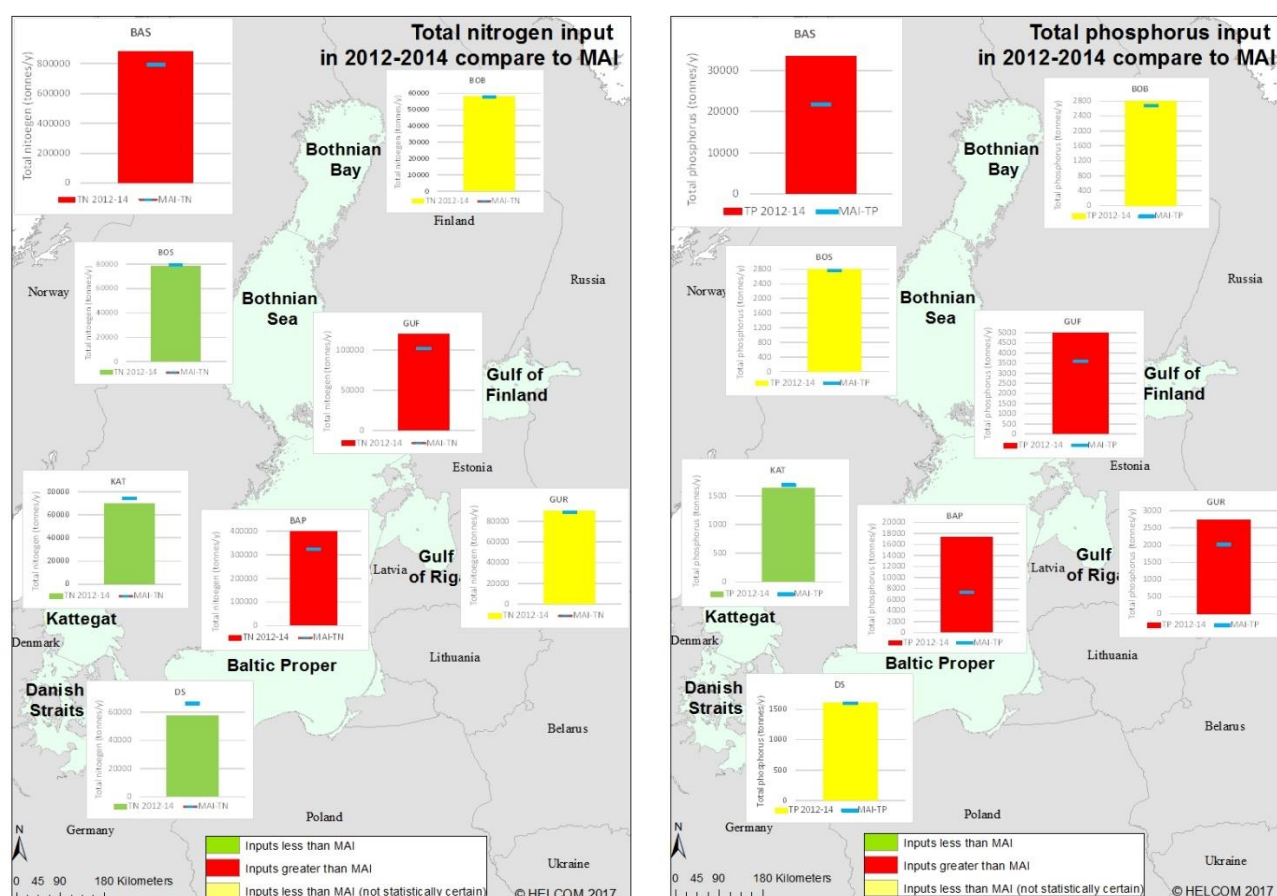


Inputs of nitrogen and phosphorus to the Baltic Sea (2012-2014)

Key message

A significant reduction of nutrients input has been achieved for the whole Baltic Sea. In the last 3-year assessment (2012-2014) the average normalized input of nitrogen was reduced by 13% and phosphorus by 19% since the reference period (1997-2003) (Results figure 1). The maximum allowable input (MAI) of nitrogen in this period was fulfilled in the Kattegat, Danish Straits and Bothnian Sea (Key message figure 1 and Results tables 1a and 1b). Nitrogen inputs into Bothnian Bay and the Gulf of Riga are close to MAI but cannot be considered as fulfilled due to statistical uncertainty. MAI for phosphorus input is fulfilled in the Kattegat only. The inputs to the Danish Straits, Bothnian Sea and Bothnian Bay cannot be considered as fulfilled due to statistical uncertainty. Since the mid-1990s (Results table 2), total normalized nitrogen and phosphorus inputs to the Baltic Sea in 2014 were reduced by 19% and 24%, respectively.



Key message figure 1: For each sub-basin and the whole Baltic Sea (BAS), 3 year average annual normalized total nitrogen and phosphorus inputs (tons per year) including statistical uncertainty in 2012-2014 are compared with the maximum allowable nutrient inputs (MAI t/y, shown as a blue line). Green colour indicates that inputs during 2012-

2014 were lower than MAI, red colour when they 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. *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 in order to eventually obtain good environmental 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

	Primary importance	Secondary importance
BSAP Segment and Objective	- Eutrophication segment: nutrient reduction scheme - Has an influence on reaching objective <i>Concentrations of nutrients close to natural levels</i>	Maritime segment: Minimum air pollution from ships and minimum sewage pollution from ships (Nutrient levels also affect biodiversity ecological objectives)
MSFD Descriptors and Criteria	- 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 - Criterion 5.1. Nutrients concentration in the water column	Influence on achieving GES of the follow criteria: 1.6. Habitat condition 5.2. Direct effects of nutrient enrichment 5.3. Indirect effects of nutrient enrichment
Other relevant legislation: (e.g. WFD): 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 area (NECA) in the Baltic and North seas designated by IMO.		

Cite this indicator

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Results and confidence

Fulfilment of MAI in 2012-2014 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 reduction targets for nitrogen inputs were met in 2012-2014 (Key message figure 1 and Results table 1a). However, since the reference period (1997-2003), notable reduction of nitrogen input has been achieved to all sub-basins except the Gulf of Finland and Gulf of Riga, where the reductions are not statistically significant (Results figure 1). The highest reduction was observed to Kattegat and Danish Straits (21%) and the lowest to the Bothnian Bay and Gulf of Finland – 9.0% and 5.4, respectively (Results figure 1).

Results table 1. The average normalized annual inputs of (a) nitrogen and (b) phosphorus during 2012-2014, the average normalized inputs during 2012-2014 including statistical uncertainty, the remaining reduction needed to reach MAI and inputs in 2012-2014 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 2012-14	2012-14 statistical uncertainty	N input 2012-14 with stat. uncertainty	Remaining reduction to reach MAI	% of MAI input 2012-14 with stat. uncertainty	Classification of achieved reduction
Bothnian Bay (BOB)	57622	55255	2910	58165		101	Yellow
Bothnian Sea (BOS)	79372	73859	4939	78798		99	Green
Baltic Proper (BAP)	325000	389108	25425	414533	89533	128	Red
Gulf of Finland (GUF)	101800	119804	14298	134102	32302	132	Red
Gulf of Riga (GUR)	88417	81806	14420	96226		109	Yellow
Danish Straits (DS)	65998	54176	3417	57593		87	Green
Kattegat (KAT)	74000	66767	2973	69740	0	94	Green
Baltic Sea (BAS)	792209	840773	44393	885166	121835	112	Red

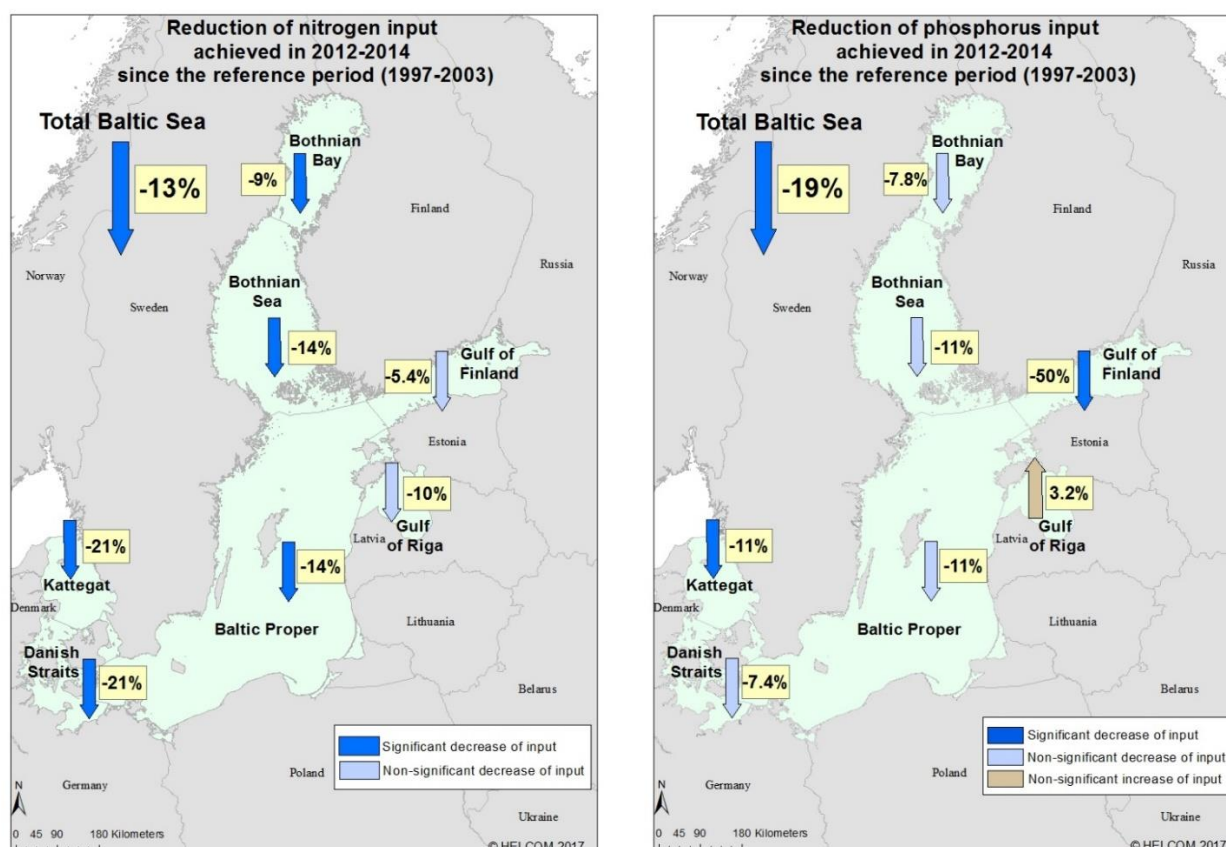
Table 1b.

Baltic Sea Sub-basin	MAI*	P input 2012-14	2012-14 statistical uncertainty	P input 2012-14 with stat. uncertainty	Remaining reduction to reach MAI	% of MAI input 2012-14 with stat. uncertainty	Classification of achieved reduction
Bothnian Bay (BOB)	2675	2545	319	2864		107	Yellow
Bothnian Sea (BOS)	2773	2506	301	2807		101	Yellow
Baltic Proper (BAP)	7360	16011	1398	17409	10049	237	Red
Gulf of Finland (GUF)	3600	4413	2243	6656	3056	185	Red
Gulf of Riga (GUR)	2020	2444	293	2737	717	135	Red
Danish Straits (DS)	1601	1502	109	1611		101	Yellow
Kattegat (KAT)	1687	1483	152	1635		97	Green
Baltic Sea (BAS)	21716	30902	2675	33577	13822	155	Red

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

None of the three 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 2012-2014 (Key message figure 1 and Results table 1b). However, reduction of phosphorus inputs was observed in all sub-basins except the Gulf of Riga. The highest input reduction since the reference period (1997-2003) of 50% was achieved to the Gulf of Finland (Results figure 1). However, a statistically significant reduction was achieved only to the Kattegat. The input of phosphorus to the Gulf of Riga has slightly increased by 3.2%, but the level of statistical uncertainty for the data on waterborne inputs to the Gulf of Riga is rather high.

Compared to the first evaluation of MAI fulfilment (Svendsen et al., 2015), EMEP has revised the modelled nitrogen air deposition to the Baltic Sea for 1995-2012. This has led to an increase in the annual deposition to the Baltic Sea of 16 to 23%. The increase on annual nitrogen deposition to the individual sub-basins is between 9 and 27 %.



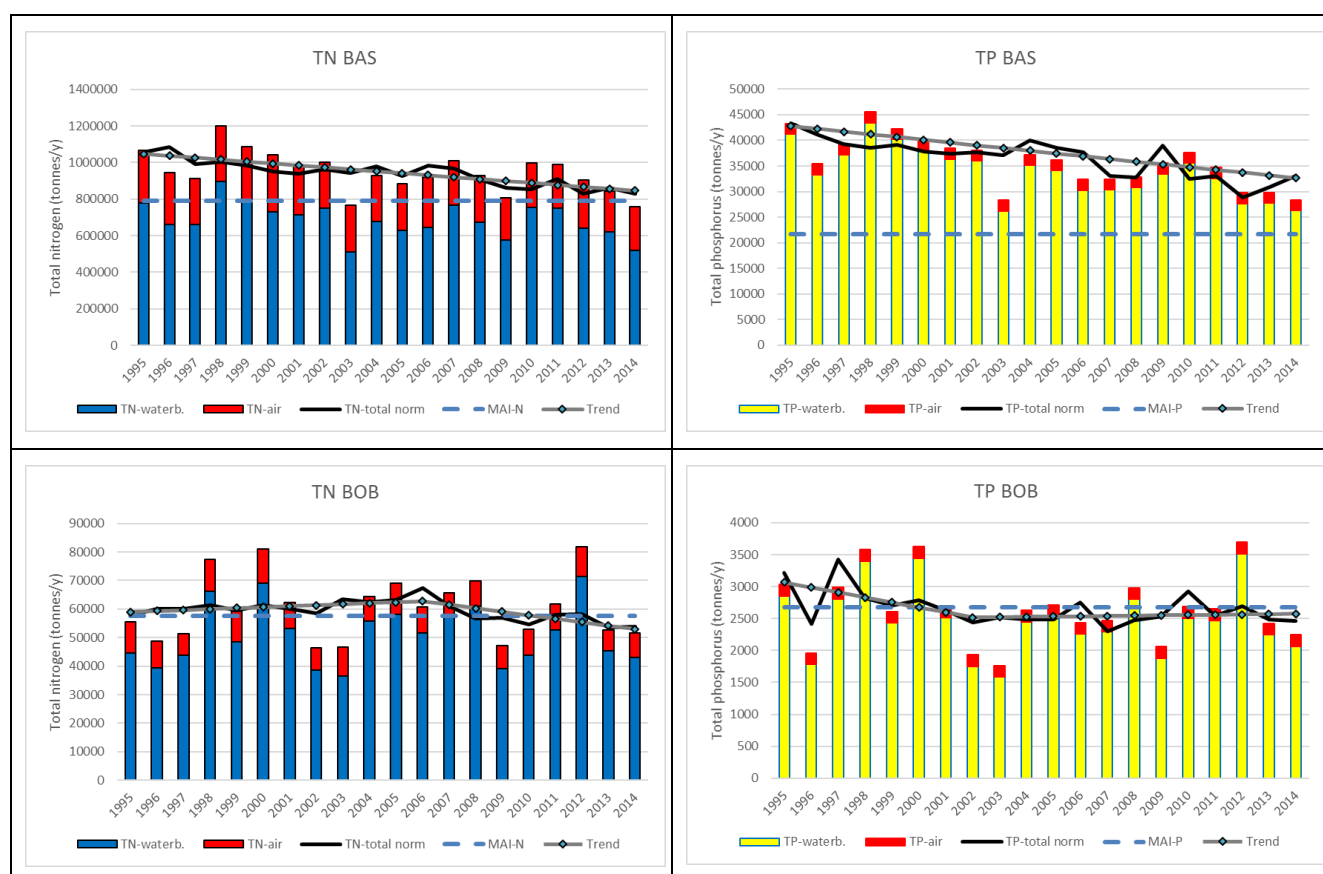
Results figure 1. Reductions of average annual inputs of nitrogen (left) and phosphorus (right) achieved in 2012-2014 since the reference period 1997-2003 (in %). The average annual inputs in 2012-2014 and in the reference period were calculated using normalized annual data. The arrows and colours indicate decreasing (↓) and increasing (↑) inputs as well as the statistical significance of changes.

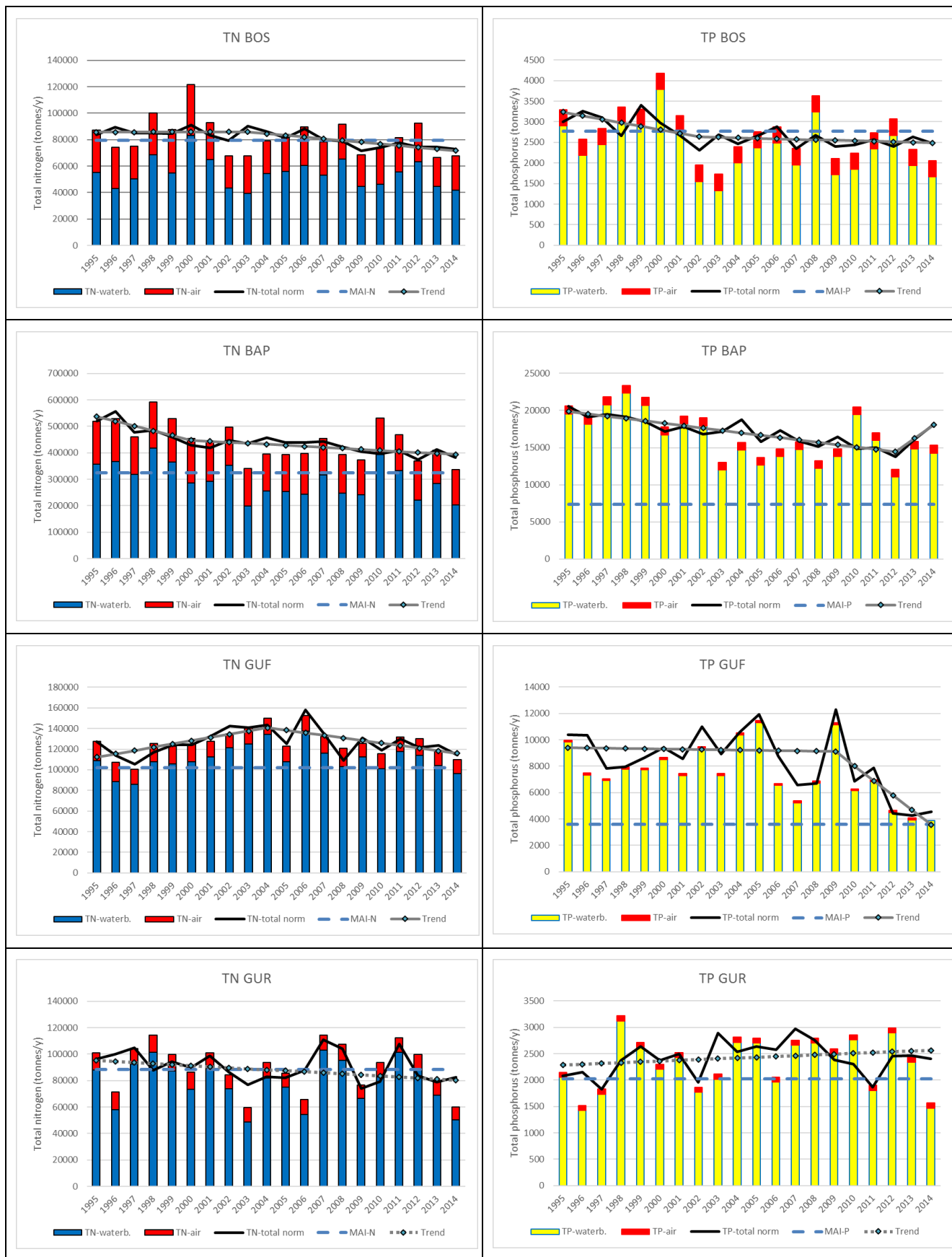
Trends

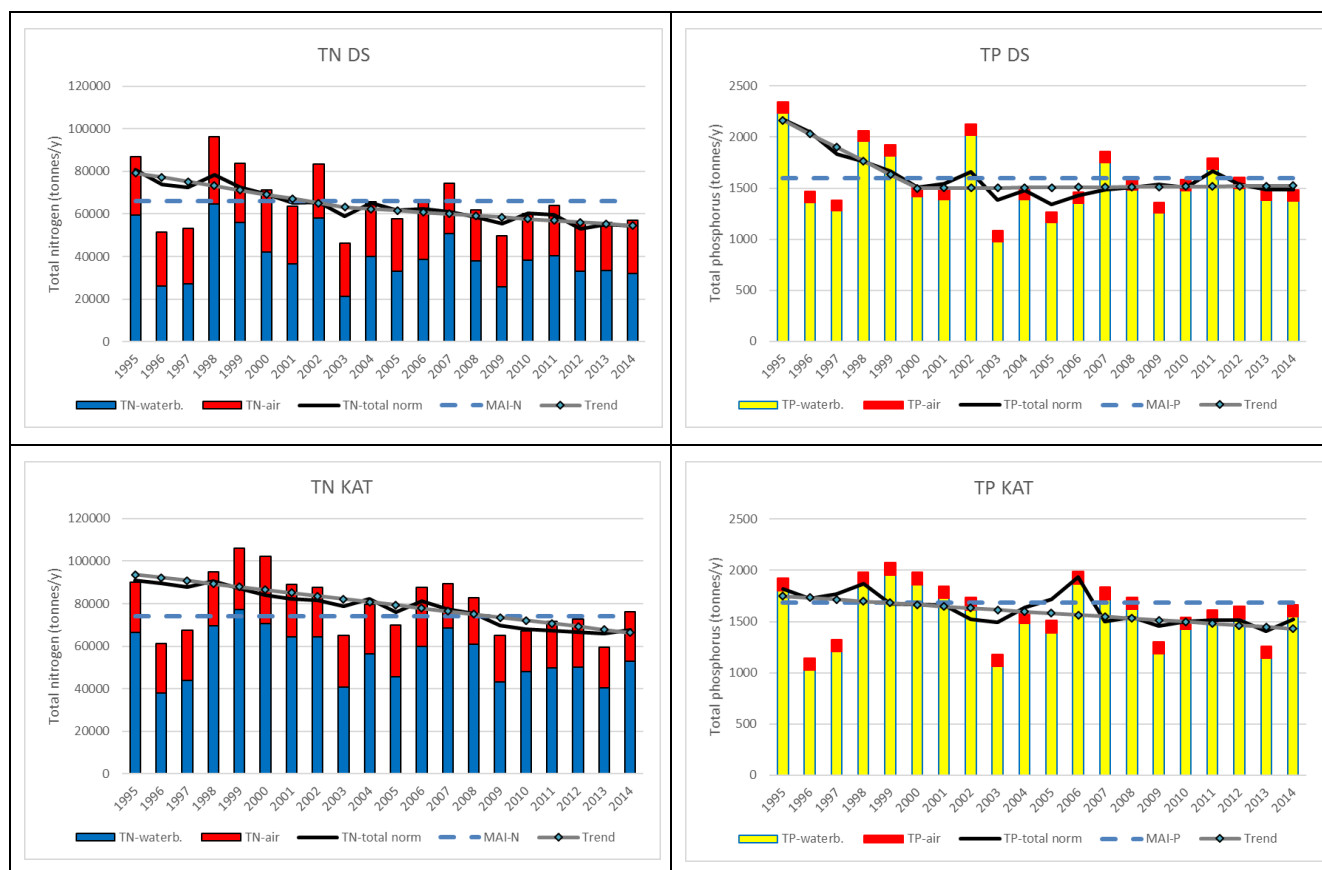
Normalization is used for the annual riverine and atmospheric inputs to reduce the impact of inter annual variations of the inputs caused by weather conditions (primarily variations in precipitation). With

normalisation the comparability of the inter-annual inputs increases, facilitating trend detection and also identification of effects of undertaken measures in the catchment areas. Without normalization, the effects could be disguised by large natural annual variation of precipitation and river flow.

Trend analyses show that total inputs of nitrogen to the Baltic Sea from 1995 to 2014 decreased statistically significant with 22%. The reduction of nitrogen inputs was between 7-33% to the different sub-basins (Results table 2) and statistically significant to all except for the Bothnian Bay, Gulf of Finland and Gulf of Riga (Results figure 2). Total phosphorus inputs to the Baltic Sea also decreased statistically significant with 24%. The reduction was statistically significant to the sub-basins Bothnian Sea, Baltic Proper, Gulf of Finland, Danish Straits and Kattegat. The trend indicates an increase of total phosphorus input to the Gulf of Riga by 16%, but this trend is not statistically significant due to rather high uncertainty caused by high variability in reported phosphorus inputs. Phosphorus concentrations in the monitored river Vistula in 2014 were exceptionally high, which caused a break point in the time series for total phosphorus input to the Baltic Proper in 2012 and affected normalized input into the whole Baltic Sea.







Results figure 2. Actual total air- and waterborne annual input of nitrogen (TN) and phosphorus (TP) to the Baltic Sea and sub-basins from 1995 to 2014 (tonnes). The normalized 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 (solid line - statistically significant trend; dotted line - not statistically significant trend). The MAI as adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a) is shown as the bold dotted blue line.

The trend analysis includes a test for breakpoints in the time series of total normalized annual nitrogen and phosphorus inputs 1995-2014. A break point in the trend has been identified for all basins except for total nitrogen to Gulf of Riga, Kattegat and the Baltic Sea and total phosphorus to Kattegat and the Baltic Sea.

Results table 2. Percentage of change in annual airborne and waterborne normalized inputs of nitrogen and of total nitrogen and phosphorus normalized annual inputs to the Baltic Sea sub-basins and to the Baltic Sea from 1995 to 2014 based on a statistical trend analysis. Statistical significant changes are indicated by bold letters.

Sub-basin	Change in airborne N inputs since 1995 (%)	Change in waterborne N inputs since 1995 (%)	Change in total N inputs since 1995 (%)	Change in total P inputs since 1995 (%)
Bothnian Bay	-26	-1.9	-6,6	-23
Bothnian Sea	-28	-3.1	-13	-17
Baltic Proper	-27	-26.1	-27	-12
Gulf of Finland	-25	-8.0	-10	-56
Gulf of Riga	-26	-12.3	-14	16
Danish Straits	-26	-36.1	-33	-31
Kattegat	-31	-22.9	-25	-16
Total Baltic Sea	-27	-19.3	-22	-24

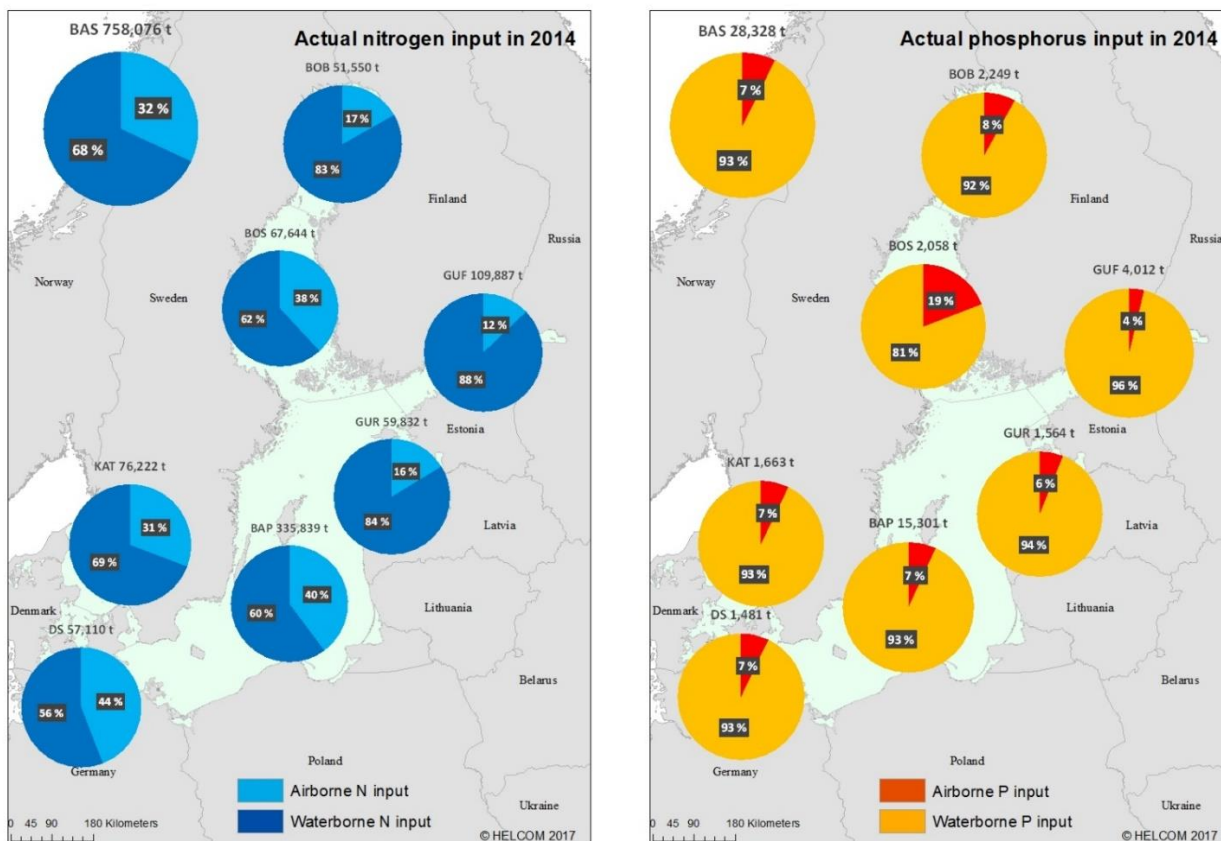
The total nutrient input to the Baltic Sea varies significantly depending on wet or dry weather conditions. For example, 2010 was a very wet year in the southern part of the Baltic Sea catchment area, hence the actual (non-normalized) nutrient inputs were very high to e.g. Baltic Proper (Results figure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

Actual airborne and waterborne inputs in 2014

In 2014, the average water flow was more than 8% lower than the average for 1995-2014, especially low was the flow to the Gulf of Riga (36%) and to the Baltic Proper (17%). On the other hand, the flow to the Kattegat (+12%) was comparatively higher than average for the considered period. The total input of nitrogen was about 758,000 tonnes, and the portion of atmospheric deposition was about 32%. The total phosphorus input to the Baltic Sea in 2014 was about 28,300 tonnes with a contribution of atmospheric deposition about 7% (Results table 3, Results figure 3).

Results table 3. Annual average water flow as well as actual annual waterborne and airborne inputs of phosphorus and nitrogen to the Baltic Sea sub-basins in 2014. Average flow 1995-2014 is shown for comparison.

Sub-basin	Average flow 1995-2014 (m ³ /s)	Flow (m ³ /s)	Nitrogen (t)			Phosphorus (t)		
			Waterborne	Airborne	Total	Waterborne	Airborne	Total
Bothnian Bay	3394	3106	42908	8642	51550	2068	181	2249
Bothnian Sea	2961	2667	41851	25793	67644	1664	394	2058
Baltic Proper	3657	2972	202330	133509	335839	14255	1046	15301
Gulf of Finland	3513	3462	96503	13384	109887	3862	150	4012
Gulf of Riga	1095	704	50251	9572	59823	1470	93	1564
Danish Straits	221	209	31902	25208	57110	1376	105	1481
Kattegat	1096	1227	52748	23474	76222	1545	118	1663
Total	15847	14346	518,494	239,582	758076	26240	2088	28328



Results figure 3. The total actual inputs of water- and airborne nitrogen (left) and phosphorus (right) from HELCOM countries to the Baltic Sea in 2014.

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 in Kattegat, Gulf of Finland and Baltic Proper and for phosphorus to 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.

Good environmental status

Environmental Target and progress towards GES

The environmental targets for nutrient inputs are the maximum allowable inputs (MAI) of the HELCOM nutrient reduction scheme (Good environmental status 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 environmental status (GES) 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 improved scientific basis and models, and were adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a).

Good environmental status 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. GES boundaries 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 & Mörtz, 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 shortcomings 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 variable (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 taken into

account. 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 year.

Nutrient input data can be viewed in HELCOM PLC reports (e.g. HELCOM 2012, HELCOM 2013d and HELCOM 2015).

Trend analysis and statistical processing

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

- annual flow normalized riverine inputs (A)
- point sources discharging directly to the sea (direct inputs) (B)
- flow normalized waterborne inputs ($C = A+B$)
- normalized airborne inputs (D)
- total normalized inputs ($E = C+D$) 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) and the change from 1995 to 2014 was calculated. The methodology has been agreed on by HELCOM LOAD (more information on trend analysis and determining the changes in input can be found in Larsen & Svendsen 2013). 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, which determines the most significant break point. If a break point is identified, the time series is divided into at least 2 segments, and trends are tested for each segment of the series.

The evaluation of MAI fulfilment is based on comparing MAI for each basin and the Baltic Sea with the average of normalized annual total nitrogen and phosphorus inputs of 2012-14 including uncertainty on these inputs (Results table 2). In the first evaluation of MAI fulfilment uncertainty of average of 2010-2012 normalized inputs was estimated from the variation of the 3 year inputs around the average. In the present assessment the uncertainty of the average 2012-14 input is estimated based on the analysis of trends for the whole time series 1995-2014.

For information about normalization of airborne and flow normalization of waterborne input data, see Annexes 9.3 and 9.4 of the PLC-5.5 report (HELCOM 2015) and Larsen and Svendsen (2013).

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 area and the Danish Straits combine Western Baltic and The Sound.

The entire Baltic Sea is covered by the assessment.

Relevance of the indicator

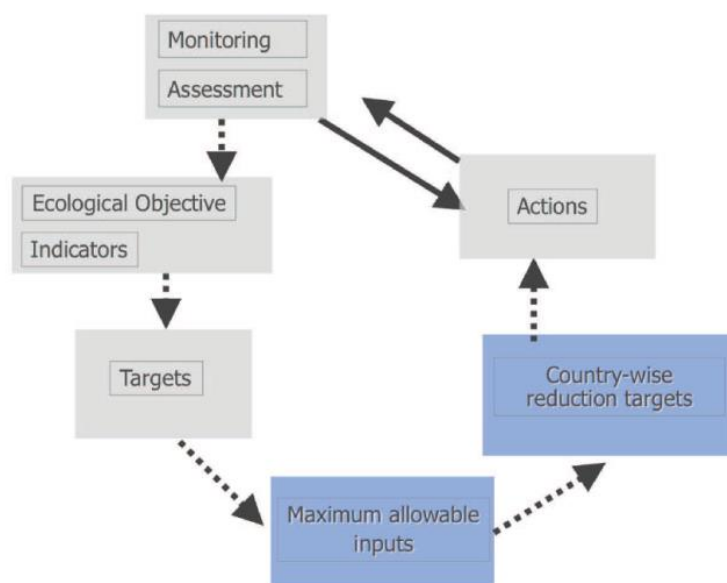
Holistic assessment

Human maritime 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 will also contribute to the next holistic assessment to be completed in 2018.

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 environmental status (GES) 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 progress of countries in reaching their share of the country-wise allocation of nutrient reduction targets (CART) is assessed separately in a follow-up system. Relevance figure 1 illustrates how the nutrient reduction scheme fits into an eutrophication management cycle.



Relevance figure 1. The management cycle of the HELCOM Baltic Sea Action Plan.

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

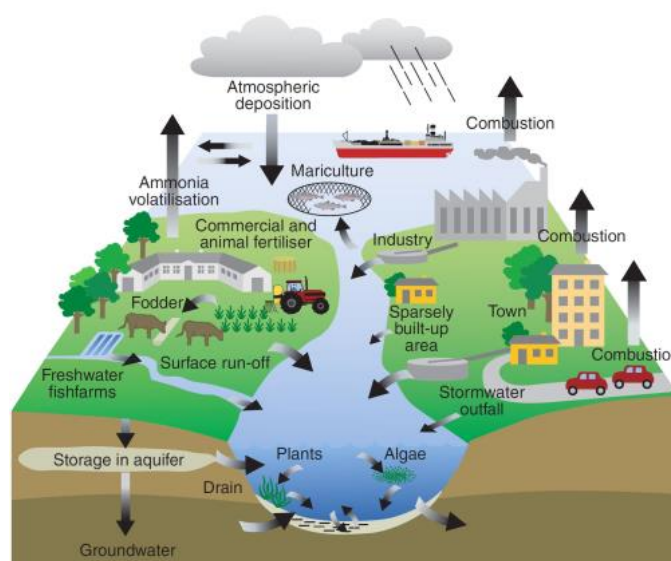
pressure indicator on inputs of nutrients relates to HELCOM eutrophication state core indicators. More information on this is provided in the section below on Environmental Target and progress towards GES.

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 on the Baltic Sea NO_x emission control area (NECA) has been submitted to IMO.

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 20th 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. wastewater 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 & Mörtz, 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 time-scales 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 & Mörtz, C.M, document 2-43 HOD 41-2013.

Relevant core indicators on eutrophication status:

- [Nitrogen concentrations](#)

- [Phosphorus concentrations](#)
- [Water transparency](#)
- [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 inputs of nitrogen](#)
- [Nitrogen emissions to the air in the Baltic Sea region](#)
- [Phytoplankton biomass and species succession](#)
- [Shifts in the Baltic Sea summer phytoplankton communities in 1992-2006](#)
- [Spatial distribution of winter nutrient pool](#)
- [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 [latest assessment on eutrophication status in the Baltic Sea](#) (HELCOM 2014).

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-6 project](#).

An overview of agreed monitoring of nutrient inputs is also described in the [HELCOM Monitoring Manual](#). An [overview of monitoring carried out by Contracting Parties in 2012](#) was compiled by the PLC-6 project, which summarizes the frequency of monitoring of different parameters in rivers and point sources.

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 Unified 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 fix deposition rate of 5 kg P per km² have 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 waste water treatment plants, industry and aquaculture) discharging directly to the Baltic Sea are reported separately.

Monitoring table 1a: Numbers of rivers, monitored area 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-basin in 2010. Monitored and unmonitored areas will be updated]

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	22	220194	85	81	13	6
Bothnian Sea	15	193006	84	68	12	10
Baltic Proper	45	471514	82	89	9	2

Gulf of Finland	22	323036	78	78	13	9
Gulf of Riga	7	112414	83	86	13	1
Danish Straits	74	13485	49	45	48	7
Kattegat	39	74075	85	65	31	4
Baltic Sea	224	1407724	82	82	14	4

Monitoring table 1b: Numbers of rivers, monitored area 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-basin in 2010. Monitored and unmonitored areas will be updated]

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	22	220194	85	85	12	3
Bothnian Sea	15	193006	84	59	27	14
Baltic Proper	45	471514	82	91	7	2
Gulf of Finland	22	323036	78	71	20	9
Gulf of Riga	7	112414	83	91	8	1
Danish Straits	72	12713	47	32	49	19
Kattegat	39	74075	85	60	33	7
Baltic Sea	222	1406952	81	82	13	5

Monitoring tables 1a and 1b show that more than 80% of the total Baltic Sea catchment area is covered by monitoring based on 222/224 monitoring stations. For six of the seven sub-basins between 78% and 85% of the catchment areas are monitored, and these catchments are covered by monitoring in mainly large rivers. For Danish Straits only 47-49% of the catchment is monitored even though 74 monitoring stations or 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 14% of total nitrogen and 13% 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 use 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-6 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 southwestern 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 (2017) Inputs of nitrogen and phosphorus to the Baltic Sea (2012-2014). HELCOM core indicator report. Online [Date viewed], [Web link]

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Metadata

Data on air- and waterborne nutrient inputs from 1995 to 2014 are used in this indicator (although data on waterborne inputs is also available from 1994). Data reporting has not been perfect and gaps exist in the dataset. For waterborne inputs, the PLC-6 project corrected suspicious data and filled in data gaps to establish a complete and consistent [dataset](#). Gaps in time series of national air emissions have also been corrected by EMEP experts.

Waterborne inputs

The dataset behind the present assessment was compiled by the PLC6 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, DCA 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](#) and [documentation](#) prepared by the PLC-5.5 project.

Data on waterborne inputs are available from 1994-2014 and cover inputs from the entire drainage basin of the Baltic Sea. This indicator, however, only includes data starting from 1995 since atmospheric input data is only available from 1995 onwards.

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](#) was carried out under the PLC-6 project.

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-6 guidelines. The PLC-5.5 project roughly estimates an uncertainty of 15-25%

for annual total waterborne nitrogen and 20-30% on total phosphorus inputs to Kattegat, Western Baltic, the main part of Baltic Proper, Bothnian Bay and Bothnian Sea, and for the remaining parts of the Baltic Sea up to 50% uncertainty. The uncertainty for annual water flow to the above listed sub-basins is estimated to 5-10% for most sub-basins and 10-20% for the remaining ones.

Airborne inputs

Atmospheric input data for all Baltic Sea sub-basins are available for the period 1995-2014. 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. 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. Further, it includes a meteorological model. A comprehensive description of the model and its applications is available on the [EMEP website](#).

Compared with the first evaluation of MAI fulfilment (Svendsen et al., 2015), EMEP has implemented revised models and used updated emissions figures. This led to revised inputs on normalized nitrogen air deposition to Baltic for 1995-2012, increasing the annual deposition to the Baltic Sea with between 16 to 23 %. The increase on annual nitrogen deposition to the individual sub-basins is between 9 and 27 %.

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 1). Calculations are done annual on data from two years prior to the calculations. For further details, see the annual report by EMEP to HELCOM [Atmospheric Supply of Nitrogen, Lead, Cadmium, Mercury and Dioxins/Furanes to the Baltic Sea in 2011](#).

Data on air emissions and atmospheric deposition are maintained by EMEP and can be accessed via the [EMEP website](#).

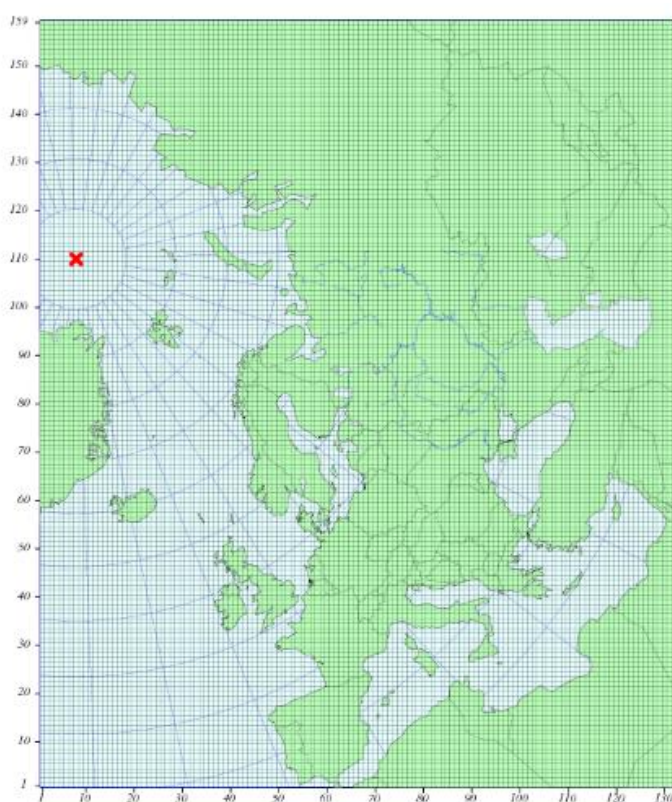
The results of the EMEP Unified model are routinely compared to available measurements at EMEP and HELCOM stations. The comparison of calculated versus measured data indicates that the model predicts the observed air concentrations of nitrogen within an accuracy of approximately 20-30%. Further work is required on reducing uncertainties in emission data and better parameterization of physical processes in the EMEP Unified 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 km² 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 $\pm 50\%$ and for minor basins as Gulf of Riga and The Danish Straits even higher uncertainty. As atmospheric deposition in average only constitutes 7% of total phosphorus inputs these uncertainties are less critical than in the case of atmospheric deposition of nitrogen, which in average constitutes 32% of total nitrogen inputs to the Baltic Sea.

[Data on actual (non-normalized) riverine flow as well as atmospheric and waterborne inputs of nitrogen and phosphorus will be available as an [Excel file](#) when the indicator is approved and published]



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 has in cooperation with [Reduction Scheme Core Drafting Group, RedCore DG](#) elaborated the present core pressure indicator on nutrient inputs.

Contributors and references

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Archive

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Earlier versions of the core indicator:

[Core indicator – web-based report 2015](#) (pdf)

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