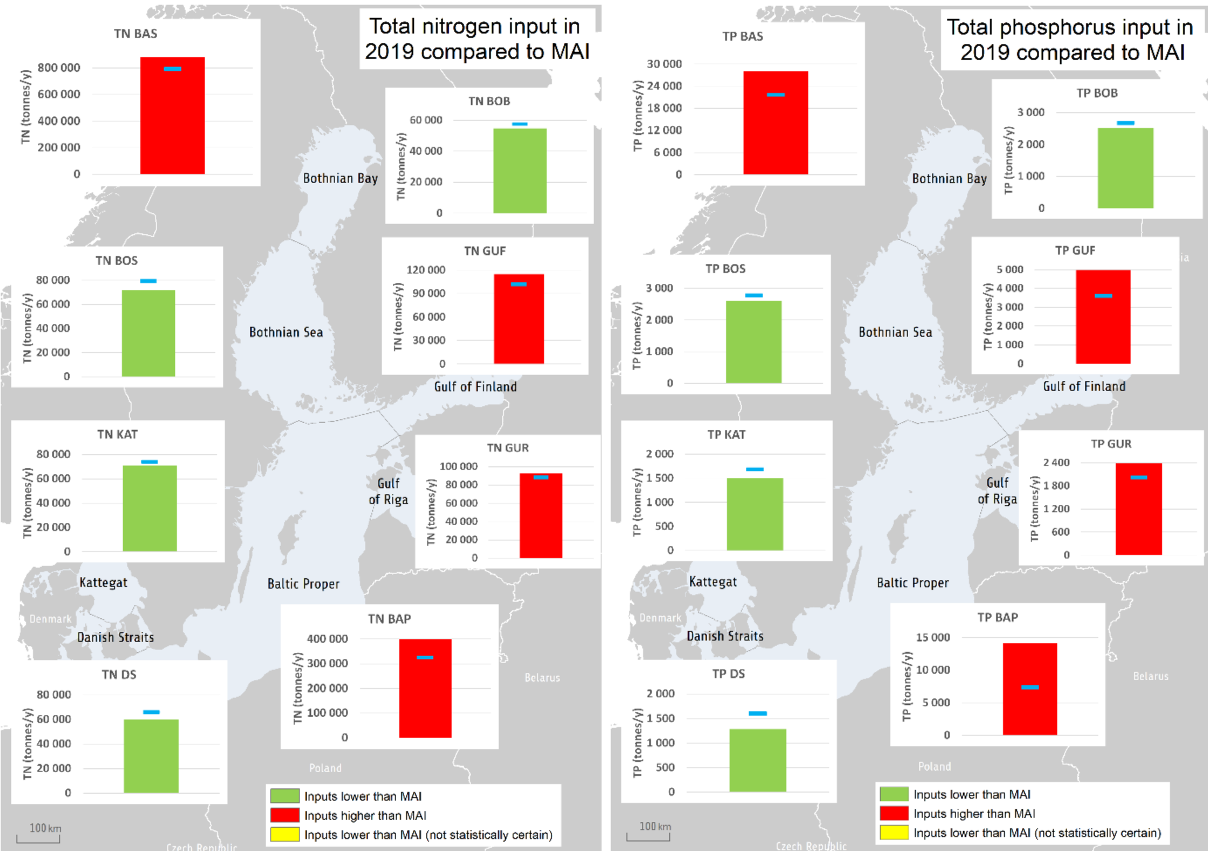
HELCOM core indicator report
November 2021

Inputs of nutrients (nitrogen and phosphorus) to the sub-basins (2019)

Key message

A significant reduction of nutrients input has been achieved for the whole Baltic Sea. This assessment shows that the normalized total input of nitrogen[1] was reduced by 11% and phosphorus by 28% between the reference period (1997-2003) and 2019 (Results figure 1). In 2018 the corresponding reductions were 12% for total inputs of nitrogen and 26% for total phosphorus. The maximum allowable input (MAI) of nitrogen in this period was fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat (Key message figures 1 and Results tables 1a and 1b). MAI for phosphorus input was also fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat. In the remaining sub-basin MAI was not fulfilled for either total nitrogen or for total phosphorus.



Key message figure 1. Total input of nitrogen and phosphorus to each sub-basin and the whole Baltic Sea (BAS). Trend-based estimate of total nitrogen and phosphorus inputs in 2019 (tons per year) including statistical uncertainty are compared with the maximum

[1] Total inputs of nitrogen and phosphorus are the sum of the respective waterborne inputs (which consists of riverine inputs and direct inputs (point sources discharging directly to the sea)) and airborne inputs. Nitrogen and phosphorus inputs include all fractions of these nutrients (dissolved, particulate, inorganic and organic).

allowable nutrient inputs (MAI t/y, shown as a blue line). Green colour indicates that estimated inputs including uncertainty during… 2019 were lower than MAI, red colour indicates that inputs were higher, while yellow indicates that when taking into account the statistical uncertainty of input data it is not possible to determine whether MAI was fulfilled (not relevant in 2019). *Note: the scales on the y-axes differ in the charts.*

Relevance of the core indicator

The input of nutrients is an indicator of eutrophication pressure on the marine ecosystem. In the Baltic Sea, the pressure is mainly driven by anthropogenic inputs of nitrogen and phosphorus to the sea.

The HELCOM nutrient reduction scheme defines maximum allowable inputs of nitrogen and phosphorous to Baltic Sea sub-basins, and inputs should not exceed these environmental targets to eventually obtain good status in terms of eutrophication. This core indicator presents progress in the different Baltic Sea sub-basins towards reaching the MAI.

Policy relevance of the core indicator

	BSAP segment and objectives	MSFD Descriptor and criteria
Primary link	• Eutrophication segment: nutrient reduction scheme. • Has an influence on reaching objective *Concentrations of nutrients close to natural levels.*	Descriptor 5: Human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters. D5C1 Nutrient concentrations are not at levels that indicate adverse eutrophication effects.
Secondary link	• Maritime segment: Minimum air pollution from ships and minimum sewage pollution from ships. • (Nutrient levels also affect biodiversity ecological objectives).	Descriptor 1: Pelagic habitats D1C6 The condition of the habitat type, including its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing key function, size structure of species), is not adversely affected due to anthropogenic pressures. Descriptor 6: Benthic habitats D6C5 The extent of adverse effects from anthropogenic pressures on the condition of the habitat type, including alteration to its abiotic and biotic functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing key function, size structure of species), does not exceed a specified proportion of the natural extent of the habitat type in the assessment area.
Other relevant legislation: EU Nitrates Directive; EU Urban Waste-Water Treatment Directive; Industrial Emissions Directive (IED), Water Framework Directive, WFD; 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); Water Code of Russian Federation; Federal Act on the internal maritime waters, territorial sea and contiguous zone of the Russian Federation; IMO designated 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; NOx emission control areas (NECA) in the Baltic and North seas designated by IMO.

Cite this indicator

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Results and confidence

Fulfilment of MAI in 2019 and progress since the reference period (1997-2003)

According to the revised HELCOM nutrient reduction scheme adopted in the 2013 HELCOM Ministerial Declaration (HELCOM 2013a) reduction requirements were set for nitrogen inputs to the Baltic Proper, Gulf of Finland and Kattegat and for phosphorus inputs to Baltic Proper, Gulf of Finland and Gulf of Riga.

The Kattegat is the only sub-basin out of three with set reduction targets for nitrogen inputs where the input was significantly below MAI in 2019 (Key messages figure 1 and Results table 1a). However, since the reference period (1997-2003), a statistically significant reduction of nitrogen input has been achieved to all sub-basins except the Gulf of Riga, where no reduction has been observed (Results figure 2). The highest observed input reduction was to Bothnian Sea, Danish Straits, and the Kattegat (all with 22%), the lowest to the Baltic Proper (9%) (Results figure 1). Nitrogen inputs to the entire Baltic Sea have been reduced by 11% since the reference period.

Results table 1. The trend-based estimate for normalized annual inputs of (a) nitrogen and (b) phosphorus during 2019.

The table also contains data on statistical uncertainty, the remaining reduction needed to reach MAI and inputs in 2019 including statistical uncertainty in percentages of MAI. Classification of achieving MAI is given in colours: green=MAI fulfilled, yellow= fulfilment is not determined due to statistical uncertainty, and red=MAI not fulfilled. (Units in columns 2-5: tonnes per year). NOTE: *For consistency with MAI no rounding (to tenth, hundreds or thousands) has been performed in the indicator*.

Table 1a.

Baltic Sea Sub-basin	MAI*	N input 2019	Statistical uncertainty 2019	N input including stat. uncert. 2019	Exceedance of MAI in 2019	Input 2019 including stat. uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay (BOB)	57 622	52 983	1 777	54 760		95	
Bothnian Sea (BOS)	79 372	68 878	2 762	71 640		90	
Baltic Proper (BAP)	325 000	405 061	9 128	414 189	89 189	127	
Gulf of Finland (GUF)	101 800	105 939	9 086	115 025	13 225	113	
Gulf of Riga (GUR)	88 417	89 183	3 394	92 577	4 160	105	
Danish Straits (DS)	65 998	57 997	1 909	59 906		91	
Kattegat (KAT)	74 000	69 047	1 658	70 704		96	
Baltic Sea (BAS)	**792 209**	**867 960**	**13 178**	**881 138**	**88 929**	**111**	

Table 1b.

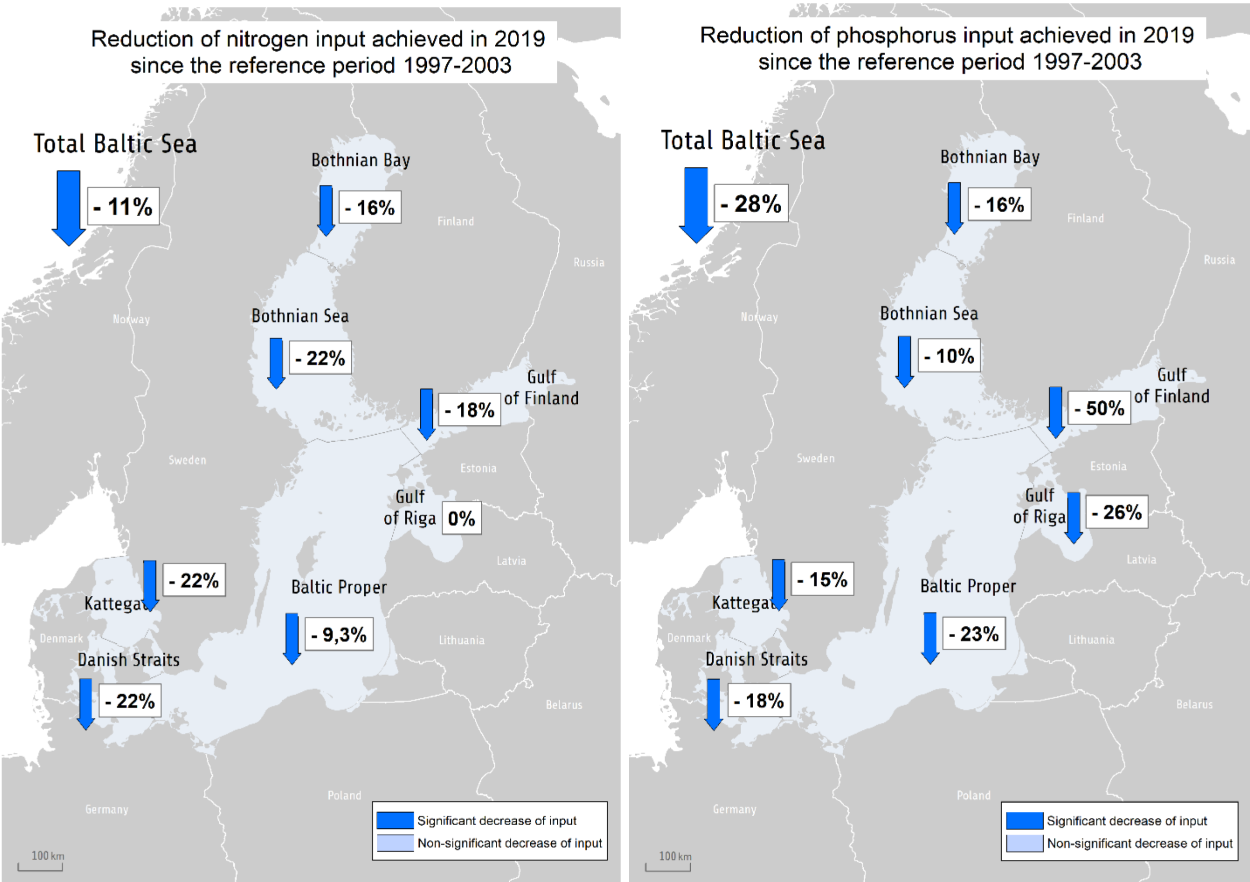
Baltic Sea Sub-basin	MAI*	P input 2019	Statistical uncertain-ty 2019	P input including stat. uncert. 2019	Exceedance of MAI in 2019	Input 2019 incl. stat. uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay (BOB)	2 675	2 371	146	2 518		94	
Bothnian Sea (BOS)	2 773	2 522	79	2 601		94	
Baltic Proper (BAP)	7 360	13 280	816	14 096	6 736	192	
Gulf of Finland (GUF)	3 600	4 083	896	4 979	1 379	138	
Gulf of Riga (GUR)	2 020	2 129	257	2 386	366	118	
Danish Straits (DS)	1 601	1 220	64	1 284		80	
Kattegat (KAT)	1 687	1 427	71	1 498		89	
Baltic Sea (BAS)	**21 716**	**26 736**	**1 330**	**28 066**	**6 350**	**129**	

*As adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a)

**Exceedance of MAI is caused by statistical data uncertainty.

None of the 3 sub-basins, the Baltic Proper, Gulf of Finland and Gulf of Riga, for which reduction targets for phosphorus inputs were set, fulfilled the requirements in 2019 (Key message figure 1 and Results table 1b). However, statistically significant reductions were achieved in all sub-basins since the reference period. The highest input reductions since the reference period (1997-2003) were achieved in the Gulf of Finland (50%), Gulf of Riga (26%) and Baltic Proper (23%) (Results figure 1). Phosphorus inputs to the entire Baltic Sea have been reduced by 28% since the reference period, and 76% of this reduction is due to reduced phosphorus inputs to the Gulf of Finland and Baltic Proper.

Compared to the first evaluation of MAI fulfilment (Svendsen et al. 2015), in 2016 EMEP revised the modelled nitrogen air deposition to the Baltic Sea for 1995-2012. This resulted in an increase of the annual deposition to the Baltic Sea of 16 to 23%. The increase of annual nitrogen deposition to the individual sub-basins was between 9 and 27 %. In the following, the EMEP deposition model was updated after the second MAI assessment (HELCOM, 2018). The update mainly concerned changing of the deposition grid resolution from 50km*50km to 0.1°*0.1° (approx. 11km*6km grid for Baltic Sea latitudes). The higher resolution was applied for computation of the annual nitrogen deposition 2000-2017, and for the present MAI assessment 1995-2019. Also, the whole time series of nitrogen emission data is updated annually, and, for years since 2000, data from FMI on ship emissions have replaced former ships emission data in the deposition calculation. The update of the model, revised reported emission data and use of weather data in the normalization procedure (section “Airborne Inputs” under chapter “Data and updating”) resulted in markedly changed deposition data compared to the previous reporting. Deposition on the Baltic Sea in the reference period (1997-2003) was 299 000 tons nitrogen in the latest EMEP estimate, compared to 227 000 tons nitrogen previously estimated, or 32% higher than calculated for the BSAP 2013. The nitrogen deposition in the reference period showed the highest increase in the Gulf of Finland (42%) and Kattegat (39%) and the lowest in the Gulf of Riga (21%).



Results figure 1. Reductions of total annual inputs of nitrogen (left) and phosphorus (right) achieved in 2019 since the reference period 1997-2003 (in %). The annual inputs in 2019 and in the reference period were calculated using normalized annual data. The arrows indicate decreasing (↓) inputs, while the colours indicate if the change was statistically significant.

Changes in total inputs of nitrogen and phosphorus since the reference period are calculated based on the average normalized inputs in the reference period and the estimated inputs in 2019, resulting from the analysis of long-term trends (1995-2019). Based on the updated modelled annual nitrogen deposition in 2019 there was a significant reduction since the reference period for all sub-basins. The overall reduction to the Baltic Sea in nitrogen deposition was 26%. For the sub-basins, the reduction was between 21 and 29%, and was highest for Kattegat and lowest for Gulf of Finland.

Phosphorus deposition on the Baltic Sea is calculated as a fixed annual rate of 5 kg P per km^2 sea surface (see section "Data and updating" of this indicator) during 1995-2019.

Reduction in atmospheric nitrogen deposition since the reference period contributes overall more than the corresponding waterborne nitrogen reductions to the reduction in total nitrogen inputs to the Baltic Sea (Results table 2). For the Baltic Sea, and the two sub-basins Baltic Proper and Gulf of Riga there were no significant reduction in the total waterborne nitrogen inputs. Only for the Gulf of Finland, Bothnian Sea and The Kattegat airborne reduction had a share that was lower than approximately 50% of the total reductions in nitrogen inputs, with shares of 20%, 30% and 41%, respectively.

Results table 2. Significant reductions in airborne nitrogen deposition, waterborne and total nitrogen inputs (tons) in 2019, respectively as compared with the reference period (1997-2003) for the Baltic Sea and sub-basins of the Baltic Sea, and the airborne deposition share (%) of the reduction. 100% = There was no significant reduction in waterborne nitrogen inputs. Remark: Significant reductions have been tested separately for airborne, waterborne and total (airborne + waterborne) TN inputs, and therefore sums of significant reductions on airborne and waterborne inputs will not necessarily add up to the significant reduction of the total nitrogen inputs. Correspondingly the airborne shares have been scaled according to the reduction on total nitrogen inputs.

TN reductions	BOS	BOB	BAP	GUF	GUR	DS	KAT	BAS
Airborne (tons)	3 070	9 470	43 700	4 750	2 970	8 450	8 370	80 800
Waterborne (tons)	6 980	9 110	-	18 600	-	8 850	12 000	-
Total TN inputs (tons)	10 100	19 000	45 000	23 400	0	16 300	19 200	115 000
Airborne reduction in % of total TN input reduction	30	51	100	20	100	49	41	100

Trends

Normalization is used for the annual riverine and atmospheric inputs to reduce the impact of inter-annual variations of the inputs caused by weather conditions (primarily variations in precipitation). With normalisation, the comparability of the inter-annual inputs increases, facilitating trend detection and identification of effects of undertaken measures in the catchment areas (Larsen & Svendsen, 2021 in press). Without normalization, the effects could be disguised by large natural annual variation of precipitation and river flow.

Trend analyses show statistically significant reduction of total (water+airborne) inputs of nitrogen to the Baltic Sea amounting to 19 % from 1995 to 2019 (Results figure 2a)[2]. For the Baltic Sea and the sub-basins except the Gulf of Riga, one or two break points were identified when evaluating the trends of total nitrogen inputs, dividing the time series into two or three sections. The Baltic Sea and the sub-basins except Bothnian Bay, Bothnian Sea and the Gulf of Riga had significant reductions in total inputs of nitrogen from 1995 to the identified break point: Kattegat 22% (1995-2010), Danish Straits 18% (1995-2002) and 14% (2003-2012) between the first and the second break point, Baltic Proper 17% (1995-2001) and Baltic Sea 10% (1995-2002). Only for Gulf of Finland (25%, breakpoint 2004), Bothnian Sea (23%, 2003), and Bothnian Bay (11%, 2008) there were significant reductions after the respective break points. A significant nitrogen input **increase** was observed to Gulf of Finland (20%, 1995-2003) and to Bothnian Bay (9%, 1995-2007).

Trends for total phosphorus inputs to the Baltic Sea revealed a steady statistically significant reduction of 35% from 1995 to 2019 (Results figure 2a). Correspondingly, from 1995 to 2019 total inputs of phosphorus also showed a steady significant decrease to Gulf of Riga[3] (31%), Baltic Proper (29%), Kattegat (20%) and Bothnian Bay (19%). Break points were detected when evaluating the trend in the time series for the remaining three sub-basins. For one of the three sub-basins, there was a significant decrease in total inputs

[2] Denmark have re-reported all annual data 1995-2018 for both nitrogen and phosphorus, taking into account analytical issues on total nitrogen (2007-2017) and to solve issues with precipitation data from the Danish Meteorological Institute used in modelling inputs from unmonitored areas.

[3] Phosphorus data from Latvia has been revised for 1995-2001 since 2017. The revised data also include the particulate phosphorus fractions.

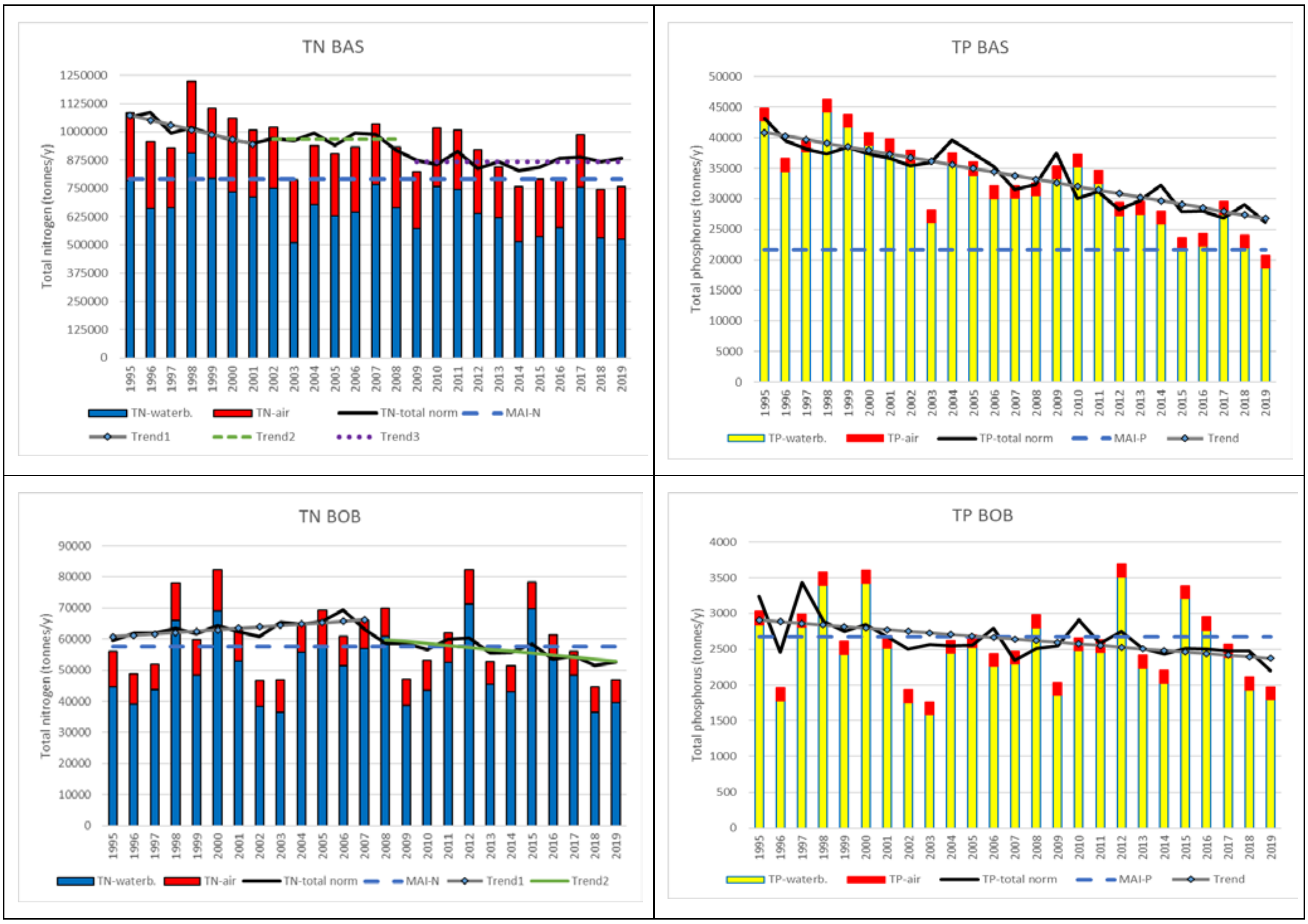
of phosphorus in the first section of the time series: Danish Straits 33% (1995-2000) and also a decrease after the break point (11%, 2001-2019). Bothnia Sea had a breakpoint in 2002, whereafter total inputs of phosphorus on average was about 16% lower, but with no trend in the inputs. Gulf of Finland had no trend in phosphorus inputs from 1995 to 2012. The Gulf of Finland had a significantly lower phosphorus input after the break point, by a marked and abrupt reduction in total phosphorus inputs after 2011 (reduction of 50% compared to the average 1995-2011 inputs), which is probably connected to rapid changes of inputs due to measures on point sources in the Russian catchment. There was a marked reduction, despite large inter-annual variation preventing efficient flow normalization. This resulted in a high uncertainty in the total inputs of phosphorus to the Gulf of Finland (22% according to Results table 1b). In addition, Gulf of Riga had a rather higher uncertainty on estimated phosphorus inputs in 2019 (12 %) compared with the remaining five sub-basins (3-6%). For estimated total inputs of nitrogen in 2019 the uncertainty was also highest in the Gulf of Finland (9%), the uncertainty on inputs in the remaining sub-basin was between 2 and 4% (according to Results table 1a).

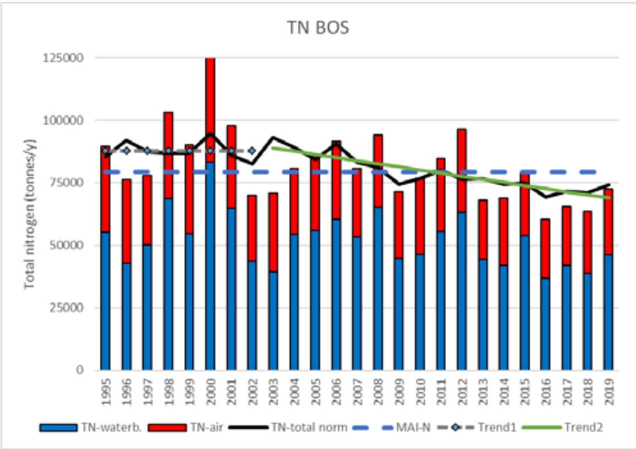
Trend analysis of the normalized timeseries of airborne inputs of nitrogen showed a significant decrease to the Baltic Sea and to the seven sub-basins from 1995 to 2019, between 29% (Gulf of Riga) and 35% (the Kattegat) (Results figure 2b and Results table 3). For the Baltic Sea and four sub-basins (Baltic Proper, Gulf of Riga, Danish Straits and the Kattegat) there is a break point in 2014. Before the break point annual reduction in airborne deposition was 1.3 (Gulf of Riga) and 1.7% (the Kattegat), decreasing after the break point to 0.8 to 1.0% annually. It should be noted that emissions from more small vessels have been included but only in the deposition calculation for 2019.

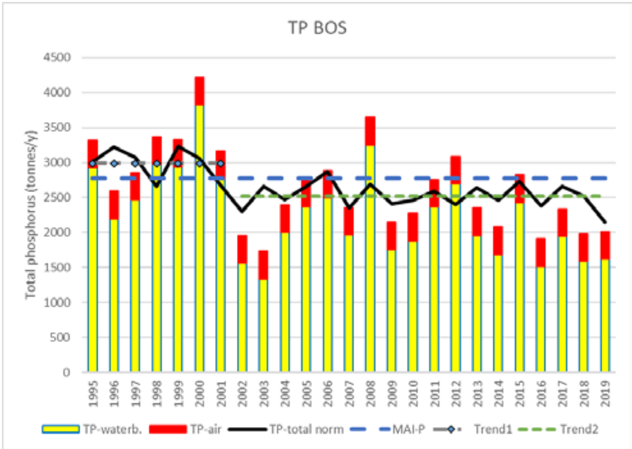
Trend analysis of the normalized waterborne nitrogen inputs showed a significant decrease from 1995 to 2019 for the Baltic Sea and 5 sub-basins (Results figures 2c and see the Results table 3). There was no significant decrease for the Gulf of Riga and the Gulf of Finland in this period. There was one break point for each of the 4 sub-basins and the Baltic Sea, and two break points for Baltic Proper and Danish Straits. No break points and no significant changes have been identified for the waterborne nitrogen inputs to Gulf of Riga. There were significant reductions in waterborne nitrogen inputs from 1995 to before the first break point to the Baltic Sea (18%, 2012), Baltic Proper (19%, 2002), Danish Straits (22%, 2003), the Kattegat (20%, 2011), and a significant increase for Bothnian Bay (14%, 2008) and Gulf of Finland (26%). There were no significant changes in inputs for Baltic Proper and Danish Straits in the section of the time series between the two breakpoints (2002-2009 for Baltic Proper and 2003-2012 for Danish Straits). For the last segment of the timeseries there were significant decreases in nitrogen inputs for three sub-basins: Bothnian Bay (10%, 2008-2019), Bothnian Sea (21%, 2003-2019), Gulf of Finland (25%, 2004-2019), and significant increases for Baltic Proper (19%, 2002-2019) and Baltic Sea (10%, 2012-2019). No trend in waterborne nitrogen inputs was detected for Danish Straits (2012-2019) and for the Kattegat (2011-2019). The significant increase in waterborne nitrogen inputs to the Baltic Proper and the Baltic Sea was not seen in the total (water+airborne) inputs of nitrogen as the airborne deposition of nitrogen was decreasing in the same period.

Testing for trends in flows indicated a tendency of decreasing flow to Baltic Proper (19% 1995 to 2019) and a tendency of increasing in flow to Gulf of Finland (19% 1995-2019). These tendencies are not significant with 95% certainty and seem not to have an impact on the trends detected in the waterborne inputs to the two sub-basins.

Trend analysis of the normalized waterborne phosphorus inputs showed significant decrease from 1995 to 2019 to the Baltic Sea and all the seven sub-basins (Results figures 2c and see the Results table 3). A breakpoint in the timeseries was identified for 3 sub-basins: Bothnian Sea (2001), Danish Straits (2000) and Gulf of Finland (2012). Only Danish Straits a had significant reduction of 35% before the breakpoint (1995-2000) and 12% after the breakpoint (2001-2019). For Bothnian Sea and Gulf of Finland there is a rather abrupt break point, resulting in markedly lower waterborne inputs after the breakpoint (51% for Gulf of Finland and 19% for Bothnian Bay). These abrupt jumps are often related to markedly improved wastewater treatment as occurred to Gulf of Finland around 2012, which is seen in Result Figure 3c), as a marked reduction in direct point source inputs. From 1995 to 2019 the highest reduction in waterborne input was to Gulf of Finland (51%) and Danish Straits (43%), and the lowest reduction was found to Bothnian Sea (20%) and Bothnian Bay (19%) (Results table 3).




TN BOS
Total nitrogen (tonnes/y)
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2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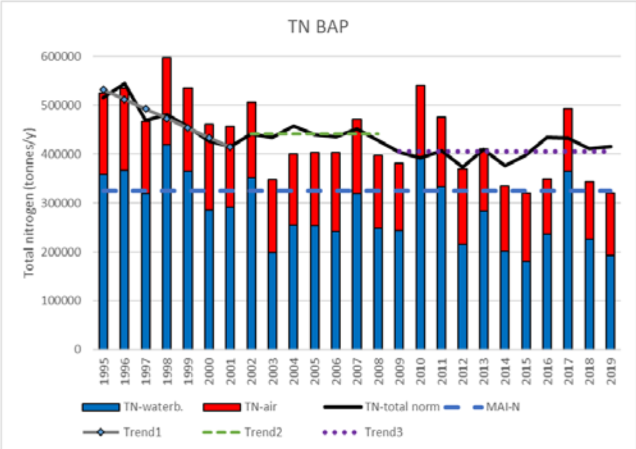
Total phosphorus (tonnes/y)
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend1
Trend2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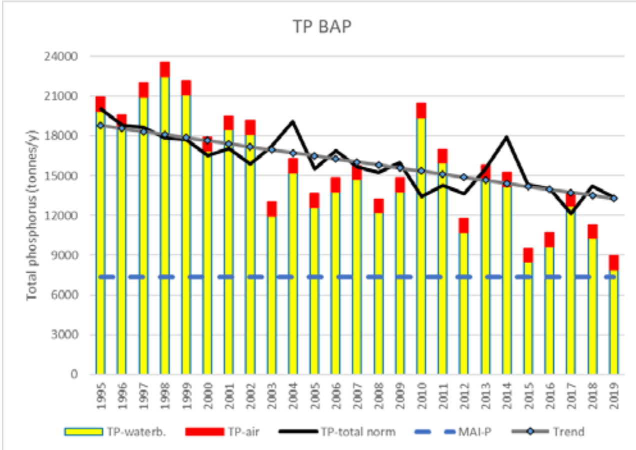
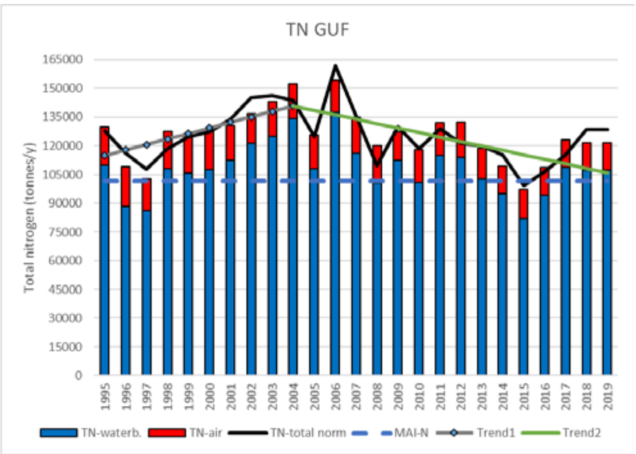
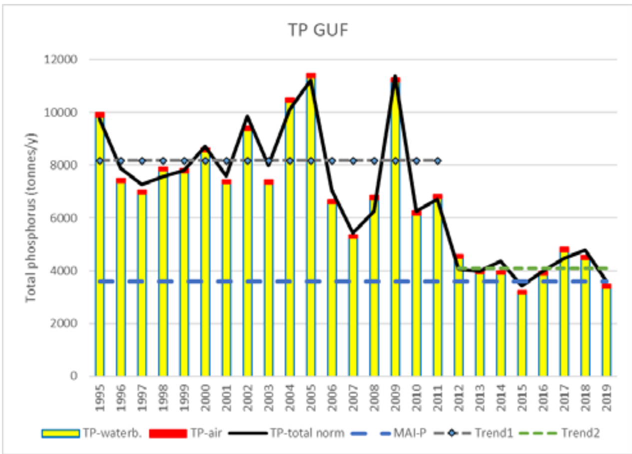
Total nitrogen (tonnes/y)
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2
Trend3


TP BAP
Total phosphorus (tonnes/y)
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend


TN GUF
Total nitrogen (tonnes/y)
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2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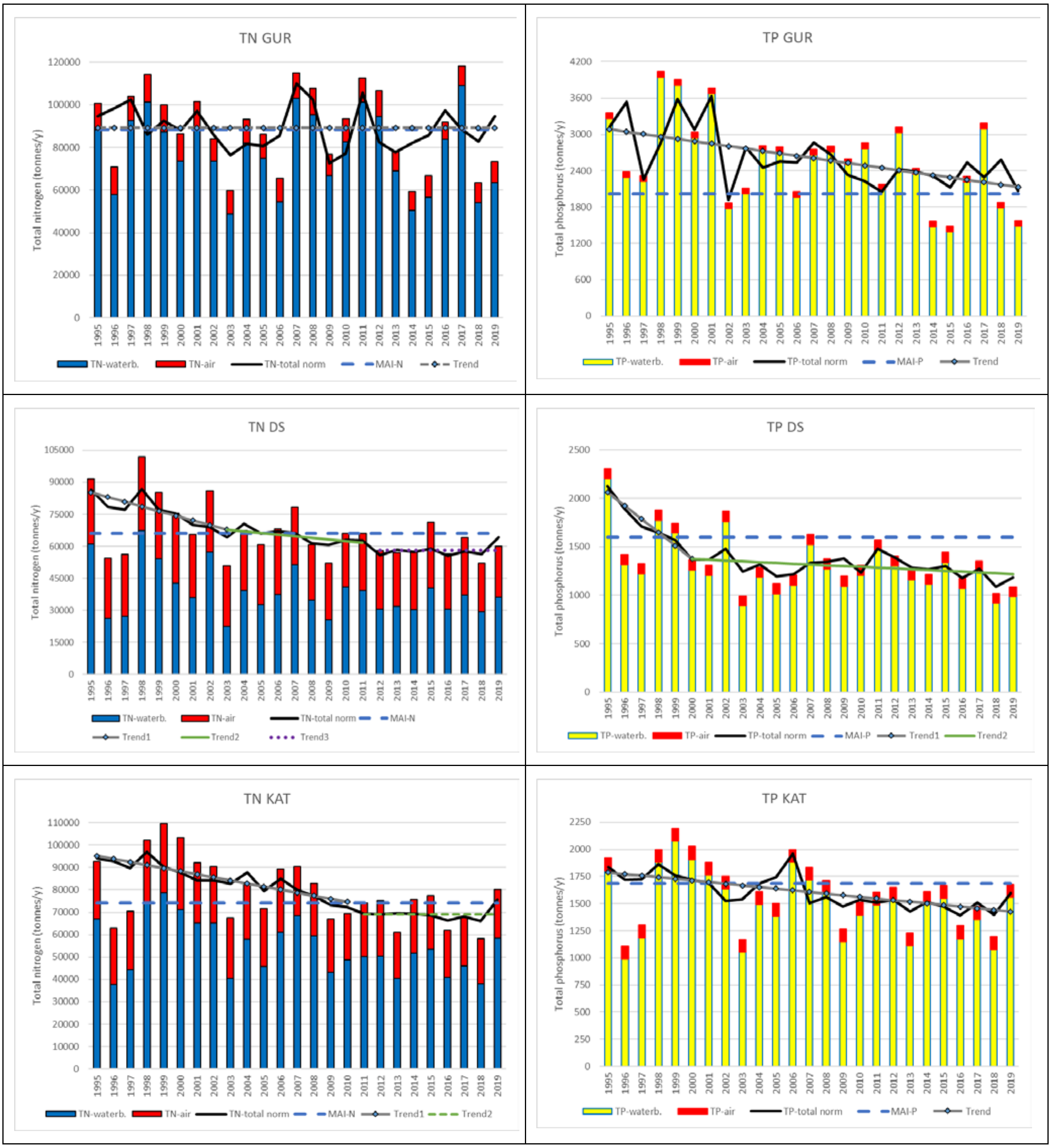
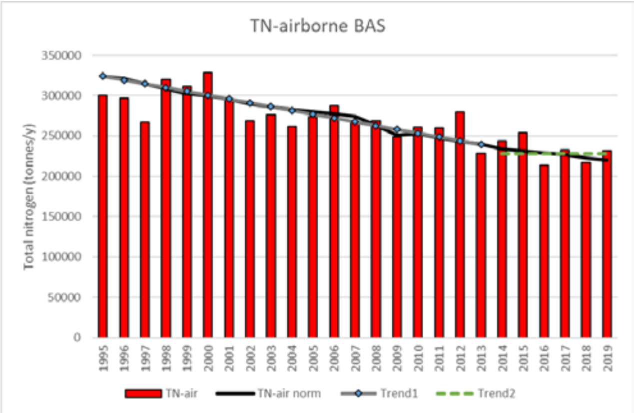
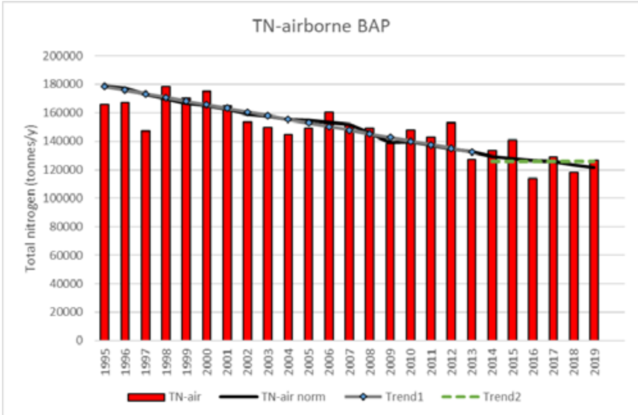
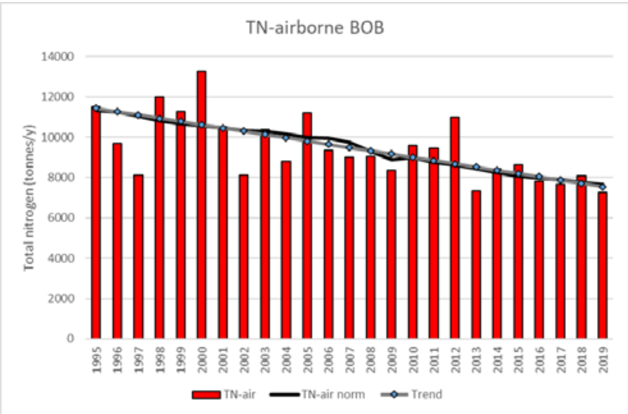
Total phosphorus (tonnes/y)
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend1
Trend2

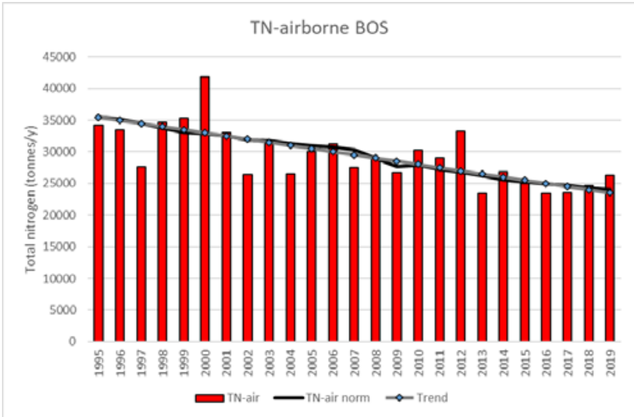


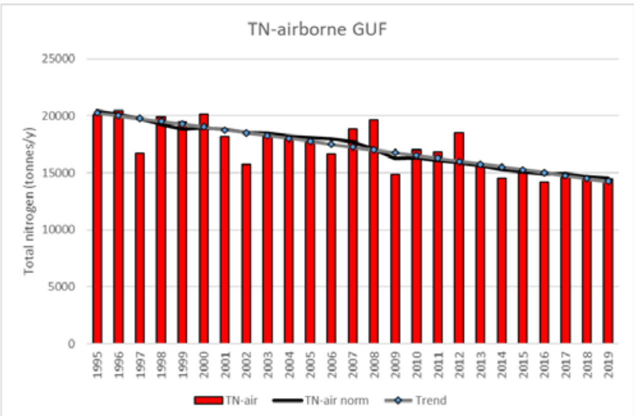
Results figure 2a. Actual total air- and waterborne annual input of nitrogen (TN) and phosphorus (TP) to the Baltic Sea and sub-basins from 1995 to 2019 (tonnes/y). The normalized total annual inputs of nitrogen and phosphorus are given as a black line. The trend line for normalized total nitrogen and phosphorus input is given as a grey line with markers. In cases when a break point divides the trend into two parts, the second part (called trend 2) is shown by a green line without marker. In cases with two breaks points the third part (called trend 3) is indicated as a purple bold line without marker. (Solid trend line shows statistically significant trend and dotted line anot statistically significant trend). The MAI as adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a) is shown as the bold dotted blue line.


TN-airborne BAS
Total nitrogen (tonnes/y)
TN-air
TN-air norm
Trend1
Trend2


TN-airborne BAP
Total nitrogen (tonnes/y)
TN-air
TN-air norm
Trend1
Trend2


TN-airborne BOB
Total nitrogen (tonnes/y)
TN-air
TN-air norm
Trend


TN-airborne BOS
Total nitrogen (tonnes/y)
TN-air
TN-air norm
Trend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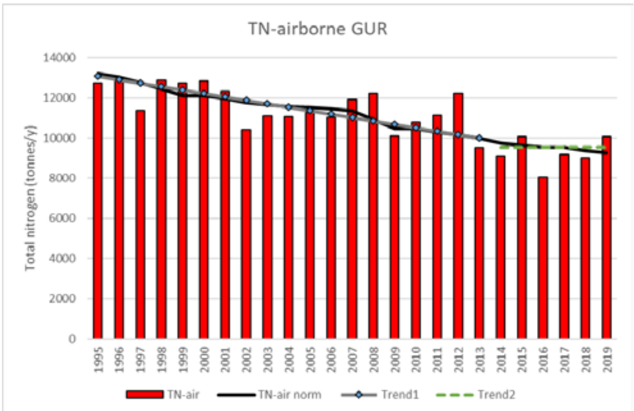
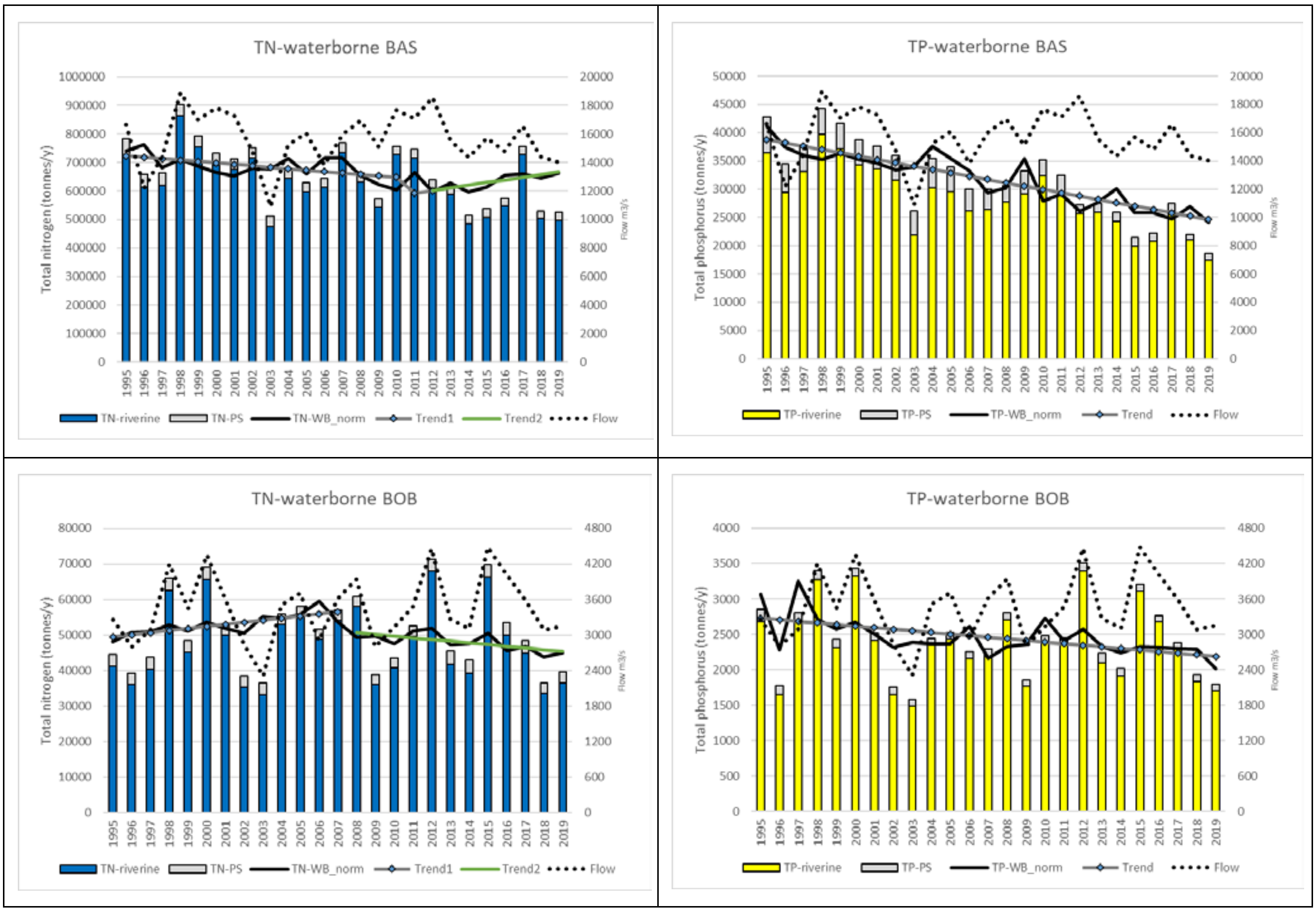
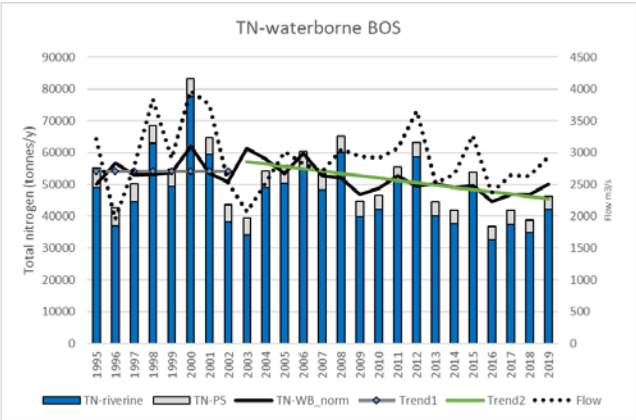
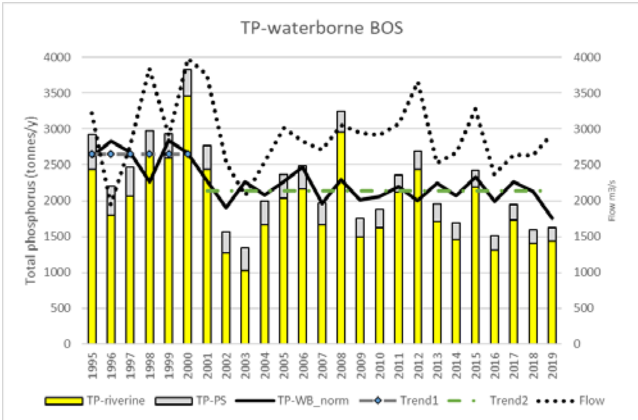
TN-air
TN-air norm
Trend

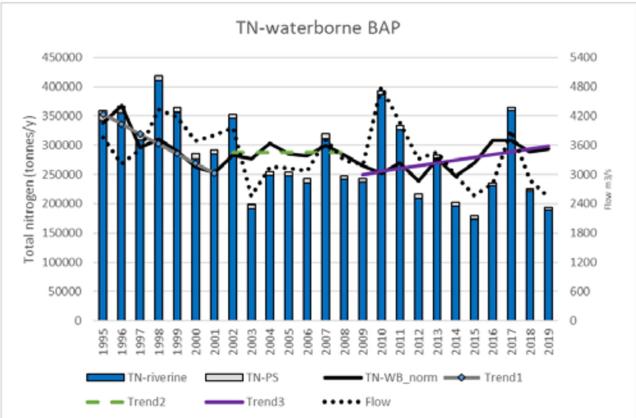

TN-airborne GUR
Total nitrogen (tonnes/y)
TN-air
TN-air norm
Trend1
Trend2

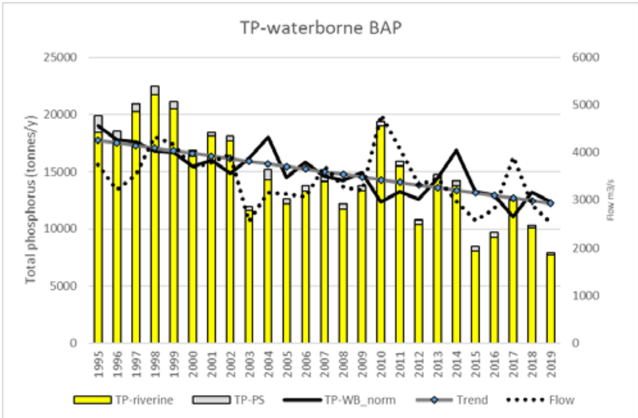
Results figure 2b. Actual annual airborne deposition of nitrogen (TN) to the Baltic Sea and sub-basins from 1995 to 2019 (tonnes/y). The normalized annual airborne deposition inputs of nitrogen are given as a black line. The trend line for normalized total nitrogen deposition is given as a grey line with markers. In cases when a break point divides the trend into two parts, the second part (called trend 2) is shown by a green line without marker. Solid trend line shows statistically significant trend and dotted line a not statistically significant trend.

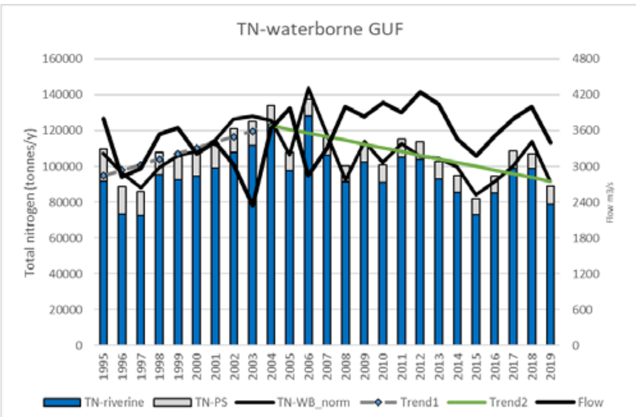


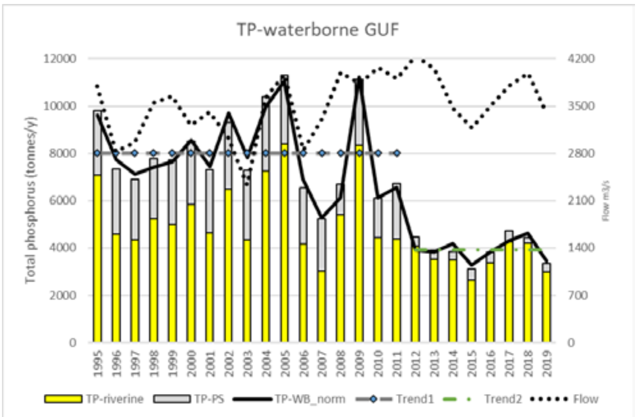

TN-waterborne BOS
Total nitrogen (tonnes/y)
Flow m3/s
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Flow

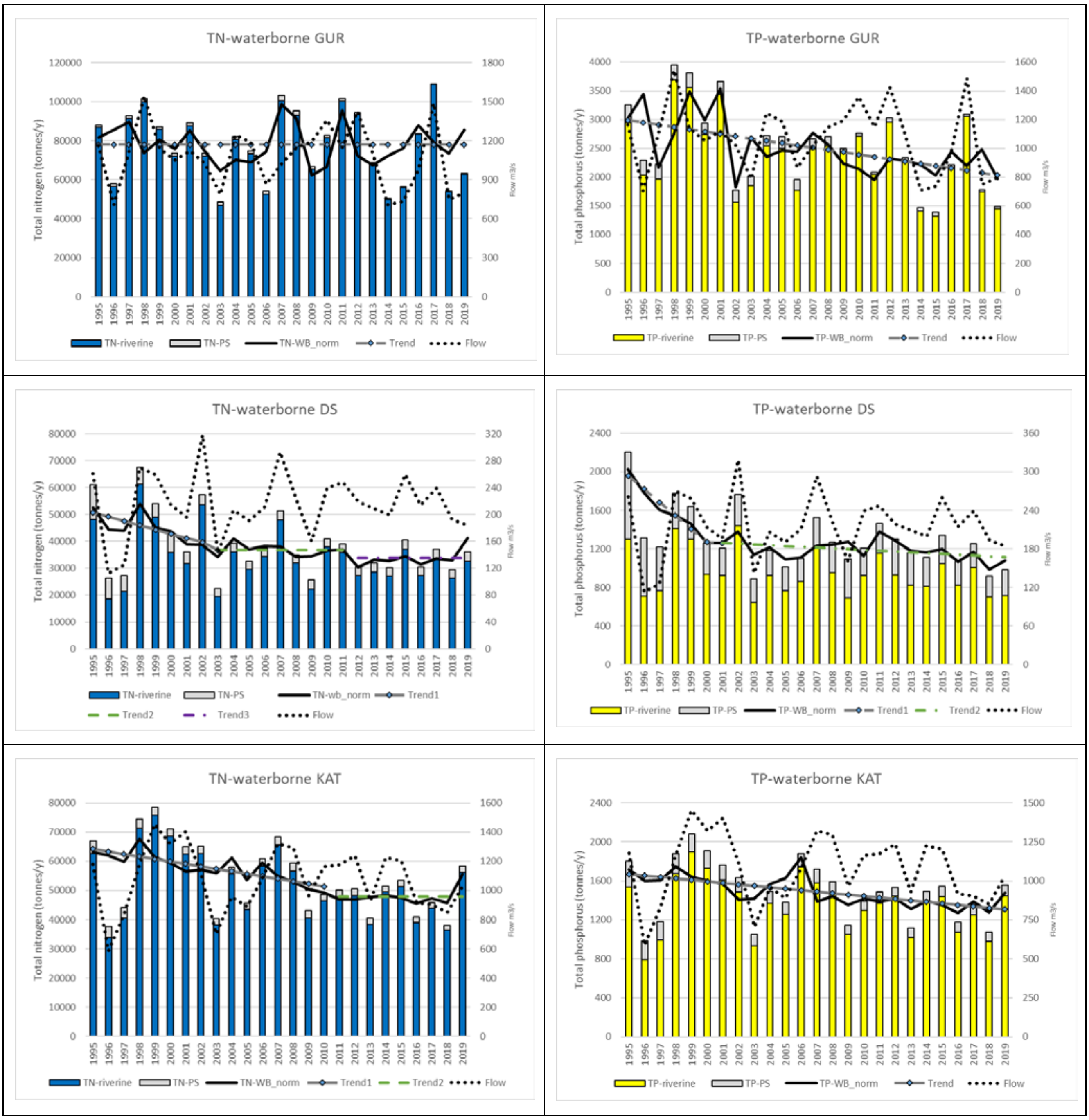

TP-waterborne BOS
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend1
Trend2
Flow


TN-waterborne BAP
Total nitrogen (tonnes/y)
Flow m3/s
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Trend3
Flow


TP-waterborne BAP
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend
Flow


TN-waterborne GUF
Total nitrogen (tonnes/y)
Flow m3/s
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Flow


TP-waterborne GUF
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend1
Trend2
Flow



Results figure 2c. Actual annual riverine and direct point source inputs (the sum is the waterborne inputs) of nitrogen (TN) and phosphorus (TP) (tonnes/y) and total waterborne flow (m^2/s^{-1}) to the Baltic Sea and sub-basins from 1995 to 2019 (tonnes). The normalized annual waterborne inputs of nitrogen and phosphorus are given as a black line. The trend line for normalized total nitrogen and phosphorus waterborne input is given as a grey line with markers. In cases when a break point divides the trend into two parts, the second part (called trend 2) is shown by a green line without marker. In cases with two breaks points the third part (called trend 3) is indicated as a purple bold line without marker. (Solid trend line shows statistically significant trend and dotted line a not statistically significant trend).

Total nutrient input to the Baltic Sea varies significantly depending on wet or dry weather conditions. For example, 2010 was a very wet year in the southern part of the Baltic Sea catchment area, hence the actual (non-normalized) nutrient inputs were very high to e.g., Baltic Proper (Results figure 2) and relatively high to the whole Baltic Sea. Additionally, atmospheric deposition was also rather high in 2010.

Results table 3 summarizes the significant trends in airborne nitrogen inputs, and in waterborne nitrogen and phosphorus inputs as indicated in the evaluation of Results figure 2a, b and c. As atmospheric deposition of phosphorus was set as an annual fixed rate of 5 kg per km^{-2} the waterborne inputs determine changes in total phosphorus inputs to the Baltic Sea.

Results table 3. Changes in annual average normalized air- and waterborne inputs of nitrogen in 1995 and 2019 in percent. Bold indicates statistically significant changes.

Sub-basin	Change in airborne N inputs since 1995 (%)	Change in waterborne N inputs since 1995 (%)	Change in waterborne P inputs since 1995 (%)
Bothnian Bay	**-34**	**-8.2**	**-20**
Bothnian Sea	**-34**	**-16**	**-19**
Baltic Proper	**-32**	-15	**-31**
Gulf of Finland	**-30**	-3.2	**-51**
Gulf of Riga	**-29**	0	**-32**
Danish Straits	**-32**	**-33**	**-43**
Kattegat	**-35**	**-25**	**-22**
Total Baltic Sea	**-32**	**-7.7**	**-36**

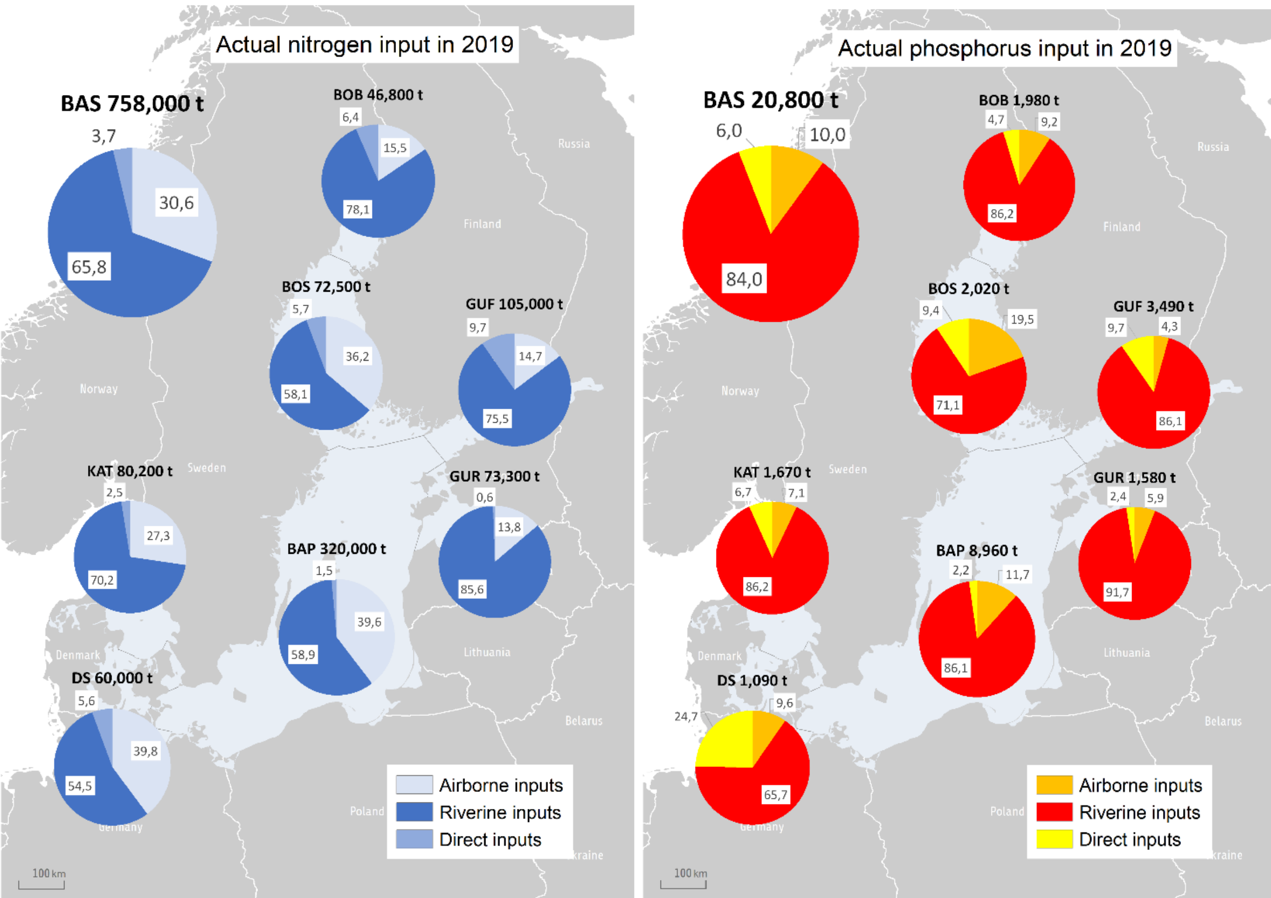
Actual airborne and waterborne inputs in 2019

In 2019 flow was overall low to the Baltic Sea (11% under average 1995-2019) and particularly low to Baltic Proper (27% under average) and the Gulf of Riga (26%) (Results table 4). To the remaining four basins the annual flow was close to average (from -3% to +4%). Actual nutrient inputs were overall low to all sub-basins in 2019 except for the Kattegat.

Total input of nitrogen was about 758 000 tonnes, which is one of the lowest yearly inputs during 1995-2019. 2018 and 2019 were the first two years in a row of very dry years in parts of the Baltic Sea catchment and the nutrient input data clearly reflect this. But in the catchment to part of Danish Straits and the Kattegat dry weather condition in 2018 with a bad harvest, resulted in an accumulation of a lot of nitrogen in the soils, that was flushed out particularly to the Kattegat due to a very wet second half of 2019 with high flows (see Results figure 3c) even though the flow during 2019 was lower (4 %) than average of 1995-2019. The share of atmospheric deposition was about 31%, and the main pathway for nitrogen inputs to the Baltic Sea was via rivers (66%). The share of direct inputs (point sources discharging directly into the sea) of nitrogen was low and on average less than 4%. The total phosphorus input to the Baltic Sea in 2019 was about 21 800 tonnes, with a contribution of atmospheric deposition by about 10% (Results table 4 and Results figure 3). The main pathway for phosphorus was also via rivers (84%). Direct inputs of phosphorus constituted on average 6% but had a significantly higher share to some basins, for example to Danish Straits (25%).

Results table 4. Annual average water flow as well as actual annual waterborne and airborne inputs of phosphorus and nitrogen to the Baltic Sea sub-basins in 2019. Average flow 1995-2019 is shown for comparison.

Sub-basin	Average flow 1995-2019 (m³/s)	Flow 2019 (m³/s)	Nitrogen 2019 (tonnes)			Phosphorus 2019 (tonnes)		
			Waterborne	Airborne	Total	Waterborne	Airborne	Total
Bothnian Bay	3 444	3 158	39 588	7 261	46 849	1 796	181	1 977
Bothnian Sea	2 913	2 928	46 219	26 246	72 465	1 624	394	2 018
Baltic Proper	3 436	2 522	193 340	126 741	320 081	7 913	1 046	8 959
Gulf of Finland	3 519	3 403	89 179	15 429	104 609	3 341	150	3 491
Gulf of Riga	1 071	799	63 205	10 090	73 294	1 486	93	1 579
Danish Straits	215	184	36 108	23 881	59 989	984	105	1 089
Kattegat	1 077	1 029	58 324	21 902	80 225	1 555	118	1 674
Total	**15 675**	**14 023**	**525 964**	**231 549**	**757 513**	**18 699**	**2 088**	**20 787**



Results figure 3. The actual inputs of riverine, direct (point sources discharging directly into the sea) and airborne nitrogen (left) and phosphorus (right) to the Baltic Sea in 2019.

Comparing MAI assessments 2015-2019

The classification of achieved reductions in the MAI assessment 2015-2019 are very consistent for both nitrogen and phosphorus (Results table 5a and 5b).

Maximum allowable nitrogen inputs were fulfilled in three basins (Bothnian Sea, Danish Straits and Kattegat) in the five annual assessments (2015-2019). MAI was not fulfilled for Baltic Proper, Gulf of Finland and for the Baltic Sea in any assessment. MAI was not fulfilled in the Gulf of Riga in 2016-2019. For Bothnian Bay (2015-2017) and Gulf of Riga (2015), due to statistical uncertainty of inputs, MAI fulfilment could not be judged, but in 2018 and 2019 MAI was fulfilled for Bothnian Bay. Bothnian Bay and Gulf Riga have improved their classification since 2015.

Maximum allowable phosphorus inputs were only fulfilled in Kattegat for the five assessments (2015-2019). For Bothnian Sea and Danish Straits MAI has been fulfilled since 2016, but in 2015 fulfilment could not be judged due to statistical uncertainty of inputs. MAI was not fulfilled in Baltic Proper, Gulf of Riga and for the Baltic Sea in any assessment. MAI was not fulfilled in Gulf of Finland in 2015, 2017 and 2019. For Bothnian Bay (2015-2017) and Gulf of Finland (2016 and 2018) MAI fulfilment could not be judged due to statistical uncertainty. High uncertainty on the inputs to Gulf of Finland is one reason for the changing status of fulfilment of MAI. In 2018 and 2019 MAI was fulfilled for Bothnian Bay. Bothnian Bay, Bothnian Sea and Danish Straits have improved their classification since 2015.

Result table 5a. Classification of achieving MAI in 2015 (1995-2015 data), 2016 (1995-2016 data), 2017 (1995-2017 data), 2018 (1995-2018 data) and 2019 (1995-2019) for nitrogen: green=MAI fulfilled, yellow= fulfilment is not determined due to statistical uncertainty, and red=MAI not fulfilled

Baltic Sea Sub-basin	Classification of achieved reduction TN2015	Classification of achieved reduction TN2016	Classification of achieved reduction TN2017	Classification of achieved reduction TN2018	Classification of achieved reduction TN2019
Bothnian Bay					
Bothnian Sea					
Baltic Proper					
Gulf of Finland					
Gulf of Riga					
Danish Straits					
Kattegat					
Baltic Sea					

Result table 5b. Classification of achieving MAI in 2015 (1995-2015 data), 2016 (1995-2016 data), 2017 (1995-2017 data), 2018 (1995-2018 data) and 2019 (1995-2019) for phosphorus: green=MAI fulfilled, yellow= fulfilment is not determined due to statistical uncertainty, and red=MAI not fulfilled

Baltic Sea Sub-basin	Classification of achieved reduction TP2015	Classification of achieved reduction TP2016	Classification of achieved reduction TP2017	Classification of achieved reduction TP2018	Classification of achieved reduction TP2019
Bothnian Bay					
Bothnian Sea					
Baltic Proper					
Gulf of Finland					
Gulf of Riga					
Danish Straits					
Kattegat					
Baltic Sea					

Confidence of the indicator status evaluation

The confidence is affected by the certainty of the quality of the nutrient input data, the trend in the inputs and the uncertainty of MAI, in relation to how far the nutrient inputs are from MAI:

The confidence of the assessment is overall high, but can be further detailed as:

- High for basins with nutrient reduction requirements: nitrogen to Kattegat, Gulf of Finland and Baltic Proper and phosphorus to the Baltic Proper, Gulf of Finland and Gulf of Riga.
- Moderate for phosphorus to Bothnian Sea and nitrogen to Danish Straits due to limitations in the MAI calculation.

Thresholds and Status evaluation

Environmental Target and progress towards good status

The environmental targets for nutrient inputs are the maximum allowable inputs (MAI) of the HELCOM nutrient reduction scheme (Thresholds table 1). The MAI indicate the maximal level of annual inputs of water- and airborne nitrogen and phosphorus to Baltic Sea sub-basins that can be allowed while still achieving good status in terms of eutrophication.

A provisional nutrient reduction scheme was adopted in the HELCOM Baltic Sea Action Plan (HELCOM 2007). The presented MAI were revised based on an improved scientific basis and models and were adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a). The MAI of 2013 have been incorporated in the updated BSAP that was adopted in 2021 (HELCOM, 2021).

Thresholds table 1. Maximum allowable annual inputs (MAI) of nitrogen and phosphorus to the Baltic Sea sub-basins.

Baltic Sea Sub-basin	Maximum allowable annual nitrogen inputs (tonnes)	Maximum allowable annual phosphorus inputs (tonnes)
Bothnian Bay	57,622	2,675
Bothnian Sea	79,372	2,773
Baltic Proper	325,000	7,360
Gulf of Finland	101,800	3,600
Gulf of Riga	88,417	2,020
Danish Straits	65,998	1,601
Kattegat	74,000	1,687
Baltic Sea	**792,209**	**21,716**

MAI was calculated by the Baltic Nest institute (BNI) - Sweden using the coupled physical-biogeochemical model BALTSEM. Obtaining MAI is formally an optimization problem: finding the highest possible inputs that will still satisfy given eutrophication targets (e.g. threshold values for eutrophication indicators).

The basin-wise MAI were obtained by satisfying all eutrophication targets in all basins, taking into account ecological relevance and model accuracy. More details are provided in Gustafsson, B.G & Mörth, C.M, (document 2-43 HOD 41-2013).

For basins without additional reduction requirements, the 1997-2003 averaged normalized inputs obtained within the PLC 5.5 project are used as MAI. For more information, see HELCOM 2013b.

The uncertainty in the determination of MAI can be divided into three sources: uncertainty in the eutrophication targets, uncertainties associated with model short-comings and uncertainties in the input data to the calculation. The confidence in the eutrophication targets has been classified as moderate or high, depending on the parameter (HELCOM 2013c). It is straightforward but laborious to explore how MAI varies with changes in target values from the pressure-response relationships (i.e., the model derived change in target values for a given change in nutrient inputs). The laborious aspect arises from the numerous combinations of uncertainty that can arise if many indicator values and basins are simultaneously considered. However, the impression is that the nitrogen target causes the largest uncertainty in determination of MAI for most basins. Reasons are that in most cases there are no, or only few, trustworthy measurements to indicate the pre-eutrophied situation and also because the relationship between nitrogen input and concentrations in sea waters is rather weak in basins featuring hypoxia and strong nitrogen limitations (i.e. the Baltic Proper and the Gulf of Finland) because of large internal feedback from nitrogen fixation and denitrification.

When calculating MAI, attempts have been made to take into account biases in BALTSEM by discarding indicators in basins where they are not adequately modelled, and by raising a concern of whether MAI is really trustworthy because of model deficiency/bias.

Note: both MAI and CART calculations are affected by the input data to the model. If input data are inconsistent, it may cause over- or underestimation of MAI and CART, and thus an unfair distribution of reduction requirement between countries.

Assessment protocol

Data sources

The HELCOM Contracting Parties annually report waterborne inputs of nitrogen and phosphorus from rivers and direct point sources to Baltic Sea sub-basins. 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), which subsequently compiles and reports this information to HELCOM. In accordance with Recommendation 37-38-1 "Waterborne pollution input assessment (PLC-Water)", sources of nutrients input are assessed every six years.

Nutrient input data can be viewed in HELCOM PLC reports (e.g. HELCOM 2012, HELCOM 2013d and HELCOM 2015) and in the annual Baltic Sea Environmental Facts sheet (e.g. Svendsen & Gustafsson, 2021) and from the HELCOM PLUS database.

Trend analysis and statistical processing

Annually reported data on riverine and directs inputs are quality assured and approved by national data reporters and data assurers. Assessment dataset for 1995-2019 based on the reported data was established after expert reviewing and filling data gaps in. Riverine data are flow normalized for individual rivers. Input from unmonitored areas are aggregated and normalized for sub-basin. EMEP delivered actual and weather-normalized annual nitrogen deposition data. For information about normalization of airborne and flow normalization of waterborne input data, see chapter 10 and annex 6 of PLC guidelines (HELCOM in press) and Larsen and Svendsen (2021, in press).

As part of the HELCOM PLC-6, PLC-7 and MAI CART OPER projects the trend analysis was carried out by DCE, Aarhus University (Denmark), with linear regression Mann-Kendall methodology (Hirsch et al. 1982) on:

- flow normalized waterborne inputs (sum of flow normalized riverine data and direct point sources)
- normalized airborne inputs
- total normalized inputs of nitrogen and phosphorus

for all relevant combinations of Contracting Parties and sub-basins of the Baltic Sea. Where there is a significant trend, the annual changes were determined with a Theil-Sen slope estimator (Hirsch et al., 1982). The change since 1995 and the reference period (average of 1997-2003) was calculated based on the normalized inputs. The methodology has been agreed on by HELCOM LOAD and HELCOM PRESSURE (more information on trend analysis and determining the changes in input can be found in Larsen & Svendsen 2019, and in document "Comparison of methods applied to evaluate progress towards CARTS and fulfilment of national inputs ceilings" for CART WS 1-2017). In the indicator on inputs of nutrients (nitrogen and phosphorus) to the sub-basins 2018 (HELCOM, 2020) and in the present indicator trend analyses after screening for trend with Mann-Kendall methodology are done with linear regression, and with significant trend slope are estimated from the linear regression. Compared to the first evaluation of MAI fulfilment also a test for break points has been performed for all sub-basins of the Baltic Sea. The breakpoints were identified using an iterative statistical process as shown in Assessment Protocol table 1. which determines the most significant break point (see Larsen & Svendsen 2021). If a break point is identified, the time series is divided in two (one break point) or three segments (2 break points), and trends are tested for each segment of the series. It is tested if the trend in the segment is significant. If it is significant a slope and start value are estimated for the segment. In case of no significant trend a constant (average of the values in the segment) is used as the estimated value for the segment of the time series.

Assessment Protocol Table 1. The process for identifying breakpoints, testing for significant slopes and fitting constants (no significant slopes) and regression parameters (significant slopes) in a time series. From Larsen & Svendsen (2021).

1. step	2. step	3. step	4. step
A significant breakpoint	Test for additional breakpoints in each segment	Test for significant slopes in the segments	Fit a constant in segments with a non-significant slope. Fit regression parameters in the rest of the segments.
No breakpoint	Fit a constant for the whole time series		

The evaluation of MAI fulfilment is based on comparing MAI for each basin of the Baltic Sea with the trend estimated normalized annual total nitrogen and phosphorus inputs in 2019 including and estimated uncertainty on these inputs (Table 2) based on the most recent segment of the time series, the estimated value of the most recent year (Larsen & Svendsen 2021). In the first and second evaluation of MAI fulfilment uncertainty of average of respectively 2010-2012 and 2012-2014 normalized inputs was estimated from the variation of the three-year inputs around the average.

The testing for significant difference in the trend estimated input and inputs in the reference period (average of normalized annual inputs 1997-2003) is done by calculating 95 % confidence interval on the average normalized inputs in the reference period and the corresponding interval around the estimated inputs for the latest year (2019) inputs and testing if the two confidence intervals are statistically different (Larsen & Svendsen, 2021).

Assessment units

Nutrient input data have been compiled in accordance with PLC guidelines for the following nine sub-basins: Bothnian Bay, Bothnian Sea, Archipelago Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, Western Baltic, The Sound and Kattegat. The boundaries of the sub-basins coincide with the main terrestrial river basin catchments.

The BALTSEM model has divided the Baltic Sea into seven sub-basins in accordance with natural marine boundaries and hence the MAIs have been calculated for the following seven sub-basins: Kattegat, Danish Straits, Baltic Proper, Bothnian Sea, Bothnian Bay, Gulf of Riga and Gulf of Finland. In the BALTSEM sub-division, the Bothnian Sea includes the Archipelago Sea and the Danish Straits combine Western Baltic and The Sound.

The entire Baltic Sea is covered by the assessment.

Relevance of the indicator

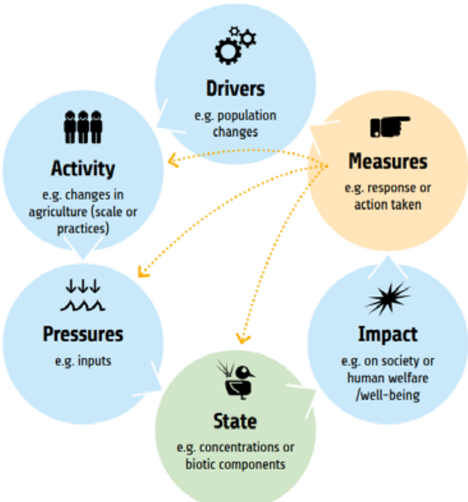
Holistic assessment

Human activities affecting the status of the marine environment is assessed using several indicators and spatial data on pressures. Each indicator focuses on one important aspect of the complex issue. In addition to providing an indicator-based evaluation of the nutrient inputs to the marine environment, this indicator also contributes to the holistic assessment of the Baltic Sea.

Policy relevance

As a follow-up to the Baltic Sea Action Plan (2007), a revised HELCOM nutrient reduction scheme was adopted in the 2013 HELCOM Ministerial Declaration (HELCOM 2013a) in which reduction requirements for nitrogen inputs to the Baltic Proper, Gulf of Finland and Kattegat and for phosphorus inputs to the Baltic Proper, Gulf of Finland and Gulf of Riga were set. The HELCOM nutrient reduction scheme defines maximum allowable inputs (MAI) of nutrients, which indicate the maximum level of inputs of water- and airborne nitrogen and phosphorus to Baltic Sea sub-basins that can be allowed in order to obtain good status in terms of eutrophication. This core indicator presents progress in the different Baltic Sea sub-basins towards reaching these maximum annual nutrient inputs levels. The updated Baltic Sea Action Plan 2021 reconfirmed the MAIs and their achievement for all sub-basins as the key prerequisite for achieving the ecological objective of a Baltic Sea unaffected by eutrophication and contains measures to follow up and assess the progress towards maximum allowable inputs (HELCOM 2021).

The progress of countries in reaching their share of the country-wise allocation of nutrient reduction targets is assessed separately in a follow-up system based on nutrient input ceilings (NIC) country per Baltic Sea sub basins, as included in the updated BSAP 2021 (HELCOM, 2021). Relevance figure 1 illustrates how the nutrient reduction scheme fits into the HELCOM causal framework DAPSIM. Setting individual indicators (or components of indicators) within a causal framework support the BSAP by providing additional information that can facilitate the follow up on how actions and measures impact on other socioeconomic and state variables (HELCOM 2020).



Relevance figure 1. The conceptual approach for a HELCOM causal framework – DAPSIM with drivers, activities, pressures, state, impact and measures. Here the quantitative targets of MAI and Nutrient Input Ceilings country by sub-basin are within the Pressures.

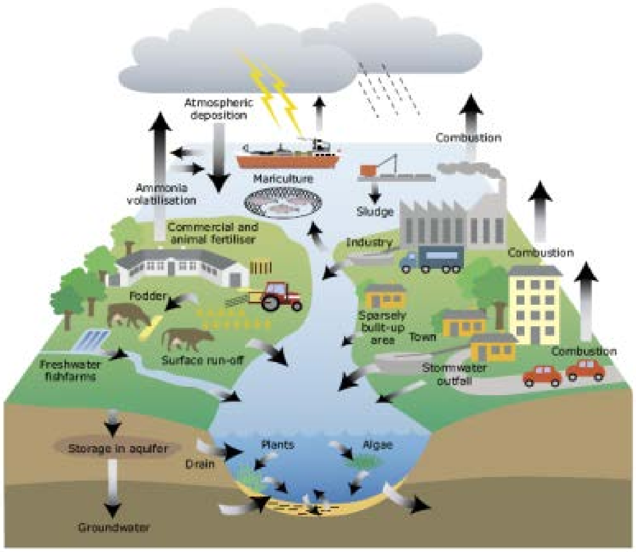
Reducing the effects of human-induced eutrophication is the stated goal of Descriptor 5 in the EU Marine Strategy Framework Directive (MSFD). The indicator is an important part in following up the effectiveness of the measures taken to achieve GES under this Descriptor. Inputs of nutrients to the Baltic Sea marine environment have an effect on the nutrient levels under criterion 5.1. It is important to note that this pressure indicator on inputs of nutrients relates to HELCOM eutrophication state core indicators. More information on this is provided in the section below on Environmental Target and progress towards GES.

The information provided in this pressure indicator also supports follow-up of the effectiveness of measures implemented under the following agreements, as each of them addresses reduction in nutrient inputs in some way or other: EU Nitrates Directive; EU Urban Waste-Water Treatment Directive; EU Industrial Emissions Directive, IED; EU Water Framework Directive, WFD; 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).

Role of nutrient inputs to the ecosystem

Eutrophication in the Baltic Sea is to a large extent driven by excessive inputs of the nutrients nitrogen and phosphorus due to accelerating anthropogenic activities during the 20^{th} century. Nutrient over-enrichment (or eutrophication) and/or changes in nutrient ratios in the aquatic environment cause elevated levels of algal and plant biomass, increased turbidity, oxygen depletion in bottom waters, changes in species composition and nuisance blooms of algae.

The majority of nutrient inputs originate from anthropogenic activities on land and at sea. Waterborne inputs enter the sea via riverine inputs and direct discharges from coastal areas. The main sources of waterborne inputs are point sources (e.g. waste water treatment plants, industries and aquaculture), diffuse sources (agriculture, managed forestry, scattered dwellings, storm overflows etc.) and natural background sources. The main sectors contributing to atmospheric inputs are combustion in energy production and industry as well as transportation for oxidized nitrogen and agriculture for reduced nitrogen. A large proportion of atmospheric inputs originate from distant sources outside the Baltic Sea region. Emissions from shipping in the Baltic and North seas also contribute significantly to atmospheric inputs of nitrogen. In addition, excess nutrients stored in bottom sediments can enter the water column and enhance primary production of plants (Relevance figure 2). For more information see HELCOM 2012 and HELCOM 2015.



Relevance figure 2. Different sources of nutrients to the sea and examples of nitrogen and phosphorus cycles. The flow related to ammonia volatilization shown in the figure applies only to nitrogen. In this report, also combustion and atmospheric deposition deal only with nitrogen. Emissions of phosphorus to the atmosphere by dust from soils are not shown in the figure. (Source: Ærtebjerg et al. 2003)

Information on the quantity of nutrient inputs is of key importance in order to follow up the long-term changes in the nutrient inputs to the Baltic Sea. This information, together with information from land-based sources and retention within the catchment, is also 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. 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.

State indicators linked to the pressure of nutrient inputs

Response in the eutrophication status from changes in nutrient inputs may be considerably slow. Model simulations indicate that it would take perhaps half a century or even more after nutrient inputs reach MAI to reach the environmental targets (Gustafsson, B.G & Mörth, C.M, document 2-43 HOD 41-2013). However, the simulations indicate that significant improvements could be expected after 1-2 decades. It should be noted that determination of these timescales are regarded as more uncertain than the ultimate long-term state because of unexpected non-linear responses of, e.g., phosphorus to improved oxygen concentrations. In coastal areas one can expect faster responses, especially when significant direct point sources are removed. This is probably also the case for the eastern part of the Gulf of Finland.

The effect of changes in nutrient inputs on the core HELCOM eutrophication status indicators DIN, DIP, chlorophyll-*a*, Secchi depth and oxygen debt are thoroughly evaluated in Gustafsson, B.G & Mörth, C.M, document 2-43 HOD 41-2013.

Relevant core indicators on eutrophication status:

Total nitrogen

Total phosphorus

Water clarity

Chlorophyll-a concentrations

Oxygen debt

Information on other relevant supporting parameters:

Concentrations, temporal variations and regional differences from satellite remote sensing

Cyanobacteria biomass

Cyanobacteria blooms in the Baltic Sea

Cyanobacteria bloom index

Impacts of invasive phytoplankton species on the Baltic Sea ecosystem in 1980-2008

Atmospheric nitrogen deposition to the Baltic Sea

Nitrogen emissions to the air in the Baltic Sea area

Phytoplankton biomass and species succession

Shifts in the Baltic Sea summer phytoplankton communities in 1992-2006

Spatial distribution of winter nutrient pool 2007

An unusual phytoplankton event five years later: the fate of the atypical range expansion of marine species into the south-eastern Baltic

Bacterioplankton growth rate

See also the 'State of the Baltic Sea' report (HELCOM 2018).

Monitoring requirements

Monitoring methodology

Waterborne inputs

Contracting Parties measure water flow and concentrations of selected parameters in riverine water and point source discharges. Estimates of inputs from unmonitored areas are based on modelling including information of point sources discharges (monitored or estimated). These data are used to calculate total annual inputs to the sea. These measurements and estimates are carried out by the Contracting Parties. The methods for monitoring and calculating waterborne pollution inputs are described in the HELCOM Pollution Load Compilation (PLC) guidelines. Updated guidelines were developed by PLC-7 project.

An overview of agreed monitoring of nutrient inputs is also described in the HELCOM PLC guidelines (HELCOM in press) and monitoring data are available from HELCOM PLUS database (HELCOM PLC) at http://nest.su.se/helcom_plc/).

Atmospheric inputs

Atmospheric emissions and measured atmospheric deposition are reported by countries to the Co-operative Programme for Monitoring and Evaluation of the Long-Range Transboundary Air Pollutants in Europe (EMEP), which compiles and reports to HELCOM. EMEP models the deposition of nitrogen input based on emission measurements and estimates and information on meteorological parameters. The results of the EMEP model are routinely compared to available measurements at EMEP and HELCOM stations. The deposition of phosphorus is not modelled but based on measurements from (rather few) monitoring stations, and a fixed deposition rate of 5 kg P per km^2 has been used in the latest PLC assessment (HELCOM 2014b; HELCOM 2015). Details of the monitoring activities and the model are available in the HELCOM Monitoring Manual.

Current monitoring

Waterborne inputs

Inputs from large rivers are monitored and the measurements used for calculating inputs that are reported. Inputs from smaller unmonitored rivers are generally estimated by models. Inputs from point sources (municipal wastewater treatment plants, industry and aquaculture) discharging directly to the Baltic Sea are reported separately.

Monitoring table 1a. Numbers of rivers, monitored area (2019) and percentages of waterborne nitrogen inputs that were monitored, unmonitored, and direct point source discharges of total waterborne nitrogen inputs to the Baltic Sea sub-basins in 2019.

Sub-basin	Number of rivers	Monitored area (km^2)	Monitored area (% of total area)	Total N monitored (%)	Total N unmonitored (%)	Total N direct (%)
Bothnian Bay	21	234 000	88	90	4	6
Bothnian Sea	20	193 000	85	80	14	6
Baltic Proper	46	517 000	90	89	10	1
Gulf of Finland	22	402 000	96	89	1	10
Gulf of Riga	7	121 000	89	85	14	1
Danish Straits	120	14 300	52	40	55	5
Kattegat	96	77 400	88	68	29	3
Baltic Sea	**332**	**1 559 000**	**89**	**87**	**10**	**3**

Monitoring table 1b. Numbers of rivers, monitored area (2019) and percentages of waterborne phosphorus inputs that were monitored, unmonitored, and direct point source discharges of total waterborne phosphorus inputs to the Baltic Sea sub-basins in 2019.

Sub-basin	Number of rivers	Monitored area (km^2)	Monitored area (% of total area)	Total P monitored (%)	Total P unmonitored (%)	Total P direct (%)
Bothnian Bay	21	234 000	88	91	5	4
Bothnian Sea	20	193 000	85	80	11	9
Baltic Proper	46	517 000	90	94	3	2
Gulf of Finland	22	402 000	96	90	1	9
Gulf of Riga	7	121 000	89	87	11	2
Danish Straits	120	14 300	52	29	48	23
Kattegat	96	77 400	88	66	27	7
Baltic Sea	**332**	**1 559 000**	**89**	**88**	**7**	**5**

Monitoring tables 1a and 1b show that about 90% of the total Baltic Sea catchment area is covered by monitoring based on more than 300 monitoring stations. For six of the seven sub-basins between 85% and

96% of the catchment areas are monitored, and these catchments are covered by monitoring in mainly large rivers. For Danish Straits only about 50% of the catchment is monitored even though 120 monitoring stations or more than one third of all river monitoring stations in the Baltic Sea catchment area are situated in the catchment due to many small river catchments.

Monitoring tables 1a and 1b also show that estimated/calculated inputs from unmonitored areas constitute 10% of total nitrogen and 7% of total phosphorus waterborne inputs to the Baltic Sea.

Details of the monitoring activities are available in the **HELCOM Monitoring Manual**.

Atmospheric inputs

Details of the monitoring activities and the model are available in the **HELCOM Monitoring Manual** and Monitoring table 2 gives an overview of the number of nitrogen monitoring stations located at the Baltic Sea used to compare model and monitored nitrogen deposition.

Monitoring table 2. Number of monitoring stations situated close to the Baltic Sea used for measuring wet and dry deposition of nitrogen compounds in 2010.

Sub-basin	Wet deposition of N	Dry deposition of N
Bothnian Bay	2	0
Bothnian Sea	1	3
Baltic Proper	6	6
Gulf of Finland	2	2
Gulf of Riga	0	0
Danish Straits	2	3
Kattegat	2	3
Baltic Sea	**15**	**17**

Description of optimal monitoring

Waterborne inputs

Guidelines for sampling discharges from point sources and inputs via rivers are given in the PLC guidelines. For riverine inputs, as a minimum 12 samples 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 a major annual variation the samples can be more evenly distributed during the year. Overall, for substances transported in connection with suspended solids, lower bias and better precision is obtained with higher sampling frequency.

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. If the discharges are not monitored continuously the measurements must cover low, mean and high river flow rates, i.e. they should as a minimum reflect the main annual river flow pattern. Further details are provided in the PLC-6 guidelines.

Atmospheric inputs

Collection of air emission data and modelling atmospheric deposition are coordinated by EMEP. There are rather few stations located at the coast or on small islands in the Baltic Sea, and not all stations are measuring all components. Further, only some stations have long time series. Not all national monitoring stations are included in the list of "HELCOM stations" but could be used by EMEP. There are also some problems with the representativeness of the stations, i.e. rather many in the south-western part of the Baltic Sea but few in the eastern and northern parts that cause challenges when verifying the EMEP model results. For phosphorus it is especially important to establish a more extensive and representative monitoring station network, as there are no models developed to estimate the atmospheric phosphorus deposition. Thorough analysis of the monitoring data would improve the understanding of the development in the atmospheric deposition and also offer recommendations on how to improve and possibly expand monitoring.

Data and updating

Access and use

The data and resulting data products (tables, figures and maps) available on the indicator web pages can be used freely given that the source is cited. The indicator should be cited as following:

HELCOM (2022) Inputs of nutrients (nitrogen and phosphorus) to the sub-basins (2019). HELCOM core indicator report. Online. [Date Viewed], [Web link].

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Metadata

Data on air- and waterborne nutrient inputs from 1995 to 2019 are used in this indicator. Data reporting has not been perfect and some few gaps exist in the dataset. For waterborne inputs, the PLC-6 project corrected suspicious data and filled in data gaps for 1995-2014 to establish a complete and consistent dataset. 2015-2019 data has been added and assessed by BNI, Stockholm University and DCE, Aarhus University under the PLC-7 and PLC-8 project. Gaps in time series of national air emissions have also been corrected by EMEP experts.

Data on actual (non-normalized) riverine flow as well as atmospheric and waterborne inputs of nitrogen and phosphorus are available at the link below:

Data: Inputs of nutrients to the sub-basins - 2019 indicator version

Waterborne inputs

The dataset behind the present assessment was compiled by the PLC-8 project and updated by DCE, Aarhus University and BNI, Stockholm University in cooperation with Reduction Scheme Core Drafting Group, RedCore DG.

Data on waterborne inputs, water flow and retention are reported by Contracting Parties to the PLC-Water database with reporting WEB application. The data are verified and quality assured using the PLC water database verification tools and national expert quality assurance.

There are gaps in time series of national inputs in the PLC water database. Therefore DCE and BNI amended the dataset filling in missing and correcting suspicious data to establish an assessment dataset which then was checked and approved for use in this indicator by the Contracting Parties. A description of the methods used to fill data gaps in is given in chapter 1.2 in BSEP 141 (HELCOM, 2013d) and documentation prepared by the PLC-5.5 project.

Data on water- and airborne inputs are available from 1995-2019 and cover entire drainage basin of the Baltic Sea.

Inputs are calculated from measurements taken from monitored rivers and point sources as well as calculated estimates or modelled inputs from unmonitored areas. Quality assurance guidelines for sample analysis are described in the PLC guidelines and intercalibration activities are carried out periodically. The most recent intercalibration activity with published results was carried out under the PLC-8 project in Lassen & Larsen (2021).

No official information about the uncertainty of inputs of nutrients or organic matter or flow data have been reported to HELCOM yet, but uncertainty estimates are included as a request to be reported by the Contracting Parties in the PLC guidelines. The uncertainty of annual total waterborne nitrogen and phosphorus inputs are computed for each individual sub-basin based on statistical analysis of input trends for the period 1995-2019, and examples given in Larsen & Svendsen, 2021 (in press).

Airborne inputs

Atmospheric input data for all Baltic Sea sub-basins are available for the period 1995-2019. Atmospheric transport and deposition of nitrogen compounds are used for modelling atmospheric deposition to the Baltic Sea based on official emission data reported by EMEP Contracting Parties and expert estimates. Atmospheric input and source allocation budgets of nitrogen (oxidized, reduced and total) to the Baltic Sea basins and catchments were computed using the latest version of EMEP MSC-W model. The EMEP MSC-W model is a multi-pollutant, three-dimensional Eulerian model. It takes into account processes of emission, advection, turbulent diffusion, chemical transformations, wet and dry depositions, and inflow of pollutants into the model domain. It is driven by meteorological data from the Integrated Forecast System of ECMWF (European Centre for Medium Range Weather Forecasts). A comprehensive description of the model and its applications is available on the EMEP website.

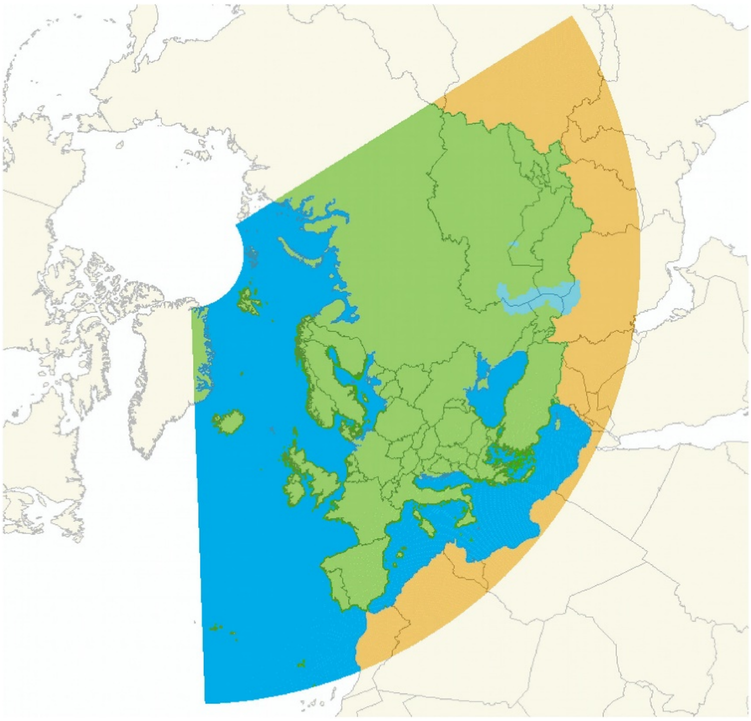
Compared to the first evaluation of MAI fulfilment (Svendsen et al. 2015), in 2016 EMEP revised the modelled nitrogen air deposition to the Baltic Sea for 1995-2012. This resulted in an increase of the annual deposition to the Baltic Sea of 16 to 23%. The increase of annual nitrogen deposition to the individual sub-basins was between 9 and 27 %. In the following, the EMEP deposition model was updated after the second MAI assessment (HELCOM, 2018). The update mainly concerned changing of the deposition grid resolution from 50km*50km to 0.1°*0.1° (approx. 11km*6km grid cells in the Baltic Sea). The higher resolution was applied for computation of the annual nitrogen deposition 2000-2017, and for the present MAI assessment 1995-2019. Also, the whole time series of nitrogen emission data is updated annually, and, for years since 2000 data from FMI on ship emissions have replaced former ships emission data in the deposition calculation. The update of the model, revised reported emission data and use of weather data in the normalization procedure (section “Airborne Inputs” under chapter “Data and updating”) resulted in markedly changed deposition data compared to the previous reporting. Deposition on the Baltic Sea in the reference period (1997-2003) was 299 000 tons nitrogen in the latest EMEP estimate, compared to 227 000 tons nitrogen previously estimated, or 32% higher than calculated for the BSAP 2013. The nitrogen deposition in the reference period showed the highest increase in the Gulf of Finland (42%) and Kattegat (39%) and the lowest in the Gulf of Riga (21%).

Atmospheric deposition of oxidized and reduced nitrogen was computed for the entire EMEP domain, which includes the Baltic Sea basin and its catchment (Data figure 17). Calculations are done annual on data from two years prior to the calculations. For further details see the annual report by EMEP to HELCOM (Gauss et al., 2020). Data on air emissions and atmospheric deposition are maintained by EMEP and can be accessed via the EMEP website.

The results of the EMEP MSC-W model are routinely compared to available measurements at EMEP and HELCOM stations. The comparison of calculated versus measured data indicates that the model predicts the observed air concentrations of nitrogen within an accuracy of approximately 20-30%. Further work is required on reducing uncertainties in emission data and better parameterization of physical processes in the EMEP MSC-W model to increase the accuracy in future model estimates.

No official information about the uncertainty of provided nitrogen emission data have been sent to EMEP from neither EMEP nor HELCOM Contracting Parties, and consequently further work on emission uncertainty is essential. Submitted emissions data are passing through QA/QC procedures and stored in the EMEP Centre for Emission Inventories and Projections CEIP in Vienna, Austria. Reviews about the consistency, comparability and trends of national inventories are available at http://www.ceip.at/. There are gaps in time series of national emissions that have to be corrected by experts to make the time series complete.

There are limited data on phosphorus deposition and no emission data for the modelling work has been available for evaluation. For most countries, measurements only covered wet deposition and there was a lack of data on particulate and dry deposition. A fixed deposition rate of 5 kg P per km^2 to the Baltic Sea has been used in the PLC-5.5 assessment (HELCOM 2014b, HELCOM 2015). The estimates of phosphorus deposition rates are mainly based on the data from monitoring stations close to the coastline of the Baltic Sea. But there are very few monitoring stations on small islands in the Baltic Sea, and therefore the use of the data mainly from stations on land might lead to an overestimation of deposition. Many monitored concentrations (dry and wet deposition) are very low and close to detection limit. Therefore, the atmospheric phosphorus deposition data and the applied deposition rate is rather uncertain for the whole Baltic roughly ±50% and for minor basins as Gulf of Riga and The Danish Straits even higher uncertainty exists. As atmospheric deposition on average only constitutes 9% of total phosphorus inputs, these uncertainties are less critical than in the case of atmospheric deposition of nitrogen, which on average constitutes 26% of total nitrogen inputs to the Baltic Sea.



Data figure 1. The EMEP model domain used for computations on atmospheric deposition.

Arrangements for updating the indicator

Annual total waterborne inputs of nitrogen, phosphorus and their fractions are reported every year by the HELCOM Contracting Parties and compiled by the PLC Data Manager at the Marine Research Centre, Finnish Environment Institute (MK/SYKE). The data collection is based on a combination of monitored data (measurements at monitoring stations close to river mouth and at point sources) and estimates of inputs from unmonitored areas.

The HELCOM PLUS is a modernized PLC database including QA facilities when uploading, and inserting data, and which allow data reports, quality assures from the Contracting Parties improved access to the waterborne input data. Further assessment dataset will be available in an assessment database under development.

Data on air emissions are reported to EMEP, which subsequently models the atmospheric deposition to the Baltic Sea. EMEP host the emission and deposition data, which can be accessed via their website. EMEP is contracted by HELCOM to provide selected data products on an annual basis.

The Baltic Nest Institute (BNI), Sweden, and Danish Centre for Environment and Energy (DCE), Aarhus University, Denmark have in cooperation with Reduction Scheme Core Drafting Group, RedCore DG elaborated the present core pressure indicator on nutrient inputs.

Contributors and references

Contributors

Lars M. Svendsen[1], Bo Gustafsson[2], Søren E. Larsen[1], and Dmitry Frank-Kamenetsky[3]

With support from the HELCOM Reduction Scheme Core Drafting Group (RedCore DG)

[1] DCE - Danish Centre for Environment and Energy, Aarhus University

[2] Baltic Nest Institute, Sweden

[3] HELCOM Secretariat

Archive

This version of the HELCOM core indicator report was published in 2022:

HELCOM core indicator on inputs of nutrients for period 1995-2019 (pdf)

Earlier versions of the core indicator:

HELCOM core indicator on inputs of nutrients for period 1995-2016 (pdf)

HELCOM core indicator on inputs of nutrients for period 1995-2017 (pdf)

HELCOM core indicator on inputs of nutrients for period 1995-2018 (pdf)

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