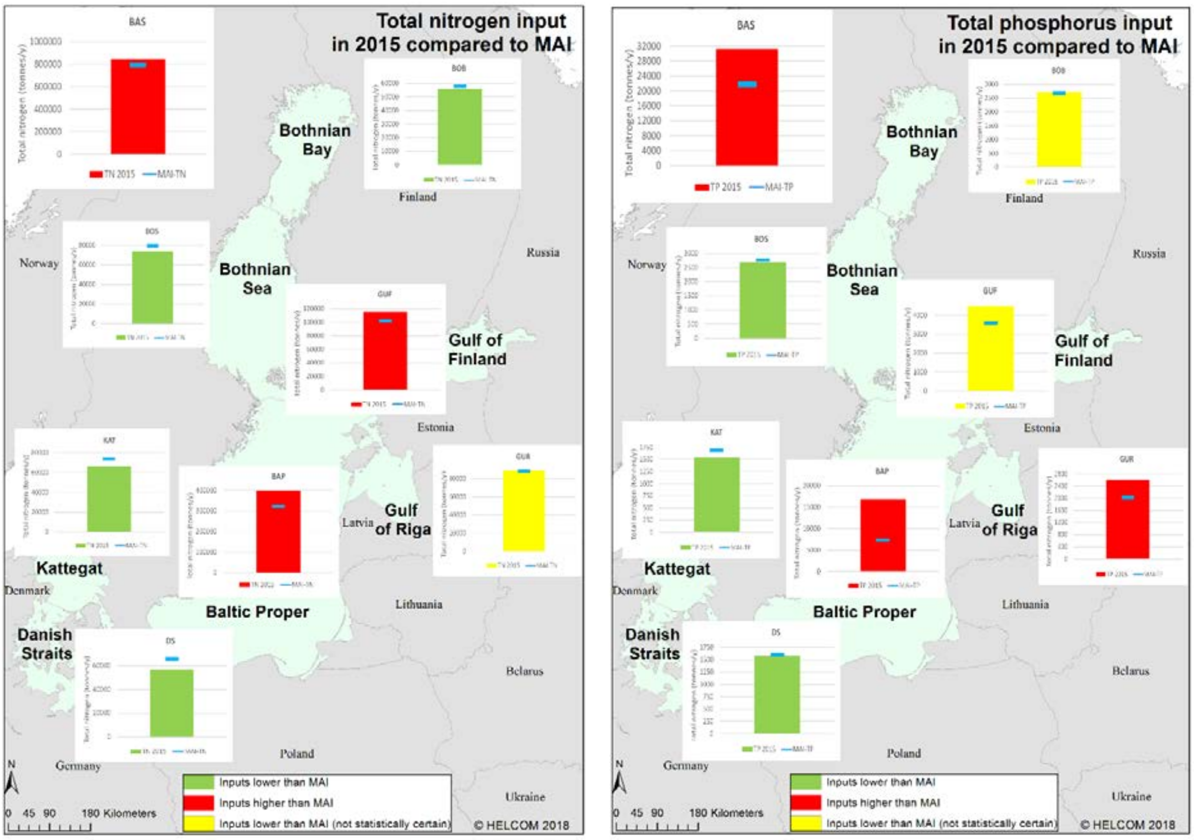
HELCOM core indicator report
August 2018

Inputs of nutrients (nitrogen and phosphorus) to the subbasins (2015)

Key message

A significant reduction of nutrients input has been achieved for the whole Baltic Sea. This assessment shows that the normalized input of nitrogen was reduced by 12% and phosphorus by 25% between the reference period (1997-2003) and 2015 (Results figure 1). The maximum allowable input (MAI) of nitrogen in this period was fulfilled in the Kattegat, Danish Straits, Bothnian Bay and Bothnian Sea (Key message figures 1 and Results tables 1a and 1b). Nitrogen input into the Gulf of Riga is below MAI but cannot be considered as fulfilled due to statistical uncertainty. MAI for phosphorus input is fulfilled in the Kattegat, Danish Straits and Bothnian Sea. The inputs to the Gulf of Finland and Bothnian Bay are below MAI but cannot be considered as fulfilled due to statistical uncertainty.



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 2015 (tons per year) including statistical uncertainty are compared with the maximum allowable nutrient inputs (MAI t/y, shown as a blue line). Green colour indicates that inputs during 2015 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 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 area (NECA) in the Baltic and North seas designated by IMO.		

Cite this indicator

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Inputs of nutrients to the subbasins HELCOM core indicator 2018 (pdf)

Results and confidence

Fulfilment of MAI in 2015 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 2015 (Results figure 1 and Results table 1a). However, since the reference period (1997-2003), statistically significant 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 2). The highest reduction was observed to Kattegat (19%) and the lowest to the Bothnian Bay (6%) and Gulf of Riga (4%), respectively (Results figure 1). The progress in nitrogen input reduction (24%) achieved in the Gulf of Finland is still statistically uncertain due to high inter-annual variability in the data.

Results table 1. The trend-based estimate for normalized annual inputs of (a) nitrogen and (b) phosphorus during 2015.

The table also contains data on statistical uncertainty, the remaining reduction needed to reach MAI and inputs in 2015 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 2015	Statistical uncertainty 2015	N input including stat. uncert. 2015	Exceedance of MAI	Input 2015 including stat. uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay (BOB)	57622	54092	1852	55944		97	
Bothnian Sea (BOS)	79372	71305	2479	73784		93	
Baltic Proper (BAP)	325000	387711	12358	400069	75069	123	
Gulf of Finland (GUF)	101800	107746	7535	115280	13480	113	
Gulf of Riga (GUR)	88417	83398	5533	88931	514**	101	
Danish Straits (DS)	65998	55033	2009	57042		86	
Kattegat (KAT)	74000	65422	1394	66816		90	
Baltic Sea (BAS)	792209	827915	17752	845667	53458	107	

Table 1b.

Baltic Sea Sub-basin	MAI*	P input 2015	Statistical uncertainty 2015	P input including stat. uncert. 2015	Exceedance of MAI	Input 2015 incl. stat. uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay (BOB)	2675	2574	149	2724	49**	102	
Bothnian Sea (BOS)	2773	2569	133	2702		97	
Baltic Proper (BAP)	7360	15327	1554	16881	9521	229	
Gulf of Finland (GUF)	3600	2853	1610	4463	863**	124	
Gulf of Riga (GUR)	2020	2372	227	2599	579	129	
Danish Straits (DS)	1601	1530	49	1579		99	
Kattegat (KAT)	1687	1477	59	1536		91	
Baltic Sea (BAS)	21716	30026	1229	31255	9539	144	

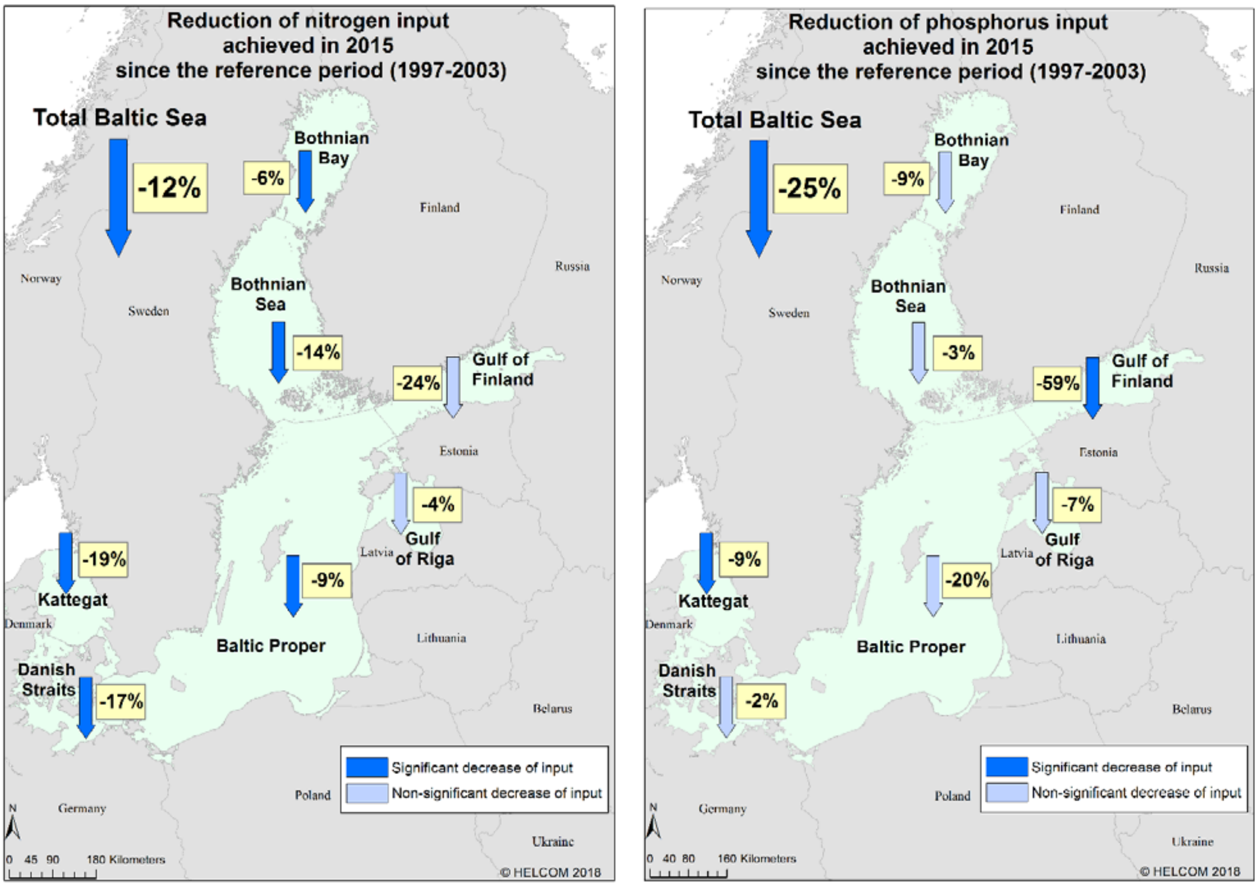
*As adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a)

**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 2015 (Results figure 1 and Results table 1b). However, reduction of phosphorus inputs was observed in all sub-basins. The highest input reduction since the reference period (1997-2003) of 59% was achieved to the Gulf of Finland (Results figure 1). A statistically significant reduction was achieved in the Kattegat, Danish Straits and Bothnian Sea. The 20 % reduction of phosphorus input to Baltic Proper is still not statistical significant.

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 increase of the annual deposition to the Baltic Sea of 16 to 23%. The increase on annual nitrogen deposition to the individual sub-basins was between 9 and 27 %.

Changes in inputs of total nitrogen and phosphorus since 1995 are estimated with a slightly different methods than the reductions since the reference period 1997-2003 (Results figure 1). It is based on the estimated normalized inputs in 1995 and 2015 resulting from the trend analysis. In previous versions of this indicator changes since 1995 was calculated from the normalized inputs in 1995 and the most recent year in the time series. HELCOM RedCore DG and PLC-7 IG will continue evaluating the most appropriated methods to apply.



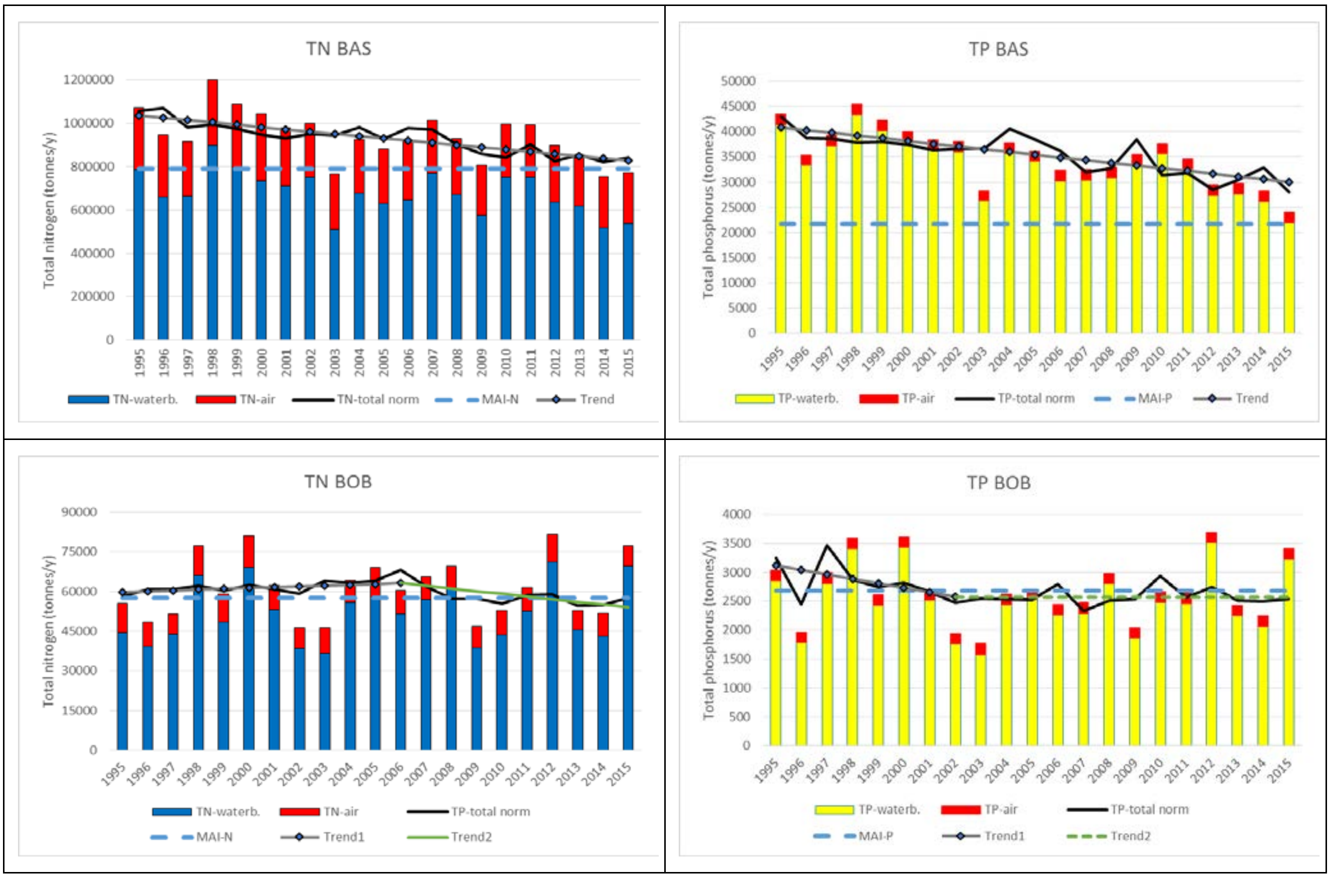
Results figure 1. Reductions of annual inputs of nitrogen (left) and phosphorus (right) achieved in 2015 since the reference period 1997-2003 (in %). The annual inputs in 2015 and in the reference period were calculated using normalized annual data. The arrows indicate decreasing (↓) inputs, while the colours indicate if the change was statistically significant.

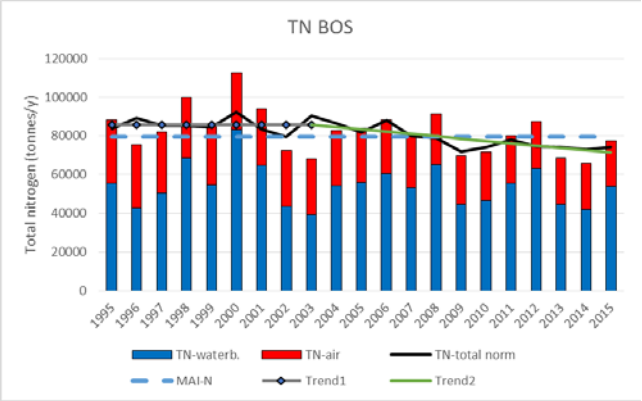
Trends

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 statistically significant steady reduction of total inputs of nitrogen to the Baltic Sea amounting to 20 % from 1995 to 2015 (Results figure 2). Correspondingly, from 1995 to 2015 total nitrogen inputs also show a steady significant decrease for Kattegat (28 %) and Gulf of Riga (12 %). For the remaining basins, break points were identified when evaluating the trends of total nitrogen inputs, dividing the time series in two sections. Baltic Proper has a significant decrease with 17% from 1995 to 2000, and with 12% from 2000 to 2015. A significant nitrogen input, an increase of 28 %, was observed in the Gulf of Finland during the 1995 to 2004 period, and a 25 % decrease from 2004 to 2015. Significant reductions are also calculated for Danish Straits during 1995-2003 (22%) and from 2003 to 2015 (13 %). For Bothnian Bay significant reduction only took place after 2006 (14%), and for Bothnian Sea after 2003 (13%).

Trends for total phosphorus inputs to the Baltic Sea reveal steady statistically significant reduction of 27% from 1995 to 2015 (Results figure 2). Correspondingly, from 1995 to 2015 phosphorus inputs also show steady significant decrease to Kattegat (17%). Break points were detected when evaluating the trend in the time series for the remaining six sub-basins. With the exception of Gulf of Finland, for the other five sub-basins there are significant decreases in total phosphorus inputs in the first section of the time series: Baltic Proper 21% (1995 to 2012), Bothnian Bay 17% (1995 to 2002), Bothnian Sea 19% (1995 to 2002), Danish Straits 31% (1995 to 2000), and for Gulf of Riga an **increase** with 15% (1995 to 2007). Since the reference period, no statistical significant trend are detected in the total phosphorus input to the Gulf of Riga due to rather high uncertainty caused by high inter-annual variability in the reported phosphorus input data. Concentrations of phosphorus monitored in river Vistula were exceptionally high in 2014. This single anomaly caused a break point in the time series for total phosphorus input to the Baltic Proper in 2012 and statistically insignificant trend in the last four years. A statistically significant decrease of 67 % is detected in total phosphorus inputs from 2009 to 2015 to Gulf of Finland, probably connected to abrupt changes of inputs due to measures on point sources in the Russian catchment. There is large inter-annual variation due to a) uncertain data prior approximately 2009 prevented efficient flow normalization and b) an abrupt reduction of point source inputs. This results in very high uncertainty in the total phosphorus inputs to the Gulf of Finland (56 % according to Results table 1b).

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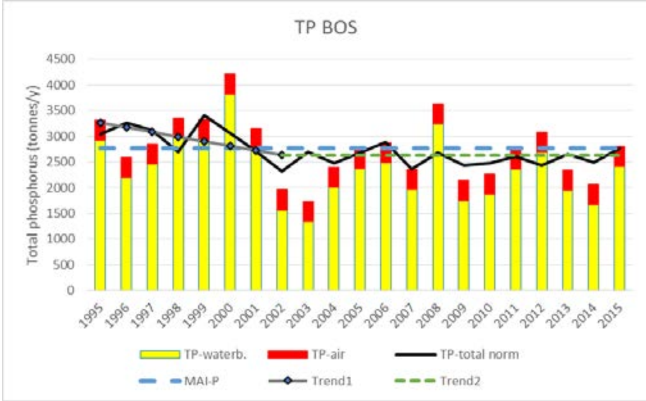
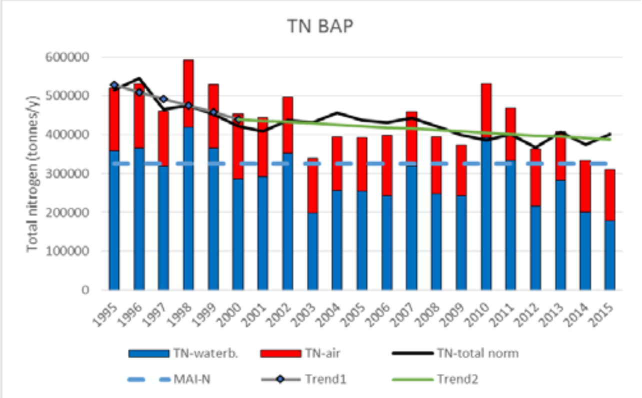
Total nitrogen (tonnes/y)
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2


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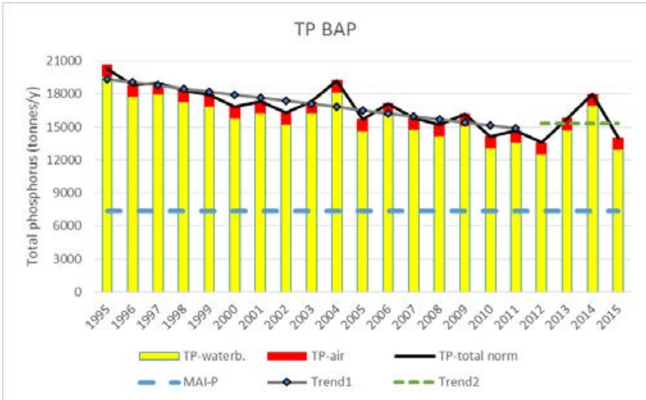
Total nitrogen (tonnes/y)
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2


TP BAP
Total phosphorus (tonnes/y)
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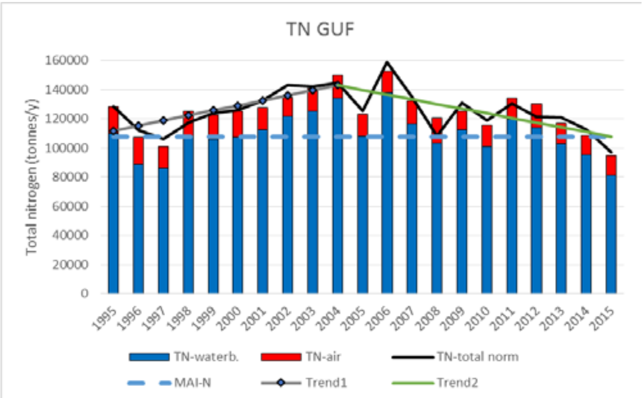
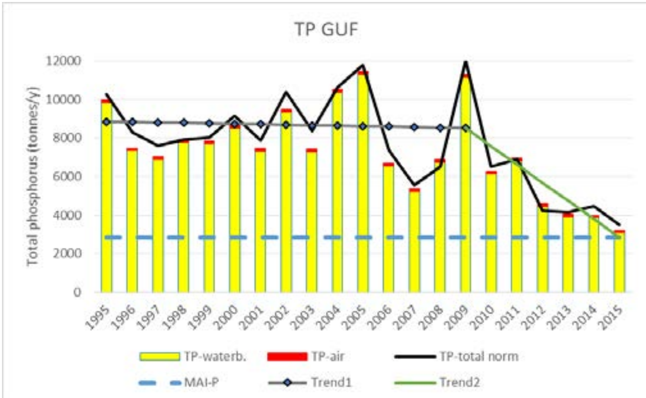

TN GUF
Total nitrogen (tonnes/y)
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2


TP GUF
Total phosphorus (tonnes/y)
TP-waterb.
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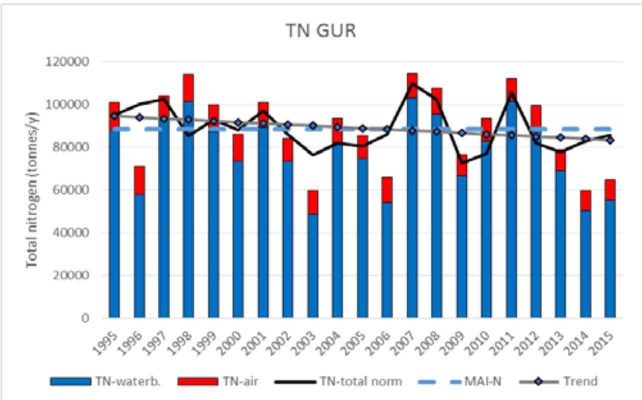
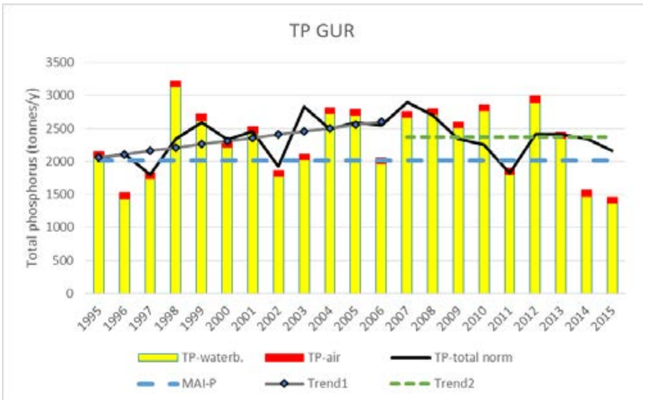
MAI-P
Trend1
Trend2


TN GUR
Total nitrogen (tonnes/y)
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend


TP GUR
Total phosphorus (tonnes/y)
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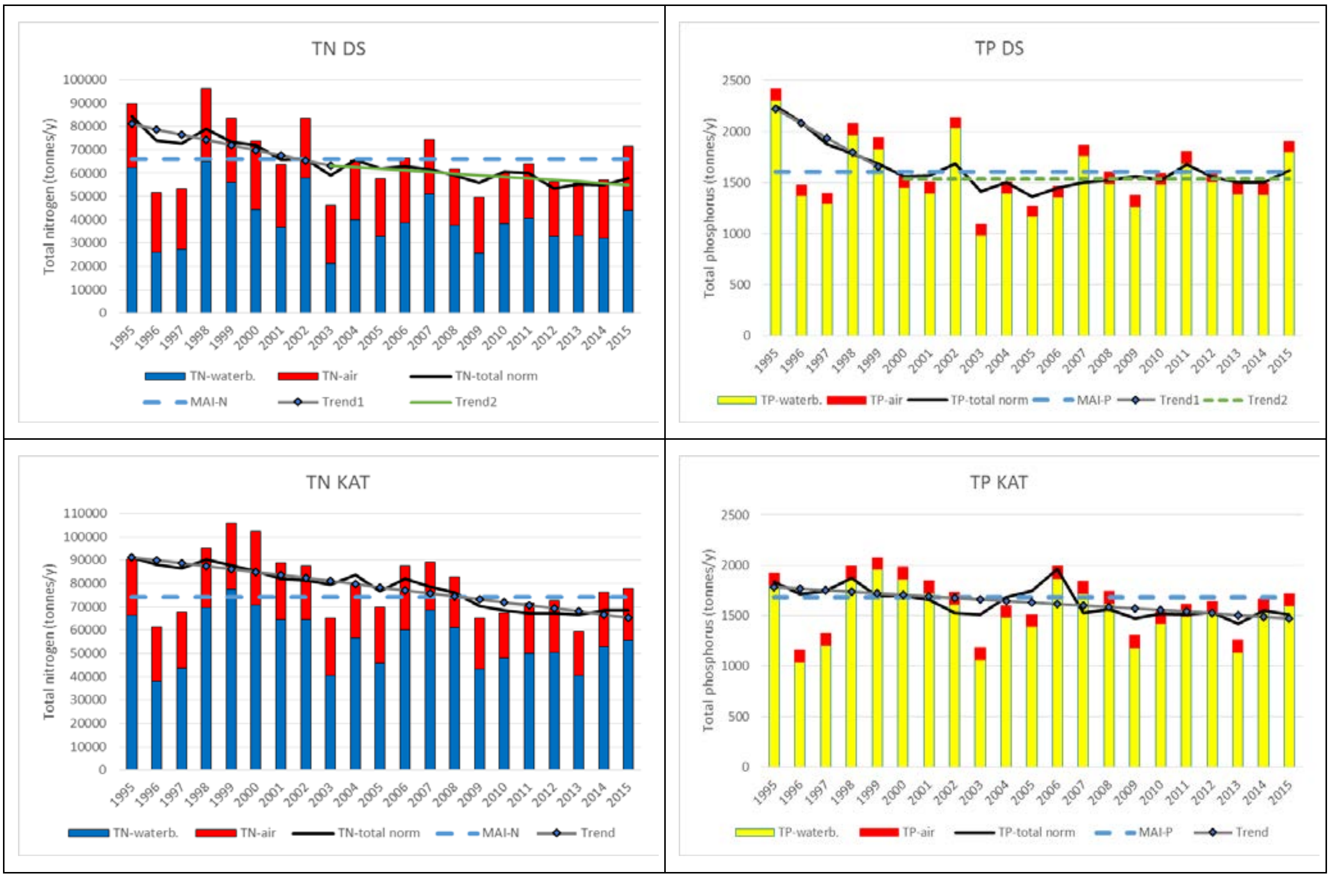
MAI-P
Trend1
Trend2



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 2015 (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 with markers. In cases when a break point divides the trend to 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 - 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.

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 2. Difference in annual average normalized air- and waterborne inputs of nitrogen in 1995 and 2015 in percent.

Sub-basin	Change in airborne N inputs since 1995 (%)	Change in waterborne N inputs since 1995 (%)
Bothnian Bay	**-27**	4,8
Bothnian Sea	**-28**	-1,1
Baltic Proper	**-27**	**-20**
Gulf of Finland	**-24**	-24
Gulf of Riga	**-27**	-6,8
Danish Straits	**-26**	**-35**
Kattegat	**-30**	**-23**
Total Baltic Sea	**-27**	**-18**

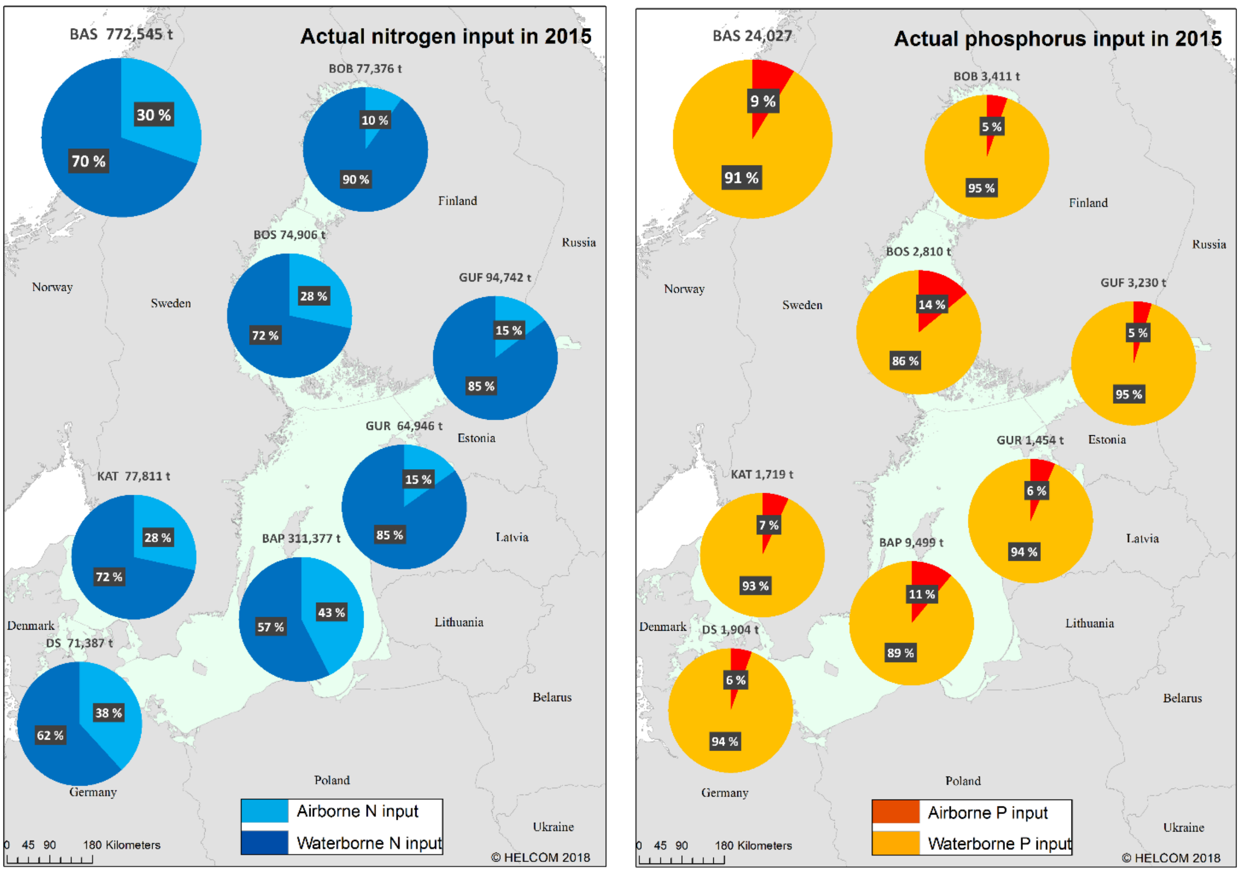
Airborne nitrogen deposition on the Baltic Sea is a major nitrogen source, and therefore the input of nitrogen has been divided in airborne and waterborne inputs, to evaluate changes in these major pathways separately. Airborne input of nitrogen to the Baltic Sea in 2015 shows statistically significant reduction of 27% since 1995 (Results table 2). This reduction slightly varies between sub-basins from 24% to the Gulf of Finland up to 30% to Kattegat. In comparison to airborne deposition, waterborne input of nitrogen to the Baltic Sea has been significantly reduced by about 18% since 1995. This reduction varies widely between sub-basins. Statistically significant reduction of waterborne input was found for Danish Straights (35%), Kattegat (23%) and Baltic Proper (20%). Reduction of waterborne input to other sub-basins is not statistically significant including the 24% reduction to the Gulf of Finland. Waterborne input of nitrogen to the Bothnian Bay has slightly increased by 2015. But this change is also within statistical deviation.

Actual airborne and waterborne inputs in 2015

In 2015, the average water flow was about the same as average for the year 1995-2015 (1% lower). Flow lower than average was observed to the Gulf of Riga (33%) and to the Baltic Proper (30%). On the other hand, the flow to the Kattegat (9%), Danish Straits (22%) and Bothnian Bay (30%) was comparatively higher than average for the considered period. The total input of nitrogen was about 773,000 tonnes, and the portion of atmospheric deposition was about 30%. The total phosphorus input to the Baltic Sea in 2014 was about 24,000 tonnes with a contribution of atmospheric deposition by about 9% (Results table 3 and 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 2015. Average flow 1995-2015 is shown for comparison.

Sub-basin	Average flow 1995-2015 (m^3/s)	Flow 2015 (m^3/s)	Nitrogen 2015 (t)			Phosphorus 2015 (t)		
			Waterborne	Airborne	Total	Waterborne	Airborne	Total
Bothnian Bay	3444	4486	69776	7600	77376	3229	181	3411
Bothnian Sea	2966	3277	53706	21200	74906	2416	394	2810
Baltic Proper	3518	2558	178877	132500	311377	8452	1046	9499
Gulf of Finland	3494	3137	80942	13800	94742	3080	150	3230
Gulf of Riga	1080	720	55146	9800	64946	1361	93	1454
Danish Straits	225	274	44087	27300	71387	1799	105	1904
Kattegat	1104	1201	55711	22100	77811	1601	118	1719
Total	**15831**	**15654**	**538245**	**234300**	**772545**	**21939**	**2088**	**24027**



Results figure 3. The total actual inputs of water- and airborne nitrogen (left) and phosphorus (right) to the Baltic Sea in 2015.

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.

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 improved scientific basis and models, and were adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a).

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 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 were 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

Annually reported data on riverine and directs inputs are quality assured and approved by national data reporters and data assurers. Assessment dataset for 1995-2015 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 aggregated and normalized for sub-basin. EMEP delivered actual and climate normalize annual nitrogen deposition data. 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).

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 2013, and in document "Comparison of methods applied to evaluate progress towards CARTS and fulfilment of national inputs ceilings" for CART WS 1-2017). 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 (see document 6-1, HELCOM PLC-7 1-2017. 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. It is tested if the trend in the segment are significant, and if the trend are significant in the latest sections a linear regression model are used to estimate the annual input values in 2015. If there is no significant trend the estimated values in 2015 is the average of the normalized annual inputs in the time series after the break point if any.

The evaluation of MAI fulfilment is based on comparing MAI for each basin and the Baltic Sea with the trend estimated normalized annual total nitrogen and phosphorus inputs in 2015 including uncertainty on these inputs (Table 2) (described in document "Comparison of methods applied to evaluate progress towards CARTS and fulfilment of national inputs ceilings" for CART WS 1-2017 . In the first and second evaluation of MAI fulfilment uncertainty of average of respectively 2010-2012 and 2912-2014 normalized inputs was estimated from the variation of the 3year inputs around the average.

Student t-test is used testing for significant difference in the trend estimated input and inputs in the reference period (average of normalized annual inputs 1997-2003).

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

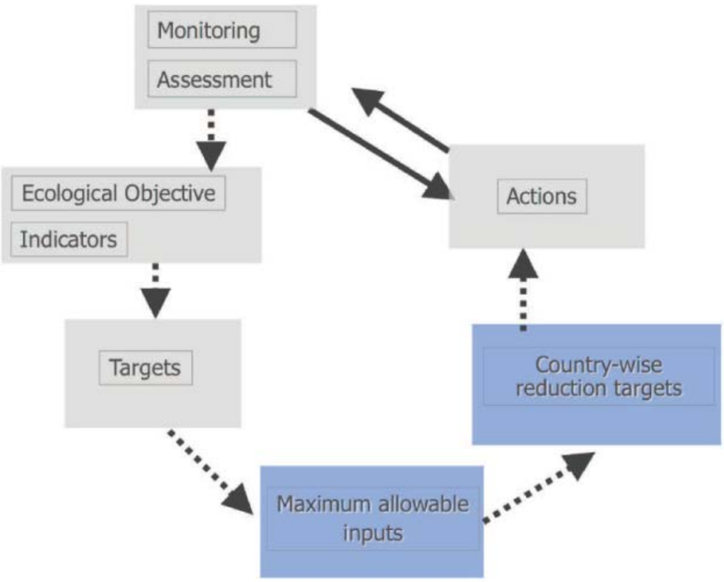
Holistic assessment

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 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 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.

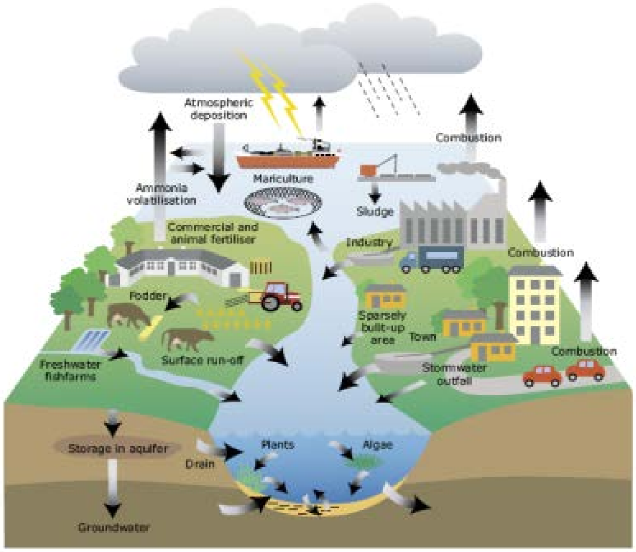
Reducing the effects of human-induced eutrophication is the stated goal of Descriptor 5 in the EU Marine Strategy Framework Directive (MSFD). The indicator is an important part in following up the effectiveness of the measures taken to achieve GES under this Descriptor. Inputs of nutrients to the Baltic 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 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 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. 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 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 & Mörth, 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 First version of the 'State of the Baltic Sea' report (HELCOM 2017).

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 km^2 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 2014].

Sub-basin	Number of rivers	Monitored area (km²)	Monitored area (% of total area)	Total N monitored (%)	Total N unmonitored (%)	Total N direct (%)
Bothnian Bay	22	237331	89	89	4	7
Bothnian Sea	15	191043	87	80	14	6
Baltic Proper	45	521451	90	88	10	2
Gulf of Finland	22	480315	96	91	1	8
Gulf of Riga	7	124873	88	85	14	1
Danish Straits	74	13099	48	38	56	6
Kattegat	39	74907	86	66	31	3
Baltic Sea	**224**	**1643018**	**83**	**86**	**10**	**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 2014].

Sub-basin	Number of rivers	Monitored area (km²)	Monitored area (% of total area)	Total P monitored (%)	Total P unmonitored (%)	Total P direct (%)
Bothnian Bay	22	237331	89	89	4	7
Bothnian Sea	15	191043	87	79	11	10
Baltic Proper	45	521451	90	94	3	3
Gulf of Finland	22	480315	96	91	0	9
Gulf of Riga	7	124873	88	86	11	3
Danish Straits	72	13099	48	29	50	21
Kattegat	39	74907	86	64	30	6
Baltic Sea	**222**	**1643018**	**83**	**88**	**7**	**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 86% and 96% 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 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-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 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 (2018) Inputs of nutrients to the subbasins. HELCOM core indicator report. Online. [Date Viewed], [Web link].

ISSN 2343-2543

Metadata

Data on air- and waterborne nutrient inputs from 1995 to 2015 are used in this indicator. Data reporting has not been perfect and gaps exist in the dataset. For waterborne inputs, the PLC6 project corrected suspicious data and filled in data gaps for 1995-2014 to establish a complete and consistent dataset. 2015 data has been added and assessed by BNI, Stockholm University and DCE, Aarhus University [Reference to the dataset when the indicator is published]. 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 subbasins - 2018 indicator version.

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 water- and airborne inputs are available from 1995-2015 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-6 project. New regional intercalibration has been perform in early 2018 by the PLC-7 project and the result will be publish later in 2018.

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 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 1995-2015 (see. Trend analysis and statistical processing).

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.

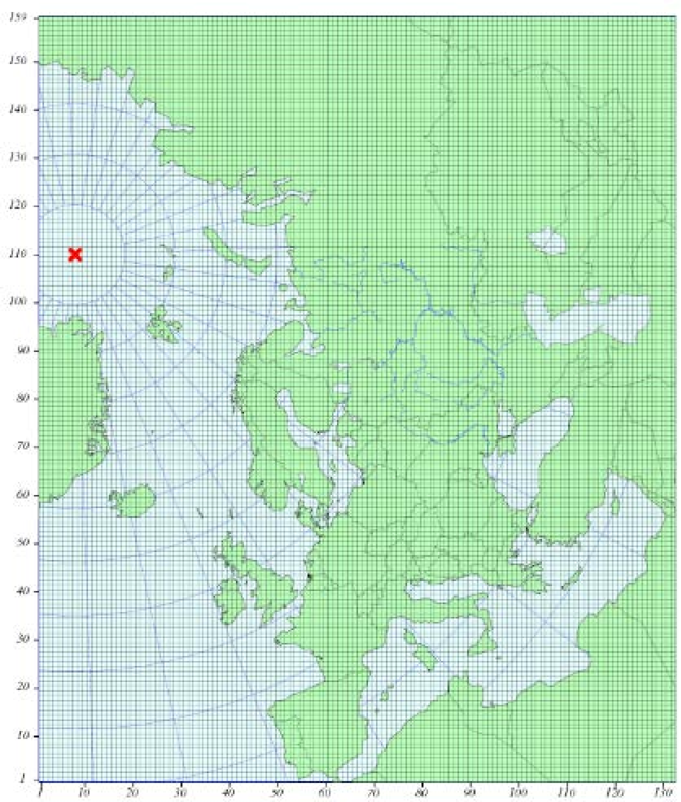
Compared with the first evaluation of MAI fulfilment (Svendsen et al. 2015), EMEP has implemented revised models and used updated emissions figures. This lead to revised inputs on normalized nitrogen air deposition to Baltic for 1995-2012, increasing the annual deposition to the Baltic Sea with between 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 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 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 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 coast line 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 30% 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 has in cooperation with Reduction Scheme Core Drafting Group, RedCore DG elaborated the present core pressure indicator on nutrient inputs.

Contributors and references

Contributors

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Archive

This version of the HELCOM core indicator report was published in July 2018:

Inputs of nutrients to the subbasins HELCOM core indicator 2018 (pdf)

Earlier versions of the core indicator:

HOLAS II component - Core indicator report – web-based version July 2017 (pdf)

Core indicator – web-based report 2015 (pdf)

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