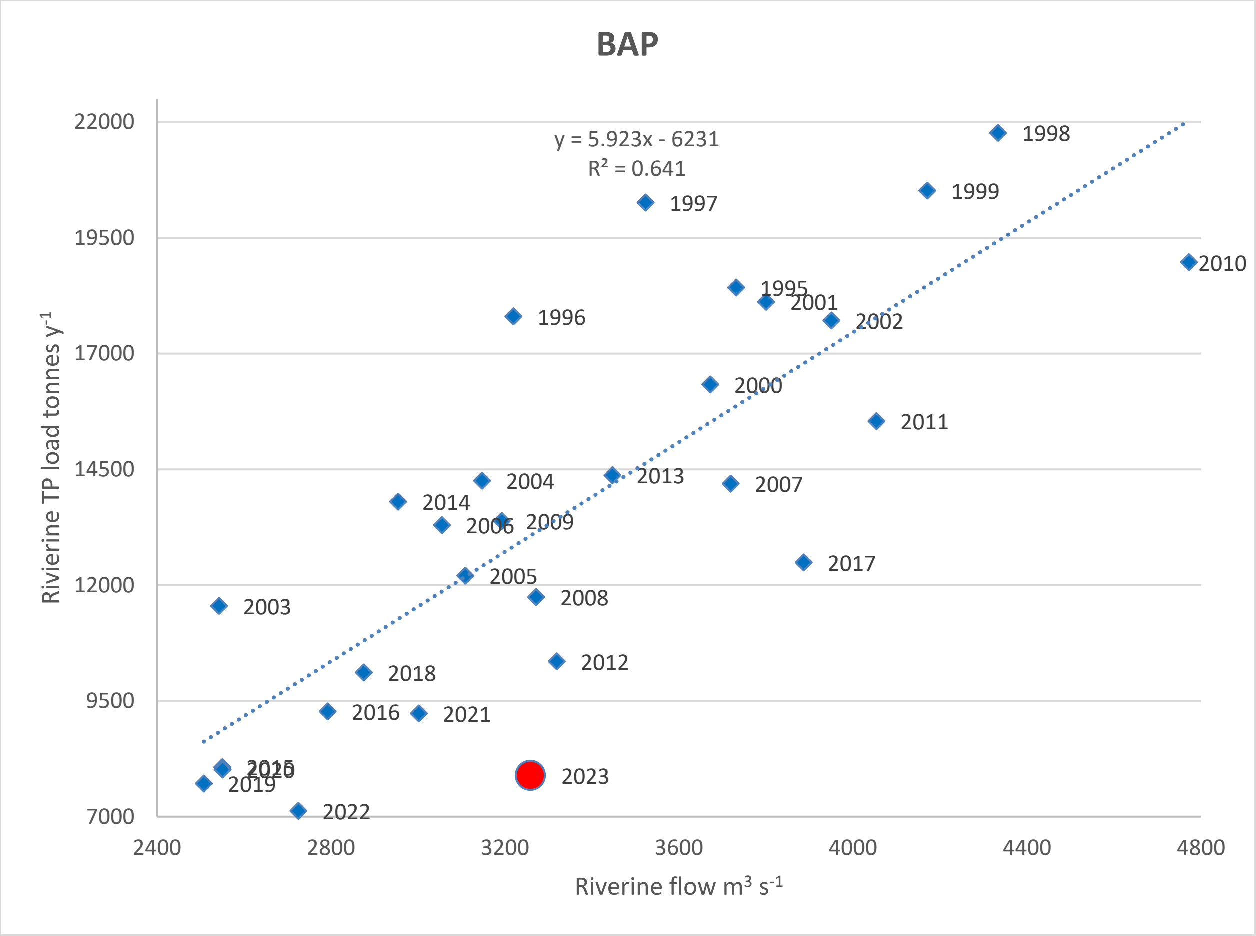
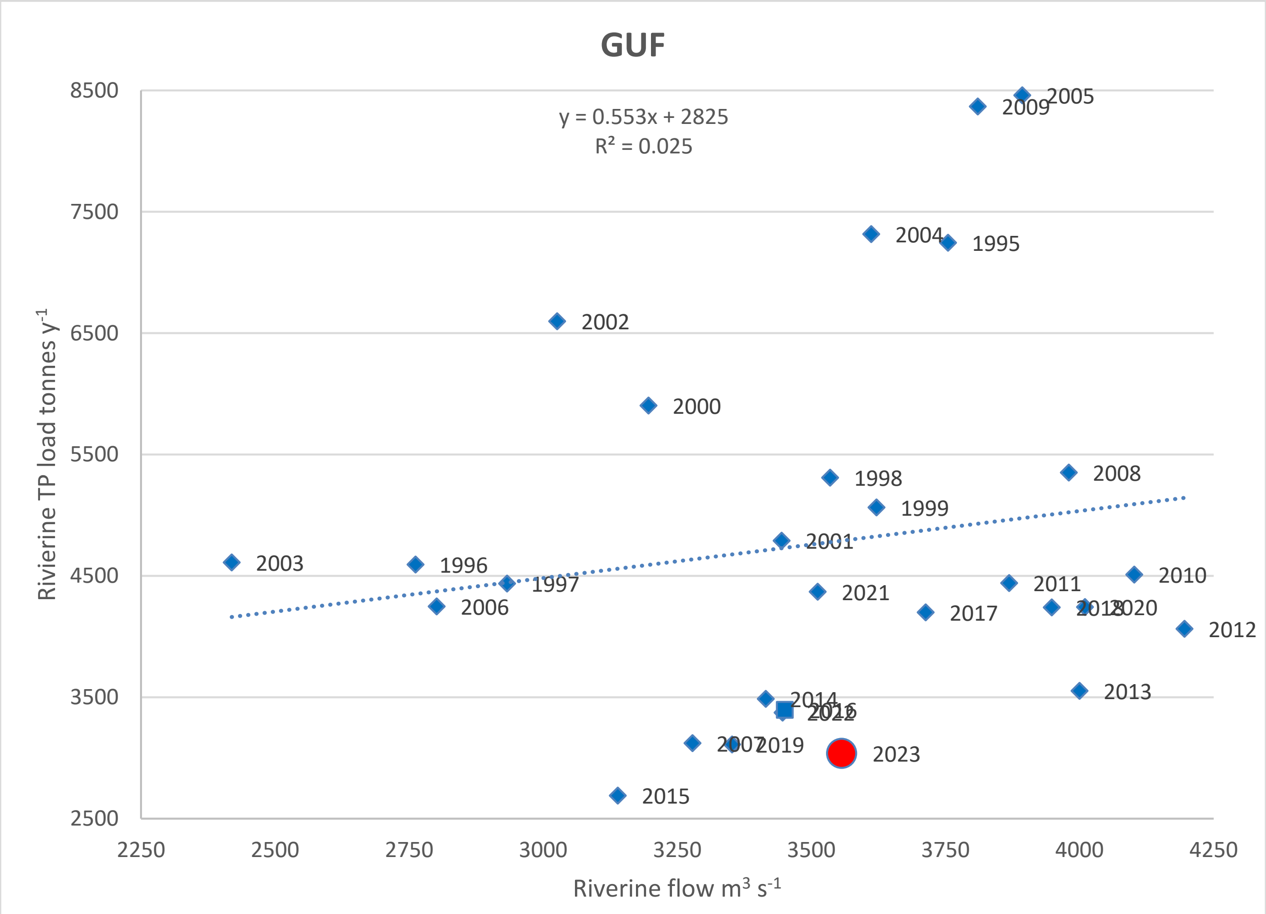
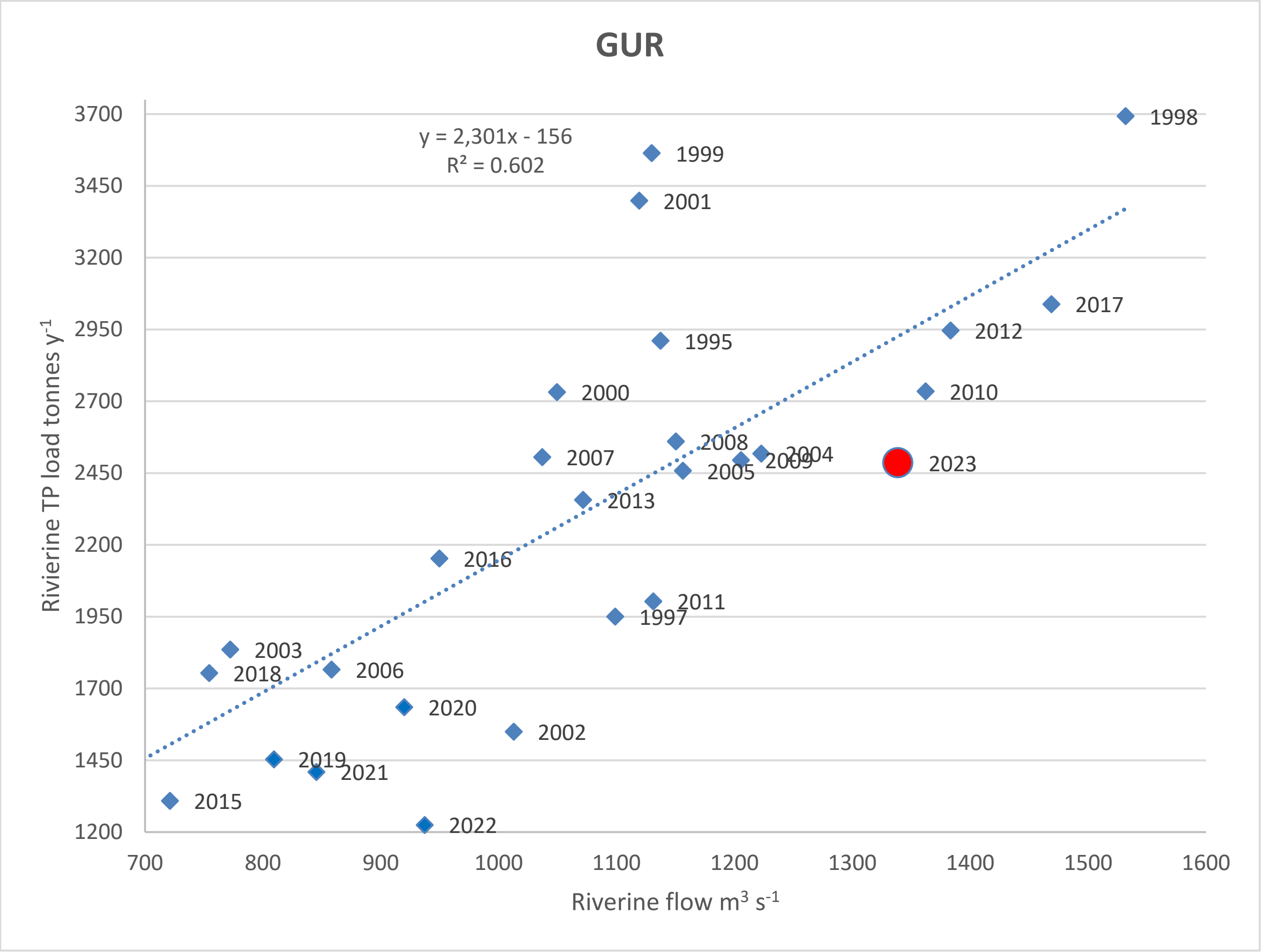
2003
2020
2018
2016
2021
2023
2015
2019
2022


BOB
y = 0.80x - 386
R² = 0.701
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
3400
3150
2900
2650
2400
2150
1900
1650
1400
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
2012
2000
1998
2015
2020
1997
1995
2008
2016
2010
2011
2004
2001
2005
2023
1999
2021
2017
2007
2013
2006
2022
2014
2018
2019
2009
1996
2002
2003


BOS
y = 0.789x - 380
R² = 0.596
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
2023
2015
2005
2013
2019
2021
2004
2007
2017
2010
1996
2009
2014
2002
2018
2022
2016
2003


BAP
y = 5.923x - 6231
R² = 0.641
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
1996
2002
2000
2011
2004
2013
2007
2014
2006
2009
2017
2005
2008
2003
2018
2012
2016
2021
2015
2020
2019
2023
2022


GUF
y = 0.553x + 2825
R² = 0.025
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
2017
2011
2018
2020
2010
2012
2014
2016
2022
2013
2007
2019
2023
2015


GUR
y = 2,301x - 156
R² = 0.602
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
2007
2005
2009
2023
2013
2016
2011
1997
2003
2018
2006
2020
2002
2019
2021
2015
2022

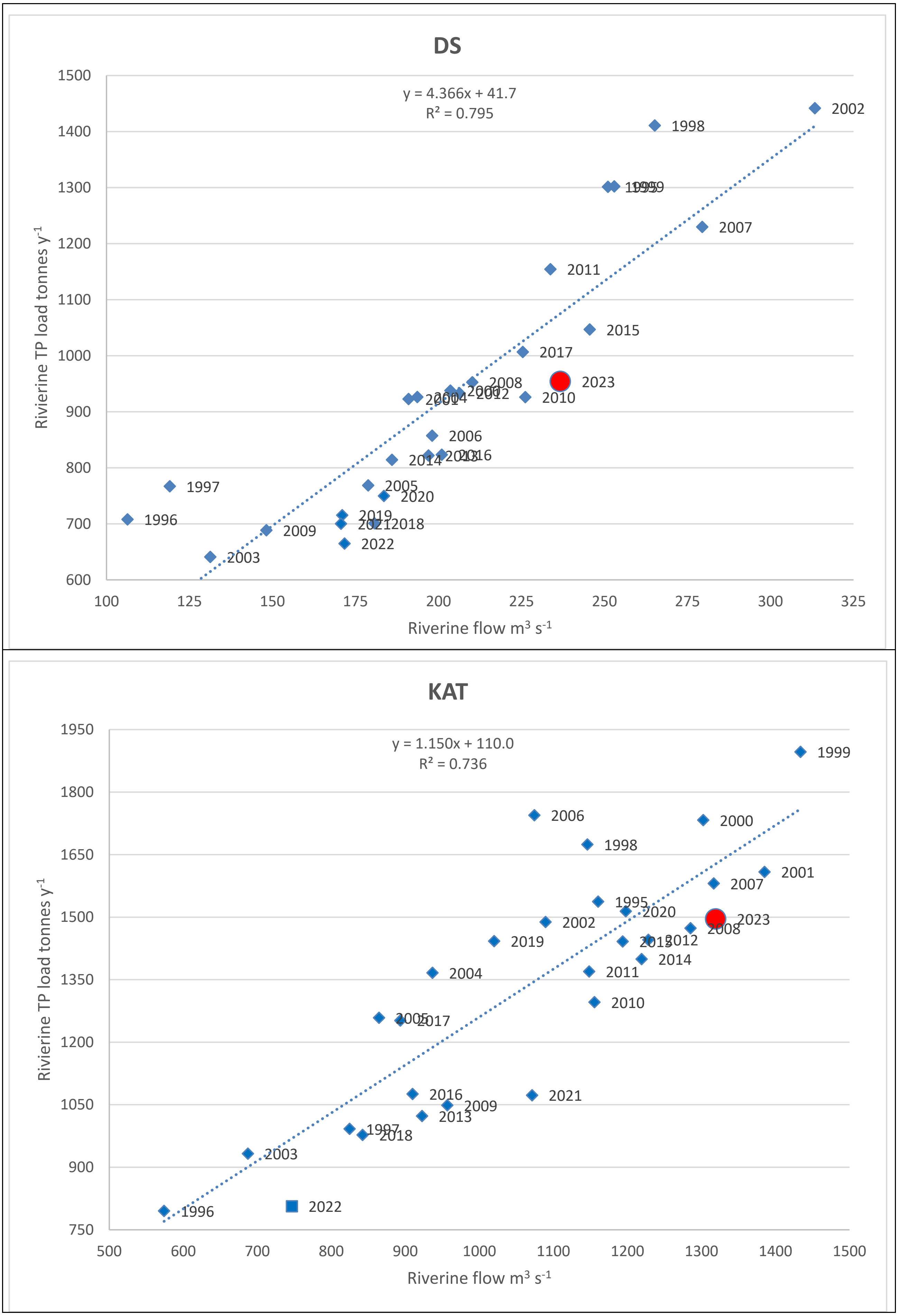
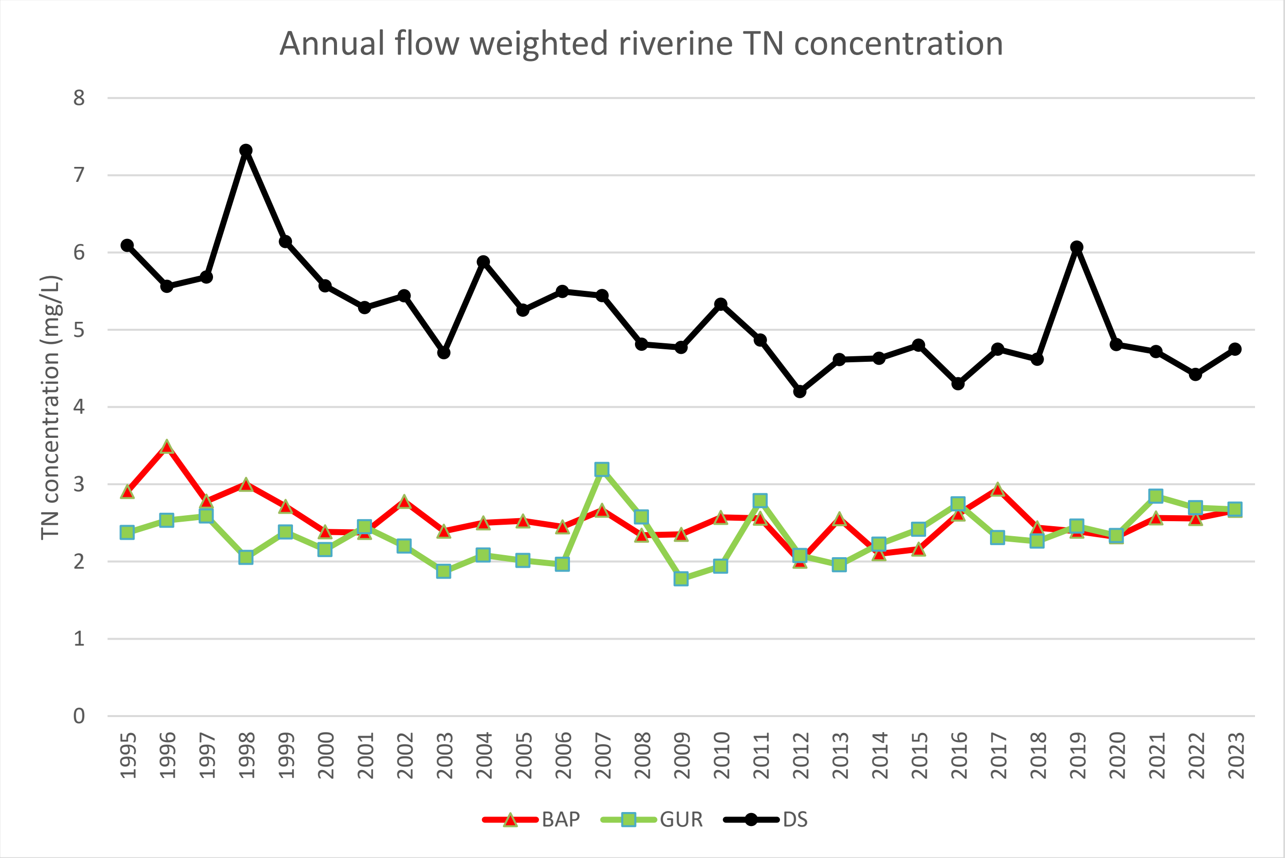
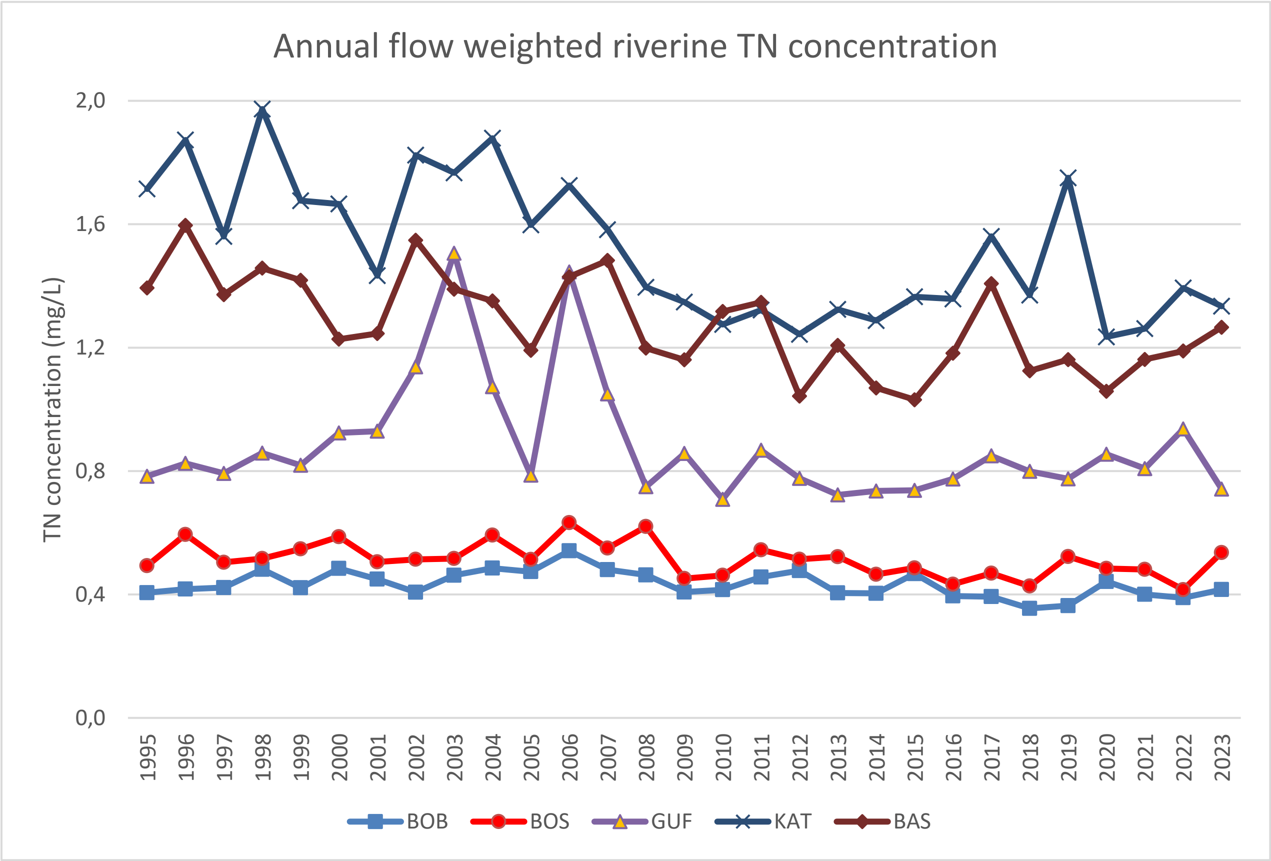


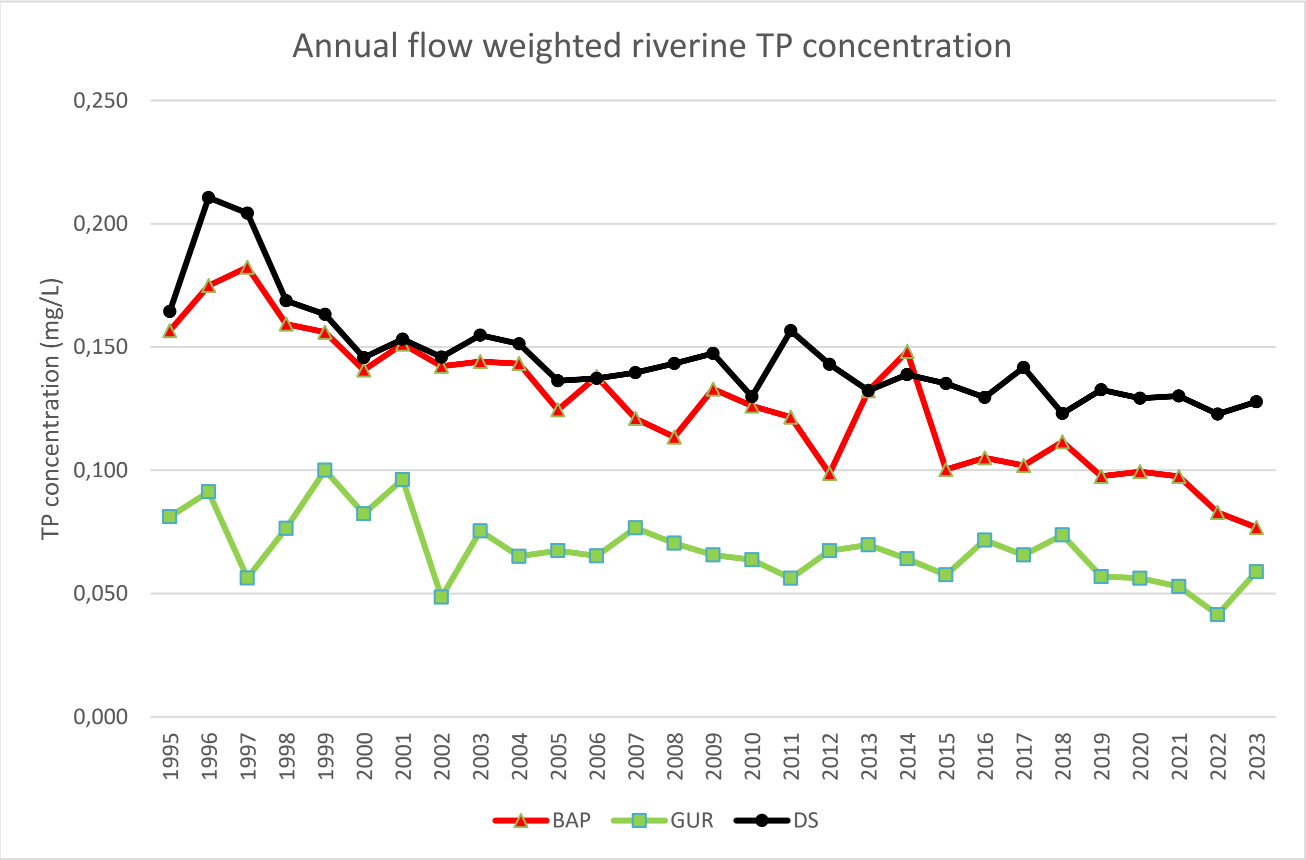
Figure 3B. As figure 3A but for total phosphorus 1995-2023. All relations besides TP to GUF are significant. For an explanation of abbreviations, see the caption to Figure 1.

Flow weighted annual riverine concentrations of 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 1995-2023 are shown for the Baltic Sea and its seven sub-basins. A statistical test on the linear regressions (test explained in the caption to Figure 3) indicates that the discharged weighted TN riverine concentrations decreased significantly (95% significance) to 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 1995-2022, see Table 1a and 1b. On average, the area specific flow to the Baltic Sea is 9 l s^{-1} km^{-2} (9.7 in 2023) and with only 5.8 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 1995-2022. 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 concentrations to Gulf of Riga in 2021 to 2023 were among the highest during 1995-2023 after two years (2019 and 2020) with very dry conditions. Flow-weighted TN and TP concentration in 2023 were higher than in 2022 for five sub-basins (only lower for Gulf of Finland (TN and TP,) Gulf of Riga (TN) and Bothnian Sea (TP).




Annual flow weighted riverine TN concentration
TN concentration (mg/L)
2,0
1,6
1,2
0,8
0,4
0,0
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
2023
BOB
BOS
GUF
KAT
BAS


Annual flow weighted riverine TP concentration
TP concentration (mg/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
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
BAP
GUR
DS

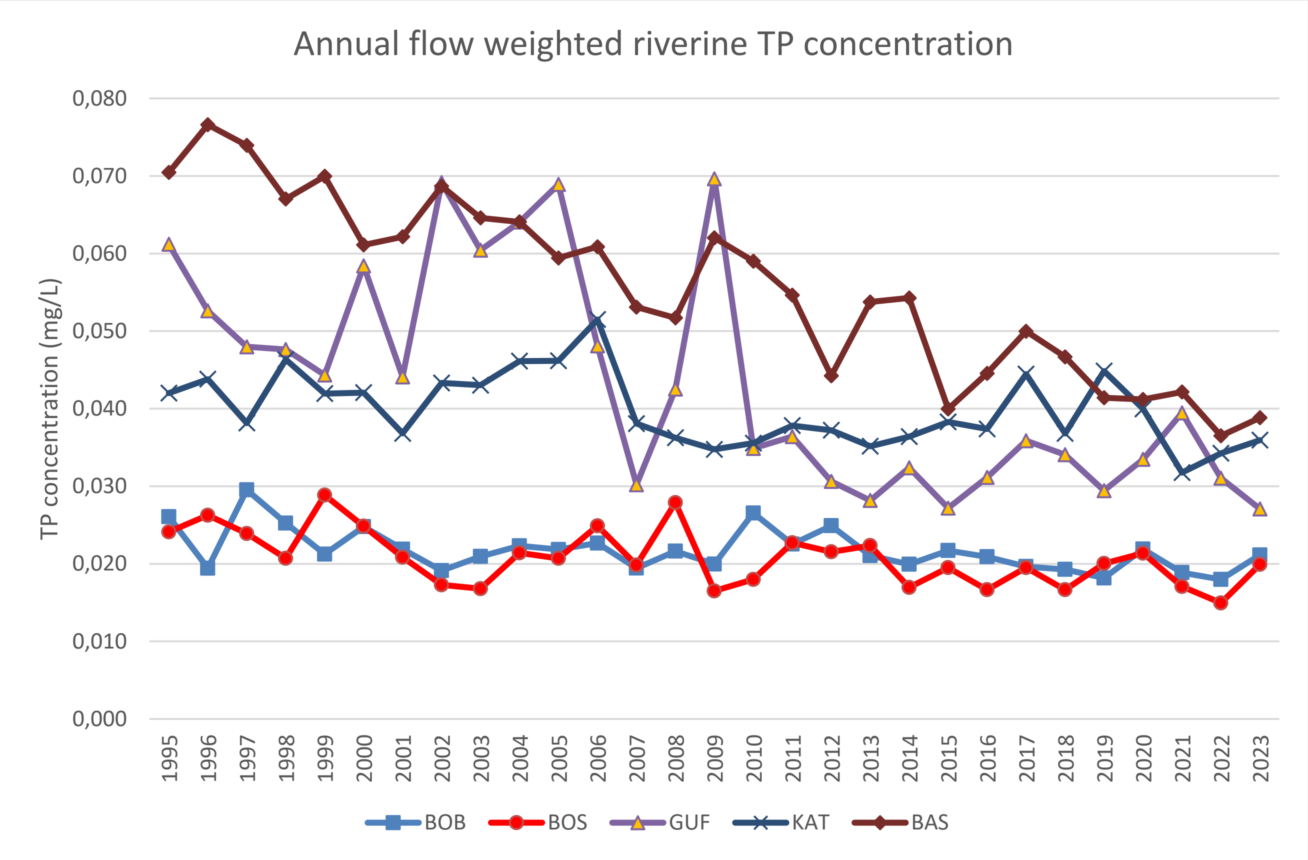


Figure 4. Annual average flow-weighted riverine total nitrogen (the two uppermost figures) and total phosphorus (the two lowermost plots) concentrations for the seven Baltic Sea basins and the Baltic Sea (calculated as total annual riverine inputs divided with the corresponding annual flow) during 1995-2023 (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 1995-2023

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).

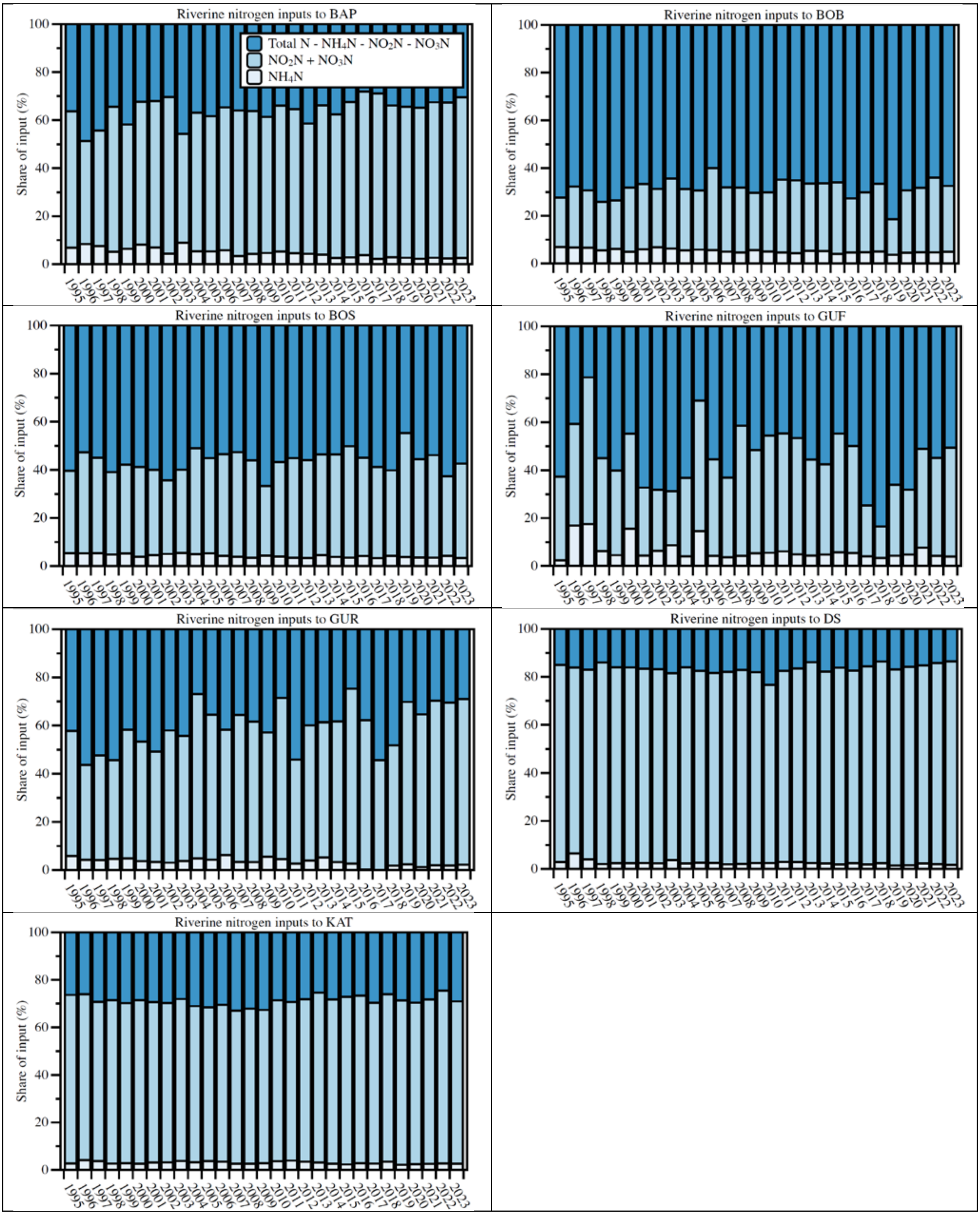


Figure 5. Shares of nitrogen fractions of the total annual nitrogen inputs to the seven Baltic Sea basins during 1995-2023.

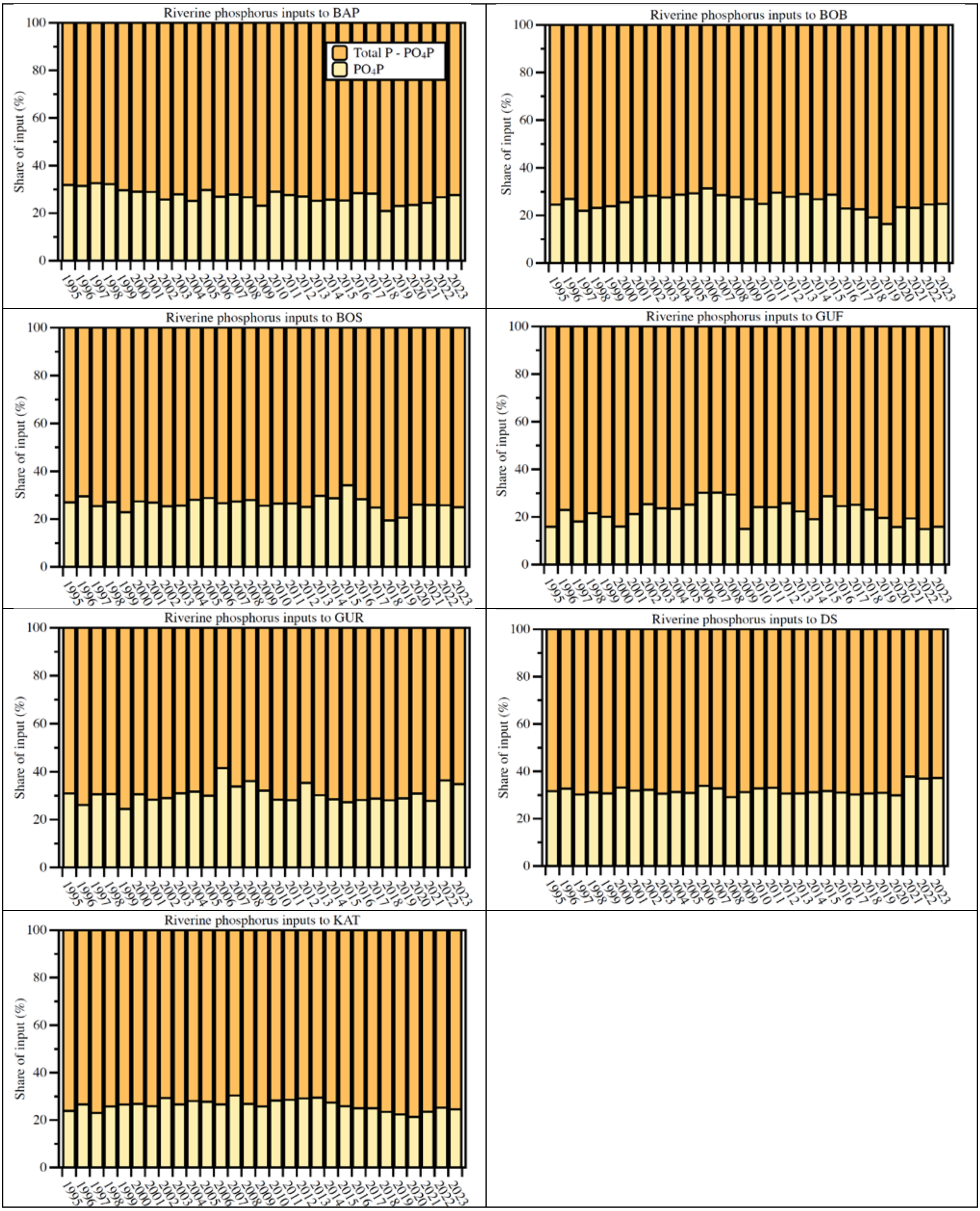


Figure 6. Shares of phosphorus fractions of the total annual phosphorus inputs to the seven Baltic Sea basins during 1995-2023.

Policy relevance and policy references[4]

Since the establishment of the Convention for the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) in 1974, the Commission for the Protection of the Marine Environment of the

Baltic Sea Area (Helsinki Commission or HELCOM for short) has been working to reduce the inputs of nutrients to the sea.

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

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

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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 (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).

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 during 1995-2023 (in m^3 s^{-1}). For an explanation of abbreviations, see the caption to Figure 1.

Flow	m3/s	actual								
River	**BOB**	**BOS**	**ARC**	**BAP**	**GUF**	**GUR**	**SOU**	**WEB**	**KAT**	**BAS**
1995	3,224	3,089	80	3,750	3,755	1,141	47	219	1,170	16,475
1996	2,784	1,850	68	3,221	2,789	693	23	92	576	12,095
1997	3,056	2,676	58	3,524	2,959	1,099	25	103	827	14,329
1998	4,153	3,712	78	4,335	3,562	1,532	53	223	1,149	18,797
1999	3,407	2,778	80	4,172	3,648	1,130	49	215	1,437	16,916
2000	4,315	3,832	101	3,691	3,232	1,052	42	176	1,311	17,751
2001	3,573	3,651	68	3,804	3,480	1,121	34	167	1,388	17,285
2002	2,844	2,439	53	3,964	3,060	1,015	56	271	1,098	14,800
2003	2,290	2,035	24	2,557	2,453	774	27	116	694	10,971
2004	3,474	2,406	81	3,162	3,648	1,223	42	164	945	15,145
2005	3,635	2,896	70	3,127	3,925	1,156	34	157	873	15,873
2006	2,865	2,708	69	3,071	2,833	860	48	163	1,083	13,699
2007	3,544	2,559	70	3,726	3,312	1,039	65	227	1,320	15,861
2008	3,888	2,829	112	3,289	4,014	1,152	42	181	1,294	16,800
2009	2,739	2,855	39	3,209	3,844	1,207	31	130	964	15,018
2010	3,073	2,799	53	4,788	4,133	1,364	41	198	1,163	17,612
2011	3,433	2,963	86	4,071	3,901	1,133	49	198	1,158	16,991
2012	4,416	3,541	86	3,333	4,228	1,385	39	180	1,237	18,445
2013	3,226	2,441	64	3,463	4,032	1,073	35	174	930	15,439
2014	3,059	2,596	53	2,972	3,447	688	45	155	1,228	14,241
2015	4,451	3,199	78	2,570	3,171	723	48	212	1,204	15,655
2016	3,958	2,314	51	2,811	3,482	951	37	178	918	14,700
2017	3,592	2,640	71	3,908	3,750	1,471	47	192	903	16,573
2018	3,096	2,654	47	2,894	3,983	756	34	158	851	14,474
2019	3,177	2,763	87	2,527	3,388	811	41	143	1,029	13,966
2020	4,182	3,306	96	2,569	4,045	922	34	163	1,207	16,524
2021	3,882	3,188	74	3,021	3,547	847	43	141	1,080	15,823
2022	3,544	2,845	64	2,744	3,481	939	36	148	755	14,557
2023	3,737	3,221	87	3,280	3,592	1,340	60	191	1,329	16,837

Table 3. Annual total nitrogen (TN) direct inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2023 (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TN	tonnes									
Direct	**BOB**	**BOS**	**ARC**	**BAP**	**GUF**	**GUR**	**SOU**	**WEB**	**KAT**	**BAS**
1995	3,491	3,653	1,497	16,671	17,386	1,164	5,497	7,289	4,245	60,894
1996	3,359	3,721	1,396	11,774	14,708	1,224	3,966	3,483	3,700	47,331
1997	3,432	3,662	1,184	10,314	13,080	1,250	2,922	2,985	3,527	42,356
1998	3,673	3,656	1,279	9,128	12,305	1,247	2,766	3,449	3,063	40,567
1999	3,541	3,551	1,247	8,167	12,618	1,251	2,208	2,874	2,773	38,229
2000	3,480	3,736	1,244	8,850	12,836	1,400	1,851	5,156	2,447	41,000
2001	3,186	3,378	1,257	6,953	12,958	1,521	1,596	2,572	2,438	35,859
2002	3,167	3,566	968	6,830	13,004	1,430	1,568	1,863	2,506	34,902
2003	3,235	3,649	896	6,693	12,903	1,815	1,371	1,666	2,086	34,313
2004	3,160	3,651	941	6,555	11,806	1,442	1,563	1,594	2,280	32,993
2005	2,934	3,656	800	6,409	10,167	1,573	1,485	1,473	2,219	30,716
2006	3,005	3,877	885	6,899	9,304	1,768	1,602	1,532	2,475	31,348
2007	3,019	3,522	829	7,718	9,608	2,379	1,862	1,494	2,635	33,067
2008	3,038	3,517	792	6,911	9,154	2,460	1,586	1,436	2,700	31,593
2009	2,890	3,368	801	6,434	10,054	1,277	1,755	1,517	2,466	30,563
2010	3,000	3,212	756	6,919	9,710	1,121	1,361	1,546	2,233	29,858
2011	3,150	3,140	697	6,972	10,075	1,143	1,553	1,691	2,306	30,727
2012	3,315	3,348	907	6,627	9,707	1,107	1,545	1,600	2,198	30,354
2013	3,678	3,378	825	6,472	9,506	696	1,753	1,499	2,009	29,815
2014	3,740	3,152	803	5,973	9,177	516	1,603	1,557	2,044	28,564
2015	3,461	3,404	786	6,271	8,805	543	1,753	1,631	2,164	28,818
2016	3,655	3,374	714	5,276	9,134	518	1,643	1,527	1,950	27,791
2017	3,363	3,290	738	5,505	10,209	432	1,796	1,603	1,918	28,854
2018	3,066	3,111	676	4,759	7,969	402	1,497	1,537	1,682	24,701
2019	3,016	3,035	663	4,686	10,099	442	1,830	1,557	2,027	27,355
2020	2,721	2,906	609	4,719	9,672	348	1,573	1,540	1,846	25,936
2021	3,195	2,834	545	4,958	9,855	394	1,834	1,483	1,875	26,973
2022	3,081	2,721	652	4,841	9,261	370	1,594	1,415	1,561	25,496
2023	2,865	2,752	630	5,253	8,700	429	2,039	1,524	2,135	26,326

Table 4. Annual total nitrogen (TN) riverine inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2023 (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TN	tonnes									
River	**BOB**	**BOS**	**ARC**	**BAP**	**GUF**	**GUR**	**SOU**	**WEB**	**KAT**	**BAS**
1995	41,185	42,642	6,480	342,047	92,747	85,143	7,264	40,953	62,735	721,196
1996	36,744	29,435	6,606	355,572	72,043	55,485	4,422	14,277	33,998	608,582
1997	40,695	37,210	6,274	309,048	73,289	89,654	4,211	17,115	40,575	618,071
1998	63,059	54,481	7,234	410,043	95,686	99,101	11,123	50,081	71,308	862,116
1999	45,276	42,042	7,307	357,061	93,503	84,813	8,621	40,365	75,791	754,779
2000	65,745	63,469	9,308	276,785	93,369	71,477	6,252	29,595	68,593	684,592
2001	50,427	52,212	7,005	284,755	100,936	86,421	5,156	26,676	62,613	676,201
2002	36,291	35,844	4,442	346,127	108,561	70,246	7,692	46,060	62,657	717,920
2003	33,127	29,255	4,166	191,896	114,916	45,561	2,944	16,518	38,281	476,666
2004	53,050	39,082	7,444	248,911	122,618	80,488	6,506	29,484	55,645	643,229
2005	54,038	41,473	6,460	247,598	96,587	73,410	4,111	25,508	43,551	592,736
2006	48,685	46,392	8,890	235,950	127,692	53,096	7,169	27,156	58,459	613,489
2007	53,491	38,185	7,349	312,552	108,545	104,323	8,366	39,580	65,701	738,092
2008	56,768	46,649	10,879	242,203	94,303	93,654	5,204	26,769	56,720	633,149
2009	35,075	37,123	4,019	236,836	102,985	67,471	3,344	18,944	40,652	546,449
2010	40,094	36,237	5,218	386,967	91,665	83,258	5,574	32,427	46,463	727,902
2011	49,237	43,624	8,650	327,310	105,839	99,413	5,923	29,935	47,866	717,797
2012	66,448	52,256	6,640	210,386	103,024	90,863	4,508	22,897	48,279	605,300
2013	41,023	34,581	6,623	277,663	91,184	66,131	4,859	23,803	38,511	584,379
2014	38,748	33,040	5,765	195,699	79,197	48,130	6,514	20,641	49,514	477,247
2015	65,338	43,175	6,906	173,783	73,003	54,953	6,866	30,295	51,370	505,687
2016	49,233	28,363	3,895	230,827	84,492	82,469	4,294	23,040	39,065	545,678
2017	44,162	32,154	6,688	359,921	99,448	106,954	7,095	26,652	43,949	727,024
2018	34,306	31,174	4,058	221,038	99,476	53,821	4,410	21,902	36,386	506,570
2019	36,190	35,381	10,203	189,210	81,926	62,697	8,570	24,152	56,297	504,626
2020	58,173	43,124	7,657	187,118	108,360	67,939	4,817	23,086	46,774	547,048
2021	48,728	42,424	5,822	242,741	89,488	75,816	6,955	18,419	42,617	573,011
2022	43,293	32,281	4,287	219,763	101,784	79,691	4,575	19,360	32,812	537,845
2023	48,780	46,034	7,650	273,492	83,204	112,991	9,080	26,358	55,508	663,098

Table 5. Annual total nitrogen (TN) waterborne (riverine + direct) inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2023 (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TN	tonnes									
Sum	**BOB**	**BOS**	**ARC**	**BAP**	**GUF**	**GUR**	**SOU**	**WEB**	**KAT**	**BAS**
1995	44,676	46,295	7,977	358,718	110,133	86,307	12,762	48,242	66,980	782,090
1996	40,103	33,156	8,003	367,345	86,751	56,709	8,388	17,760	37,698	655,913
1997	44,126	40,872	7,458	319,362	86,368	90,904	7,134	20,100	44,102	660,427
1998	66,732	58,137	8,513	419,171	107,991	100,348	13,890	53,531	74,371	902,683
1999	48,817	45,593	8,554	365,227	106,121	86,064	10,828	43,239	78,564	793,008
2000	69,225	67,205	10,552	285,635	106,205	72,877	8,103	34,751	71,040	725,592
2001	53,613	55,590	8,261	291,708	113,893	87,942	6,752	29,248	65,051	712,059
2002	39,459	39,410	5,410	352,957	121,566	71,676	9,260	47,923	65,162	752,822
2003	36,363	32,904	5,062	198,589	127,819	47,376	4,315	18,184	40,367	510,979
2004	56,211	42,733	8,385	255,466	134,424	81,930	8,069	31,078	57,925	676,222
2005	56,972	45,129	7,260	254,007	106,754	74,983	5,596	26,981	45,770	623,452
2006	51,689	50,269	9,775	242,850	136,996	54,864	8,771	28,687	60,934	644,837
2007	56,510	41,707	8,178	320,270	118,154	106,701	10,228	41,075	68,336	771,159
2008	59,805	50,167	11,671	249,114	103,456	96,113	6,790	28,205	59,420	664,742
2009	37,965	40,491	4,819	243,270	113,039	68,748	5,099	20,461	43,118	577,012
2010	43,094	39,448	5,973	393,887	101,375	84,379	6,935	33,974	48,695	757,760
2011	52,387	46,764	9,347	334,281	115,913	100,556	7,476	31,626	50,171	748,523
2012	69,763	55,604	7,547	217,012	112,731	91,970	6,052	24,497	50,477	635,654
2013	44,701	37,960	7,448	284,136	100,690	66,827	6,612	25,302	40,519	614,194
2014	42,487	36,192	6,568	201,672	88,375	48,645	8,116	22,198	51,558	505,811
2015	68,799	46,579	7,692	180,054	81,808	55,495	8,619	31,925	53,534	534,505
2016	52,888	31,737	4,609	236,103	93,626	82,988	5,937	24,567	41,014	573,469
2017	47,525	35,444	7,426	365,425	109,658	107,386	8,891	28,256	45,867	755,879
2018	37,372	34,285	4,734	225,796	107,445	54,223	5,907	23,439	38,068	531,271
2019	39,206	38,416	10,867	193,896	92,025	63,139	10,400	25,709	58,324	531,981
2020	60,894	46,031	8,265	191,838	118,032	68,288	6,390	24,626	48,620	572,983
2021	51,923	45,258	6,367	247,699	99,344	76,210	8,789	19,902	44,492	599,984
2022	46,374	35,002	4,939	224,605	111,045	80,061	6,169	20,775	34,372	563,341
2023	51,646	48,786	8,280	278,745	91,904	113,419	11,118	27,882	57,643	689,424

Table 6. Annual total phosphorus (TP) direct inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2023 (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TP	tonnes									
Direct	**BOB**	**BOS**	**ARC**	**BAP**	**GUF**	**GUR**	**SOU**	**WEB**	**KAT**	**BAS**
1995	158	288	107	1,463	2,707	314	614	288	267	6205
1996	130	273	100	755	2,738	253	438	169	192	5,047
1997	128	247	86	691	2,534	255	312	140	191	4,584
1998	128	231	87	735	2,542	253	217	146	204	4,544
1999	119	232	85	596	2,705	254	183	158	181	4,513
2000	112	246	88	529	2,631	197	165	157	176	4,300
2001	105	221	81	341	2,630	230	155	125	153	4,041
2002	102	213	59	387	2,800	208	183	140	146	4,240
2003	90	233	55	416	2,920	163	127	121	117	4,241
2004	89	245	64	961	3,116	175	133	125	123	5,031
2005	95	232	60	413	2,881	203	134	112	123	4,253
2006	104	235	67	498	2,340	184	133	111	136	3,809
2007	105	218	63	529	2,163	179	167	125	137	3,687
2008	103	204	62	472	1,289	157	192	128	120	2,726
2009	94	174	56	398	2,801	59	291	112	97	4,082
2010	92	179	43	416	1,650	46	165	113	98	2,802
2011	93	165	49	416	2,354	38	182	129	116	3,543
2012	113	176	55	418	353	76	252	117	88	1,649
2013	120	176	53	404	347	55	217	122	91	1,585
2014	139	167	48	409	356	61	147	151	93	1,570
2015	108	170	45	400	447	64	151	141	105	1,630
2016	104	159	41	385	430	46	135	112	100	1,512
2017	101	141	42	197	471	42	132	112	99	1,336
2018	95	136	39	178	203	36	108	108	99	1,001
2019	93	132	40	199	307	38	166	102	113	1,191
2020	94	123	38	180	264	33	101	97	97	1,028
2021	97	127	35	195	376	33	110	101	103	1,176
2022	68	103	38	195	290	37	105	100	84	1,021
2023	65	119	38	210	252	39	133	101	104	1,062

Table 7. Annual total phosphorus (TP) riverine inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2023 (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TP	tonnes								
River	**BOB**	**BOS**	**ARC**	**BAP**	**GUF**	**GUR**	**SOU**	**WEB**	**KAT**
1995	2,647	1,955	447	18,427	7,246	2,911	262	1,039	1,537
1996	1,711	1,084	508	17,804	4,595	2,000	152	556	795
1997	2,847	1,608	454	20,261	4,438	1,950	197	570	992
1998	3,307	1,932	544	21,770	5,310	3,693	276	1,135	1,674
1999	2,283	2,079	522	20,520	5,064	3,564	271	1,032	1,897
2000	3,366	2,411	669	16,331	5,905	2,732	168	770	1,733
2001	2,456	1,918	525	18,121	4,790	3,398	143	779	1,609
2002	1,704	1,045	310	17,715	6,598	1,549	236	1,206	1,488
2003	1,501	885	202	11,551	4,612	1,835	120	521	932
2004	2,440	1,219	463	14,256	7,316	2,518	168	758	1,366
2005	2,492	1,486	447	12,202	8,461	2,458	144	625	1,259
2006	2,038	1,582	593	13,295	4,250	1,765	200	657	1,744
2007	2,166	1,139	504	14,190	3,122	2,505	269	961	1,581
2008	2,650	1,727	860	11,740	5,352	2,560	163	789	1,473
2009	1,718	1,229	275	13,386	8,368	2,495	132	556	1,049
2010	2,562	1,294	321	18,972	4,512	2,735	171	755	1,296
2011	2,431	1,572	607	15,541	4,441	2,003	197	958	1,370
2012	3,468	1,945	524	10,355	4,064	2,946	169	764	1,446
2013	2,134	1,234	529	14,374	3,554	2,356	143	679	1,023
2014	1,914	1,037	378	13,802	3,488	1,387	214	600	1,399
2015	3,035	1,468	542	8,067	2,691	1,308	191	855	1,442
2016	2,605	974	267	9,273	3,397	2,152	126	697	1,076
2017	2,208	1,173	444	12,492	4,201	3,038	173	833	1,252
2018	1,863	1,134	239	10,114	4,241	1,754	107	594	978
2019	1,809	1,109	638	7,716	3,112	1,453	144	571	1,443
2020	2,882	1,583	658	8,020	4,245	1,635	113	637	1,514
2021	2,297	1,353	359	9,230	4,370	1,409	140	560	1,073
2022	2,000	1,025	292	7,126	3,374	1,225	98	566	806
2023	2,480	1,582	413	7,889	3,037	2,486	177	777	1495

Table 8. Annual total phosphorus (TP) waterborne (riverine + direct) inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2023 (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TP	tonnes									
Sum	**BOB**	**BOS**	**ARC**	**BAP**	**GUF**	**GUR**	**SOU**	**WEB**	**KAT**	**BAS**
1995	2,805	2,243	554	19,889	9,952	3,225	876	1,327	1,804	42,677
1996	1,841	1,357	608	18,559	7,332	2,253	590	725	987	34,252
1997	2,975	1,855	541	20,953	6,971	2,205	509	711	1,183	37,901
1998	3,436	2,163	631	22,505	7,852	3,946	492	1,282	1,878	44,185
1999	2,402	2,311	608	21,116	7,769	3,818	453	1,189	2,077	41,744
2000	3,478	2,657	757	16,860	8,535	2,929	333	928	1,908	38,386
2001	2,561	2,139	605	18,462	7,421	3,628	299	905	1,761	37,780
2002	1,806	1,258	370	18,102	9,399	1,757	418	1,346	1,634	36,091
2003	1,591	1,118	257	11,967	7,532	1,998	247	642	1,050	26,401
2004	2,529	1,463	527	15,216	10,433	2,693	301	883	1,489	35,535
2005	2,587	1,718	507	12,615	11,342	2,661	277	737	1,381	33,825
2006	2,143	1,817	660	13,793	6,590	1,950	334	768	1,880	29,934
2007	2,271	1,357	567	14,719	5,285	2,684	436	1,087	1,718	30,123
2008	2,753	1,931	922	12,212	6,641	2,717	355	917	1,593	30,042
2009	1,812	1,403	331	13,784	11,169	2,554	424	669	1,145	33,290
2010	2,654	1,472	365	19,388	6,162	2,781	336	868	1,394	35,419
2011	2,523	1,737	656	15,957	6,796	2,041	379	1087	1,486	32,662
2012	3,581	2,121	579	10,773	4,417	3,022	421	881	1,534	27,329
2013	2,254	1,410	583	14,778	3,901	2,411	360	800	1,114	27,611
2014	2,054	1,204	425	14,210	3,844	1,448	361	751	1,493	25,789
2015	3,144	1,638	586	8,466	3,138	1,372	342	996	1,546	21,229
2016	2,709	1,132	308	9,659	3,827	2,199	261	809	1,176	22,080
2017	2,309	1,314	486	12,689	4,671	3,080	306	945	1,351	27,150
2018	1,958	1,271	278	10,292	4,445	1,789	214	702	1,077	22,026
2019	1,902	1,241	678	7,915	3,419	1,491	311	673	1,555	19,185
2020	2,976	1,706	696	8,201	4,509	1,668	214	733	1,612	22,315
2021	2,395	1,479	394	9,425	4,746	1,442	250	661	1,176	21,968
2022	2,068	1,128	330	7,322	3,665	1,261	204	666	890	17,533
2023	2,545	1,701	451	8,099	3,289	2,525	310	878	1,599	21,399

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 – 2023.

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

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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.

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, 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.

<u>Unmonitored parts of the catchment</u>

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).

<u>Total waterborne inputs</u>:

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 1995-2023 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 (1995-2023) 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:

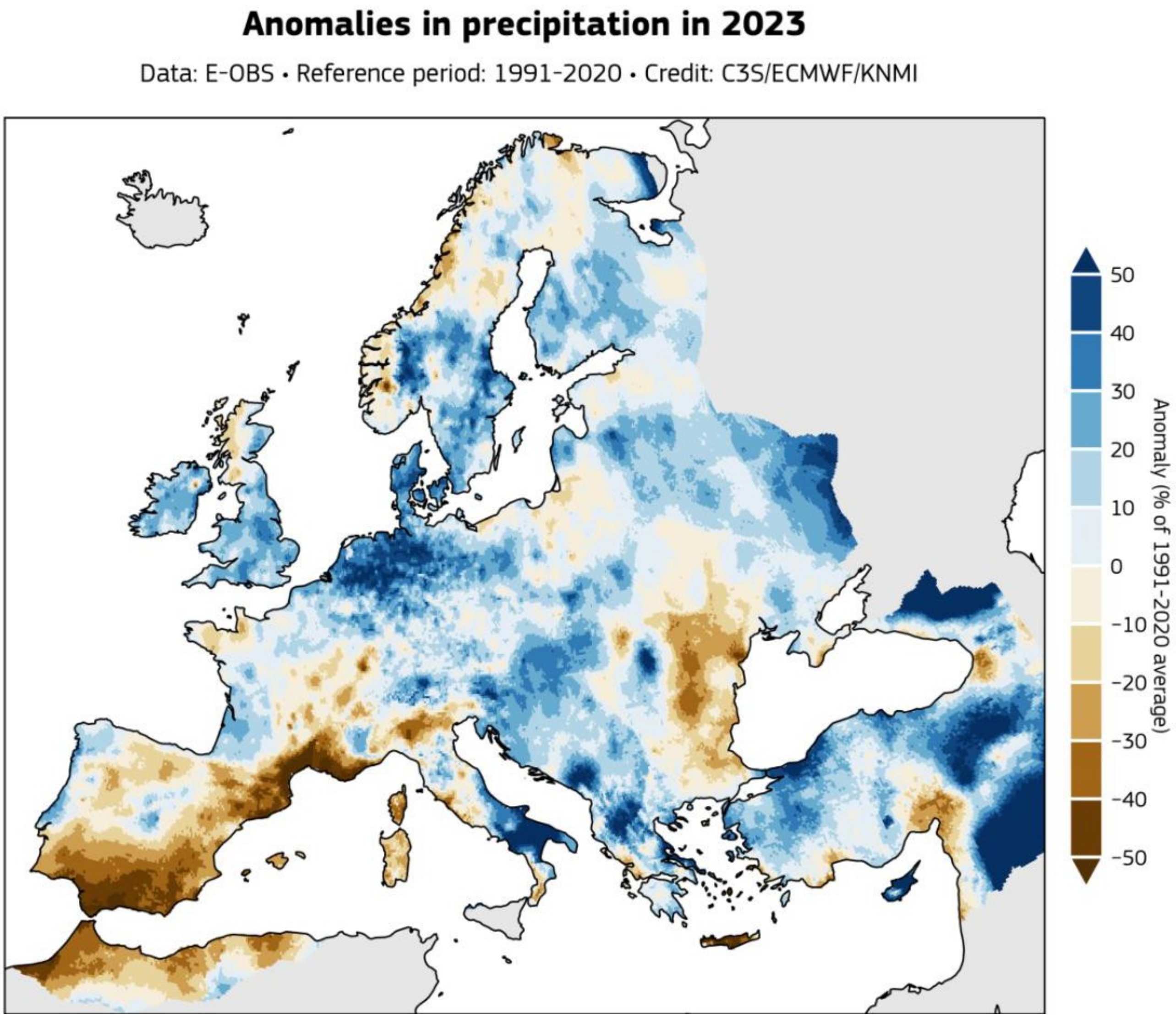
Total nitrogen and phosphorus inputs from all unmonitored areas must be modelled/estimated with methods that provide consistent and comparable results. The sampling frequency and strategy in rivers should be adjusted to flow and concentrations regime and patterns in individual rivers, and at least 12 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 laboratories 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 and annual temperature 2023 raking map from Copernicus

The annex includes maps showing precipitation in Europe in 2023 as deviation from the reference period 1991-2020 on an annual basis (figure A.1-A.3) and seasonally (figure A.4). Further included is a map ranking annual average surface air temperature in 2023 (figure A5.). The maps are downloaded from Corpernicus Climate Change Services on: https://climate.copernicus.eu/esotc/2023/precipitation. The data sources 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"



Anomalies in precipitation in 2023

Data: E-OBS • Reference period: 1991-2020 • Credit: C3S/ECMWF/KNMI

Figure A.1 Annual precipitation anomalies in 2023 expressed as a percentage of the annual average for the reference period 1991-2020. Data source. E-OBS: Credit: C3S/ECMWF/KNMI

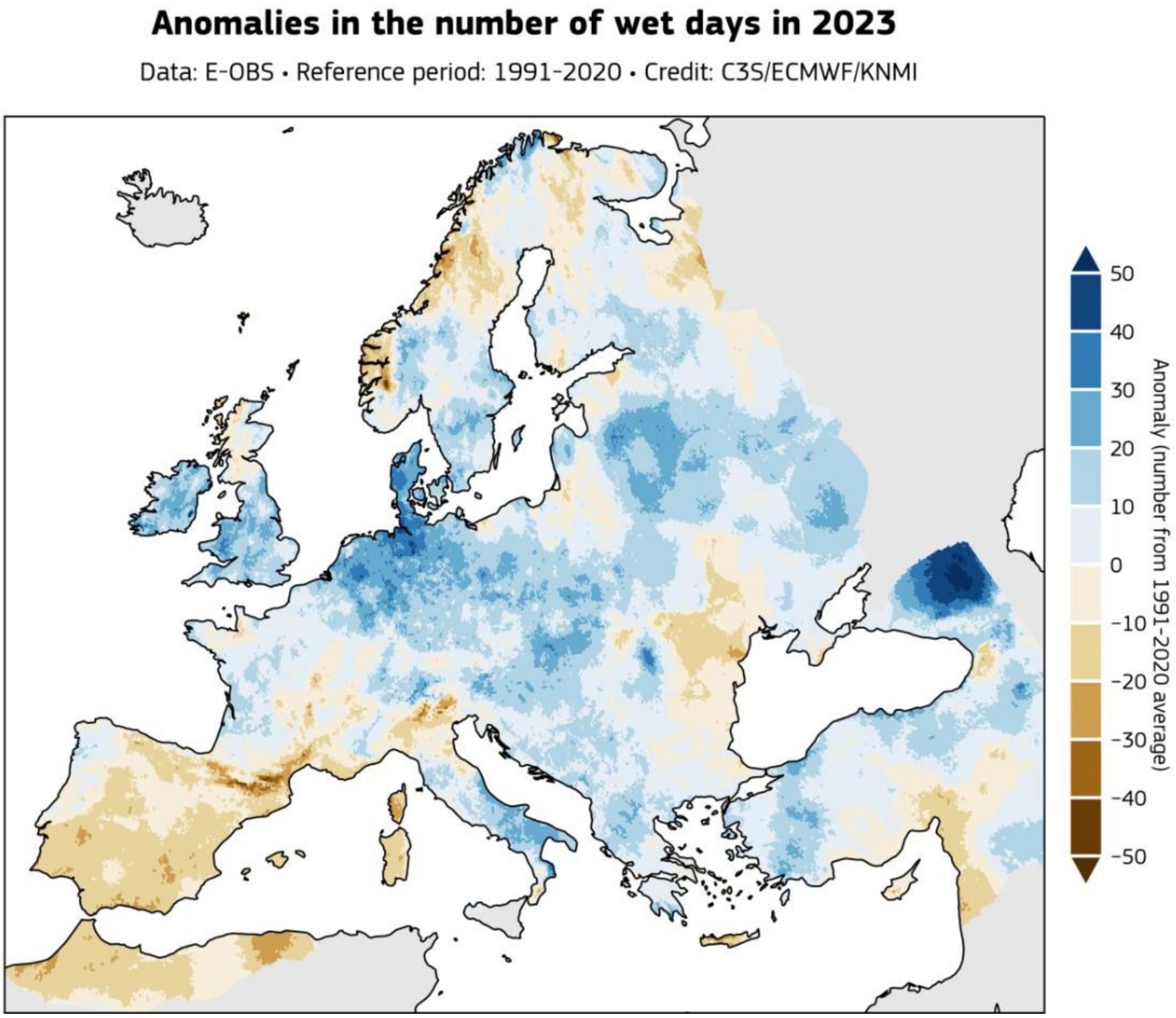


Figure A.2 Wet day anomalies in 2023 (expressed in number of days) relative to the average for 1991-2020 reference period. Shade of red are negative anomalies blue are positive. Wet day = accumulated precipitation one day 1 mm or more. Data source: E-OBS. Credit: C3S/ECMWF/KNMI

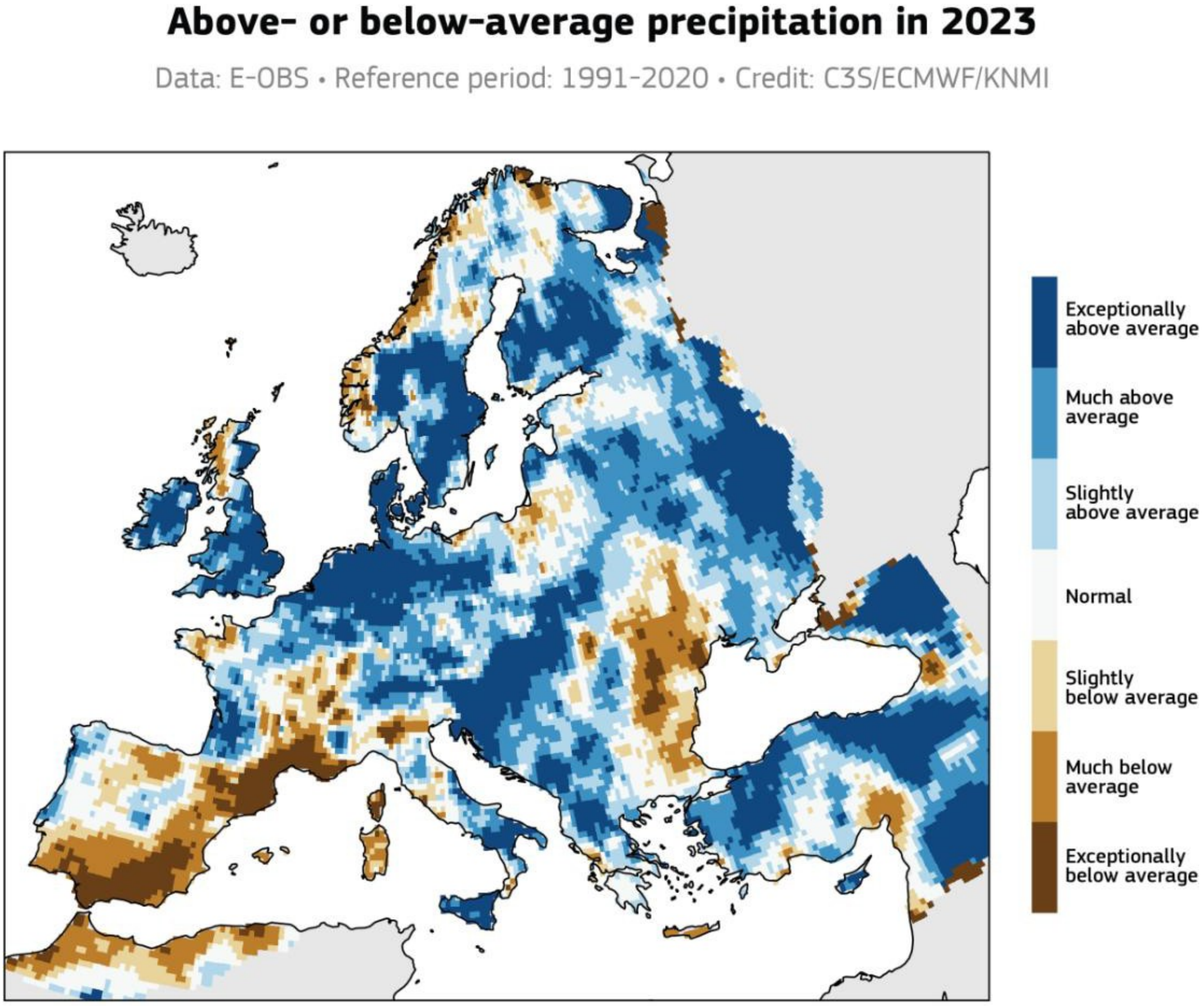


Figure A.3 The 2023 annual precipitation in a historical perspective. The darkest blue indicates that 2023 is wetter than the 90% of wettest years, the darkest brown indicates that 2023 is among the 10% of driest years. The categories ‘exceptionally above (below) average’ >90% (<10%), ‘much above (below) average’ 75–90% (10–25%), ‘above (below) average’ 60–75% (25–40%), and ‘average’ (40–60%) are relative to the 1991–2020 reference period. Data source: E-OBS. Credit: C3S/ECMWF/KNMI.

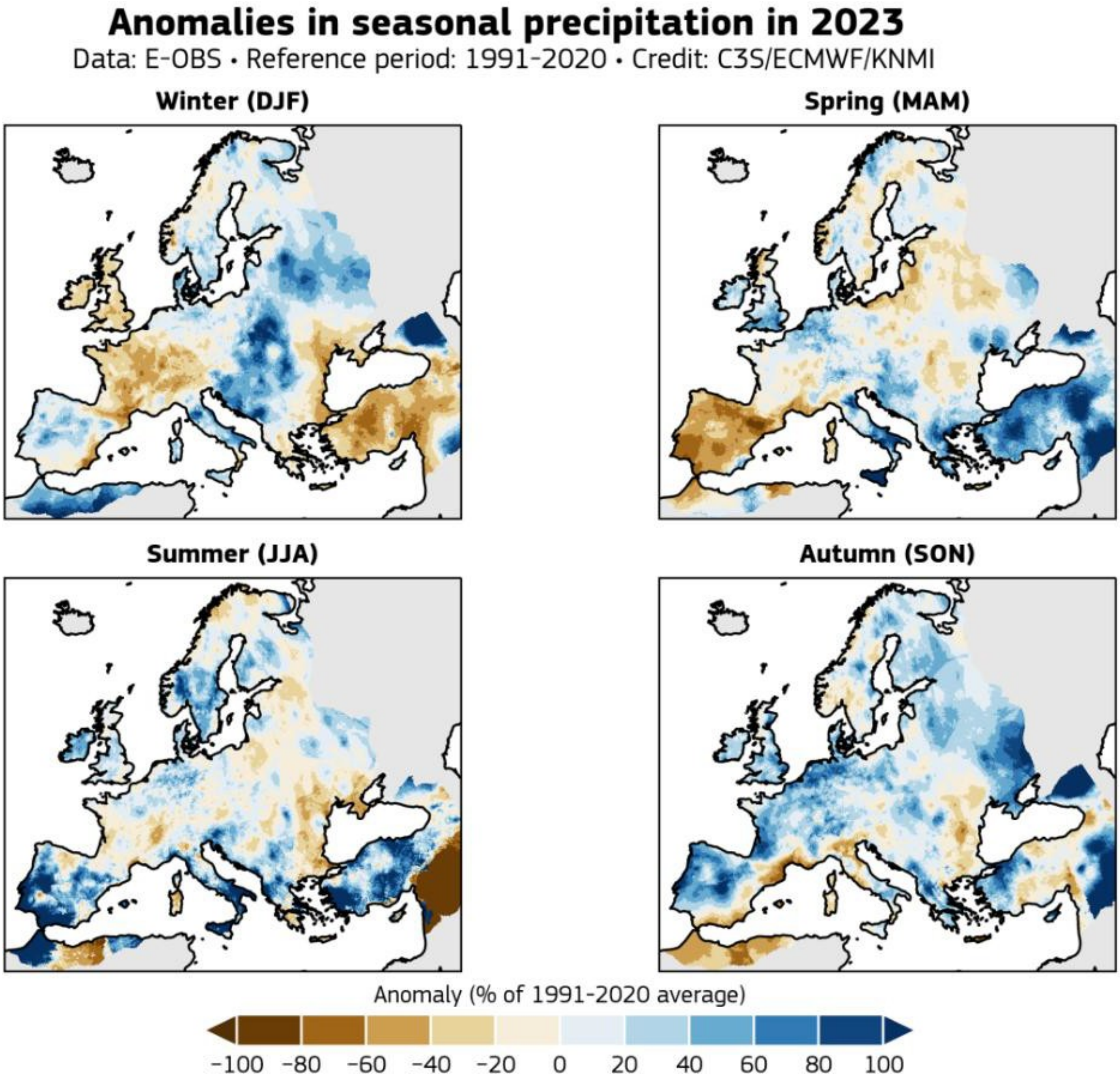


Figure A.4 Seasonal precipitation anomalies in 2023 expressed as a percentage of the seasonal average for the reference period 1991-2020. Winter covers December 2022-Februar 2023, Spring March 2023-May 2023, Summer July2023-August 2023 and Autumn September 2023-November 2023. Data source. E-OBS: Credit: C3S/ECMWF/KNMI.

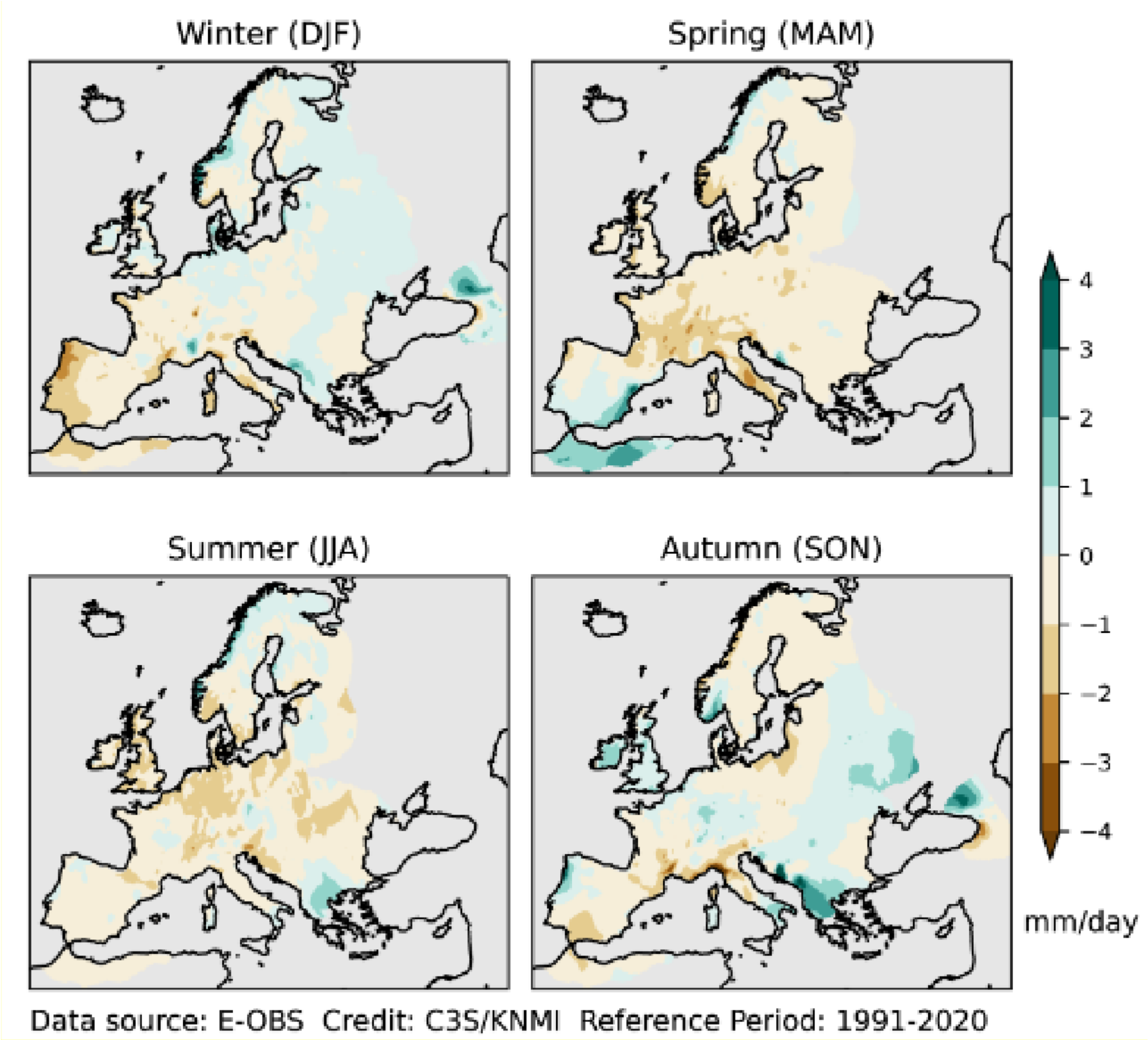


Figure A.5 Seasonal precipitation anomalies expressed as a mm/day of the seasonal average for the reference period 1991-2020. Winter covers December 2021-Februar 2022, Spring March 2022-May 2022, Summer July2022-August 2022 and Autumn September 2022-November 2022. Data source. E-OBS: Credit: C3S/ECMWF/KNMI.

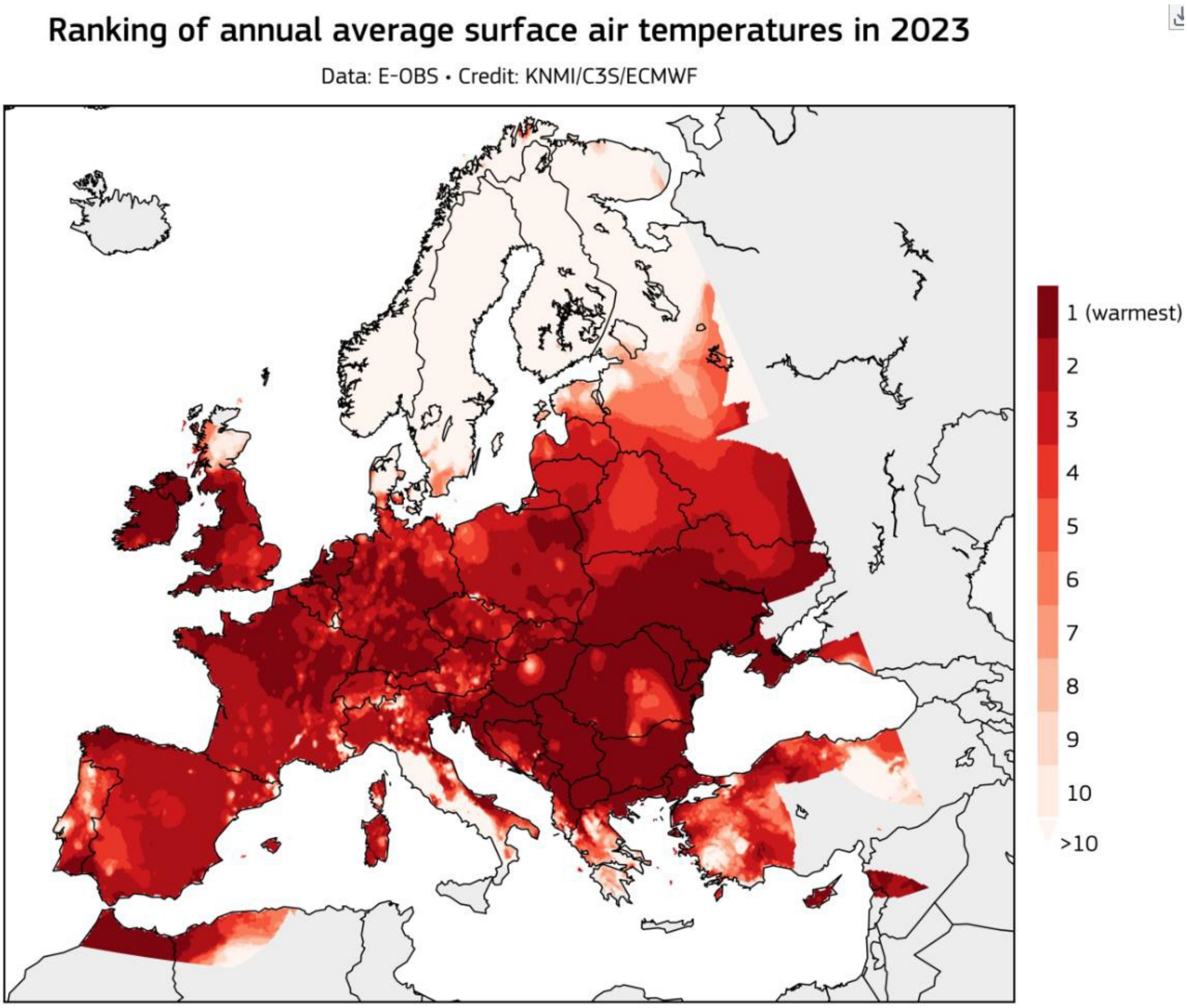


Figure A.5 *Ranking* of the 2023 annual average surface air temperatures, for the period from 1950 to 2023. Darker shades of red indicate a higher ranking; the darkest showing the warmest year on record. The lightest shading indicates areas that were outside of the top 10 warmest years. Data source: E-OBS. Credit: C3S/ECMWF/KNMI.