Baltic Sea Environment Proceedings No. 128A

Fifth Baltic Sea Pollution Load Compilation (PLC-5) An Executive Summary

Helsinki Commission

Baltic Marine Environment Protection Commission

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Content

Preface

Since the establishment of the Convention for the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) in 1974, the Commission for the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Commission or HELCOM for short) has been working to reduce the loads of nutrients to the sea. Through coordinated monitoring, HELCOM has, since the mid-1980s been compiling information about the magnitude and sources of nutrient loads into the Baltic Sea. By regularly compiling and reporting load data, HELCOM is able to follow the progress towards reaching politically agreed goals, such as the 50% reduction target in the loads of nutrients and hazardous substances by 1995 as agreed in the 1988 HELCOM Ministerial Declaration. The first Baltic Sea Pollution Load Compilation (PLC-1) was published in 1987.

In 2007, the HELCOM Baltic Sea Action Plan (BSAP)[1] was adopted by the Baltic Sea coastal countries and the European Community. The BSAP has the overall objective of reaching a Baltic Sea in good environmental status by 2021, by addressing the issues of eutrophication, hazardous substance, biodiversity and maritime activities. The BSAP acknowledges that the maximum annual nutrient input to the Baltic Sea that can be allowed and still make it possible to reach good environmental status with regard to eutrophication is about 21,000 tonnes of phosphorus and 600,000 tonnes of nitrogen, based on modeled calculations by the Baltic Nest Institute (BNI) – Sweden. BNI also estimated the necessary nutrient reductions at the sub-basin level (see **table 4-1**). In the BSAP, the shared responsibility to reach these nutrient reductions targets has been divided to the HELCOM countries through a nutrient reduction allocation scheme based on the polluter pays principles (see **table 4-2**).

The EU Water Framework Directive, WFD (2000/60/EC), and EU Marine Strategy Framework Directive, MSFD (2008/56/EC), also require good environmental status of coastal and open sea areas in Europe, respectively. Reaching the environmental goals of BSAP, WFD and MSFD is possible only by identifying the most cost effective measures to reduce pressures on the marine environment. As concerns reducing eutrophication and hence water- and airborne loads of nutrients, this can only be done if the sources and magnitude of nutrient pollution are known. This is why HELCOM pollution load compilation (PLC) data is of such great importance. High quality, complete and consistent PLC data is also a pre-requisite for being able to follow the progress of the HELCOM countries in reaching their BSAP nutrient reduction targets.

This report summarizes and combines the main results of the Fifth Baltic Sea Pollution Load Compilation (HELCOM 2011) - which covers waterborne loads to the sea - and data on atmospheric loads which 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.

The PLC 5.5 project[2] will provide updated, corrected and more complete information on pollution loads, including new data for 2009 and 2010. The additional information might change the data on inputs of nitrogen and phosphorus to some sub-basins of the Baltic Sea and thus may also change the conclusions presented in chapter 4 regarding whether changes in nitrogen or phosphorus loads are statistically significant or not. The PLC-5.5 project report is planned to be presented to the HELCOM Ministerial Meeting in 2013.

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[1] http://www.helcom.fi/BSAP/ActionPlan/en_GB/ActionPlan/

[2] Project for the review of the Fifth Baltic Sea Pollution Load Compilation for the 2013 HELCOM Ministerial Meeting (HELCOM PLC-5.5) – to be implemented during 2012-2013

1 Introduction

Eutrophication is one of the main environmental problems facing the Baltic Sea. Since the early 1900s, the Baltic Sea has become increasingly eutrophied as a result of increasing inputs of the nutrients *nitrogen* and *phosphorus* from anthropogenic activities in the catchment area and at sea.

Nitrogen and phosphorus are the main growth limiting nutrients and as such do not pose any direct hazards to marine organisms, however, high nutrient concentrations in the aquatic environment stimulate growth of algae which leads to imbalanced functioning of the ecosystem. The intense algal growth is manifested as an excess of filamentous algae and phytoplankton blooms and generally a production of excess organic matter. At the end of summer the algae die and are decomposed by oxygen consuming bacteria, resulting in oxygen depleted waters and consequently death of benthic organisms, including fish.

The total Baltic Sea catchment area comprises approximately 1,720,000 km^2, of which nearly 93% is within the borders of the nine HELCOM Contracting Parties[3] and 7% lies within the territories of four Non-Contracting Parties[4]. **Figure 1-1** shows the main sub-basins of the Baltic Sea. Of these, the sub-basin catchment areas of the Baltic Proper and the Gulf of Finland are the largest, covering 575,000 km^2 and 413,000 km^2, respectively, and the Archipelago Sea has the smallest catchment area, covering 9,000 km^2 (**table 1-1**). Over 85 million people live within the Baltic Sea catchment area. Human populations as well as anthropogenic activities such as agriculture and industry contribute the majority of nutrient input to the Baltic Sea. For more information see the Fifth Baltic Sea Pollution Load Compilation (HELCOM 2011).

Figure 1-1 Land cover, catchment area and sub-basins of the Baltic Sea.

Table 1-1 Population and surface areas of the Baltic Sea catchment and sub-regions as well as total run-off in 2006.

Sub-region	Population (thousands)	Terrestrial surface area (km^2)	Marine surface area (km^2)	Run-off in 2006 (m^3 s^{-1})
Bothnian Bay	1,370	260,675	37,200	2,890
Bothnian Sea	2,250	220,765	63,000	2,730
Archipelago Sea	530	9,000	14,100	80
Gulf of Finland	12,320	413,100	29,600	2,750
Gulf of Riga	3,820	127,840	18,800	890
Baltic Proper	54,990	574,545	207,200	2,920
Danish Straits	6,170	27,365	10,500	240
The Kattegat	3,820	86,980	22,000	1,120
Total	**85,640**	**1,720,270**	**402,400**	**13,620**

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[3] The Contracting Parties to the 1992 Helsinki Convention are Denmark, Estonia, European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden.

[4] Belarus, Czech Republic, Norway, Slovakia and Ukraine

1.1 Pathways and sources of nutrient inputs

The land-based nutrient inputs entering the Baltic Sea are either airborne or waterborne (**figure 1-2**). The main *pathways* of nutrient input to the Baltic Sea are:

- direct atmospheric deposition on the Baltic Sea water surface;
- riverine inputs of nutrients to the sea. Nutrients entering inland surface waters within the Baltic Sea catchment area are transported by rivers to the sea;
- point sources discharging directly to the sea;
- influx of nutrients from North Sea and Skagerrak to the Baltic Sea (not included in this report).

The different *sources* for the inputs of nitrogen and phosphorus are from:

- atmospheric emissions of airborne nitrogen compounds emitted mainly from traffic or combustion for heat and power generation, industrial processes, and from animal manure and husbandry;
- point sources including inputs from municipalities, industries and fish farms discharging both into inland surface waters and directly into the Baltic Sea;
- diffuse sources, mainly from agriculture, but also nutrient losses from *e.g.* managed forestry and rural areas. Losses from scattered dwellings and storm water overflows are also included under diffuse sources;
- and natural background sources, mainly natural erosion and leakage from unmanaged areas as well as the corresponding nutrient losses from *e.g.* agricultural and managed forested land that would occur irrespective of human activities.

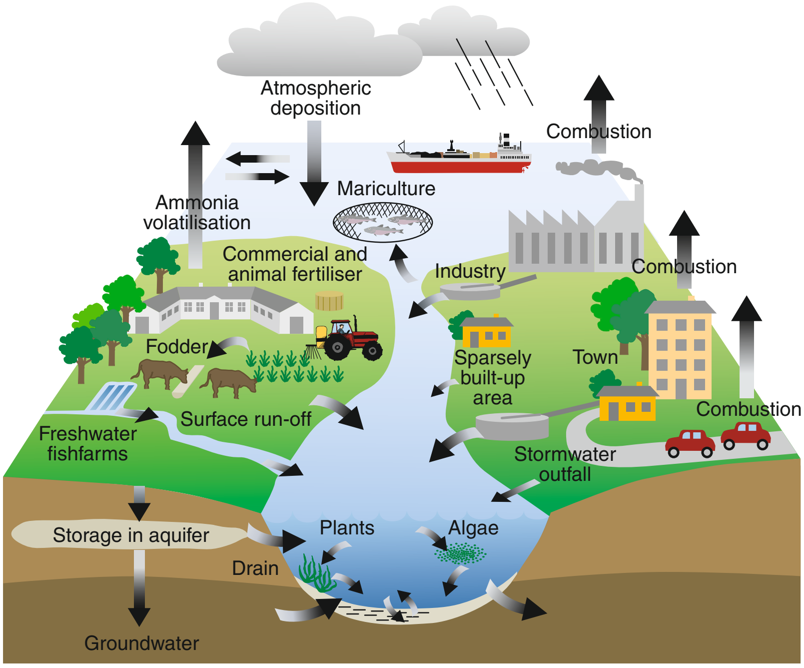


Figure 1-2 Different sources of nutrients to the sea and examples of nitrogen and phosphorus cycles. The flow related to ammonia volatilization shown in the figure applies only to nitrogen. In this report, also combustion and atmospheric deposition deal only with nitrogen. Emissions of phosphorus to the atmosphere by dust from soils are not shown in the figure. (Source: Ærtebjerg et al. 2003).

Phosphorus enters the Baltic Sea mainly as waterborne input, but can also enter as atmospheric deposition. However, it has been estimated that the airborne contribution is only 1-5% of the total phosphorus input and therefore, atmospheric deposition of phosphorus is not considered in this report.

A large part of the nutrient load to the Baltic Sea originates from outside the HELCOM area. Distant sources contribute a significant portion of atmospheric loads in particular. As indicated in **figure 1-2**, nutrients are transferred to inland waters in several ways and thereafter affected by a variety of processes. Rainfall and subsequent river run-off, as well as groundwater inflow to inland surface waters, are important controlling factors determining the actual amounts of nutrients entering the Baltic Sea. Biological, physical, morphological, and chemical factors also retain and/or transform nutrients within river systems before they enter into the sea.

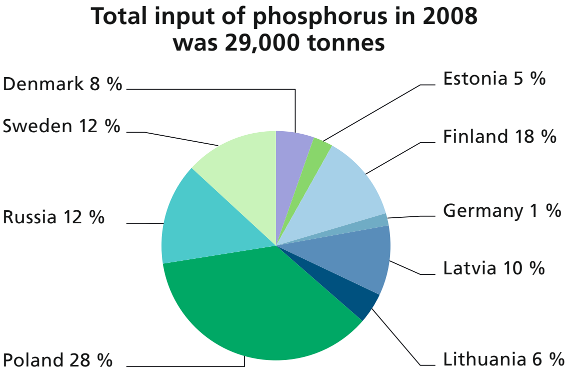
Another cause for increased nutrient levels in the sea, especially in the case of phosphorus, is the "internal load" - phosphorus pools accumulated in the sediments of the sea bed are released back to the water under anoxic conditions. Neither this internal load, nor the amount of nitrogen fixed by cyanobacteria or blue-green algae, is considered in this report.

2 Total nutrient inputs to the Baltic Sea in 2008

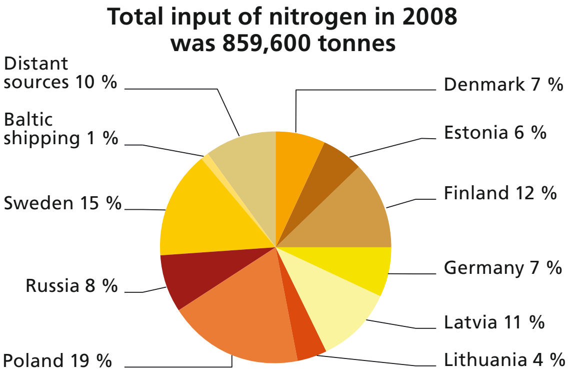
In 2008 the total input of phosphorus and nitrogen to the Baltic Sea was 29,000 tonnes and 859,600 tonnes respectively. Nitrogen supply via direct atmospheric deposition amounted to 207,400 tonnes, or 24% of the total input. The waterborne part of nitrogen input was 652,100 tonnes (**table 2-1**). The contributions of the HELCOM countries to the total inputs of phosphorus and nitrogen to the Baltic Sea are shown in **figures 2-1 a, b**. When interpreting the nutrient input figures for the year 2008, it should be noted that, compared to the long term average, precipitation was rather high that year over the Baltic Sea catchment area and was especially high in the northern parts of the Baltic Sea, which resulted in increased atmospheric deposition for the whole Baltic Sea and an unusually high proportion of nutrient inputs from Finland.

Of the total input of phosphorus to the Baltic Sea in 2008, the greatest contributors were Poland (28%), Finland (18%), Russia (12%) and Sweden (12%). For nitrogen, the greatest contributors are Poland (19%), Sweden (15%) and Finland (12%). Minor parts of the loads from Estonia and Sweden include contributions from neighboring HELCOM Contracting Parties via bordering rivers. There are also transboundary waterborne loads originating from outside HELCOM countries, i.e. from Belarus, Czech Republic, Norway, Slovakia and Ukraine. The largest portion of transboundary waterborne nutrient load to the Baltic Sea originates from Belarus and drains via Latvia and Lithuania. Furthermore, one tenth of the total nitrogen input to the Baltic Sea originates from distant sources outside HELCOM countries, from where it is transported as air pollution and deposited directly on the sea (**figure 2-1 b**).

The annual nutrient inputs to the sea are expressed as total amounts per country and subbasin. In addition to the total supply of nutrients to the sea, the environmental effects of the nutrients are also determined by their chemical form and the pathway of entering. Inorganic forms of nitrogen and phosphorus are normally readily available for algae, whereas e.g. organic nitrogen leached from coniferous forest areas is considered to have low bioavailability. Another aspect to consider is that considerable amounts of waterborne nutrients may be retained in coastal waters and thus not reach the open sea, as opposed to nitrogen deposited via the atmosphere.



a)



b)

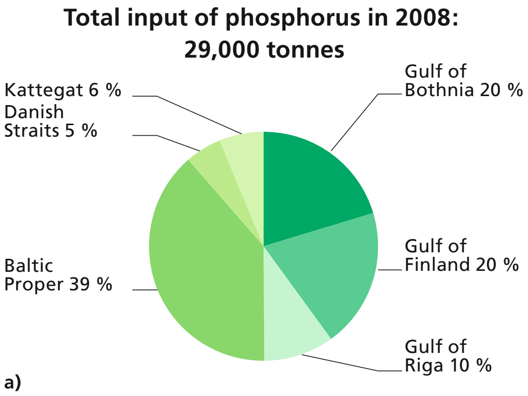
Figure 2-1 a,b **Total inputs of a) phosphorus and b) nitrogen (including waterborne and airborne loads) to the Baltic Sea in 2008.** ***Note that the waterborne inputs include transboundary loads. Baltic shipping and distant sources include only airborne inputs.*** **When interpreting the nutrient input figures for the year 2008, it should be noted that, compared to the long term average, precipitation was rather high that year over the Baltic Sea catchment area and was especially high in the northern parts of the Baltic Sea, which resulted in increased atmospheric deposition for the whole Baltic Sea and an unusually high proportion of nutrient inputs from Finland.**

Table 2-1 a, b Total runoff (water flow) as well as non-flow normalized water- and airborne inputs of phosphorus and nitrogen to the Baltic Sea in 2008 by a) country and b) sub-basin. *Note: the waterborne loads of Latvia, Lithuania, Poland and Sweden include transboundary loads. Baltic shipping and distant sources include only airborne inputs.* When interpreting the nutrient input figures for the year 2008, it should be noted that, compared to the long term average, precipitation was rather high that year over the Baltic Sea catchment area and was especially high in the northern parts of the Baltic Sea, which resulted in increased atmospheric deposition for the whole Baltic Sea and an unusually high proportion of nutrient inputs from Finland.

Country	Flow $(m^3 s^{-1})$	Phosphorus input (t)	Nitrogen input (t)		
			Water-borne	Airborne	Total
Denmark	425	2,200	43,000	16,000	59,000
Estonia	622	1,400	46,200	2,000	48,200
Finland	3,246	5,200	100,600	7,500	108,100
Germany	90	330	13,800	45,300	59,100
Latvia	818	2,900	90,000	2,000	91,900
Lithuania	461	1,700	32,800	2,400	35,200
Poland	1,559	8,100	144,500	21,700	166,200
Russia	2,795	3,600	60,800	8,000	68,800
Sweden	6,215	3,600	120,400	11,700	132,100
Baltic shipping				12,100	12,100
Distant sources				78,700	78,700
TOTAL		**29,000**	**652,100**	**207,400**	**859,600**

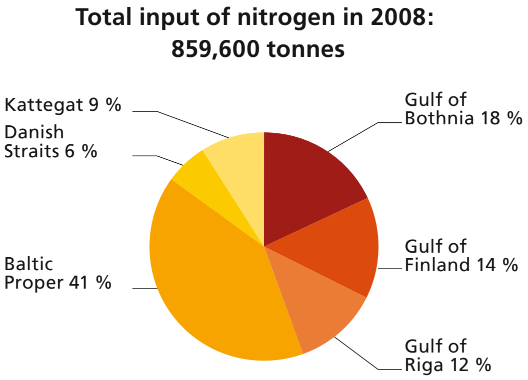
Sub-basin	Flow $(m^3 s^{-1})$	Phosphorus input (t)	Nitrogen input (t)		
			Water-borne	Airborne	Total
Gulf of Bothnia	6,969	5,900	124,700	30,000	154,700
Gulf of Finland	3,867	5,700	109,400	14,200	123,600
Gulf of Riga	819	2,900	94,200	9,600	103,800
Baltic Proper	2,928	11,200	232,400	116,500	348,900
Danish Straits	251	1,500	31,700	19,400	51,100
Kattegat	1,396	1,800	59,700	17,700	77,500
TOTAL	**16,230**	**29,000**	**652,100**	**207,400**	**859,600**

Of the Baltic Sea sub-basins, the Baltic Proper received by far the greatest proportion of nutrient inputs (**figures 2-2 a, b**). Of the 29,000 tonnes of phosphorus entering the Baltic Sea, almost 40% ended up in the Baltic Proper, 20% entered the Gulf of Bothnia and Gulf of Finland, and other sub-basins received from 5-10% of the total phosphorus input. For nitrogen, also the majority ended up in the Baltic Proper (41%) followed by Gulf of Bothnia (18%), Gulf of Finland (14%), Gulf of Riga (12%) and then Kattegat (9%) and Danish Straits (6%).



Total input of phosphorus in 2008: 29,000 tonnes

a)



Total input of nitrogen in 2008: 859,600 tonnes

b)

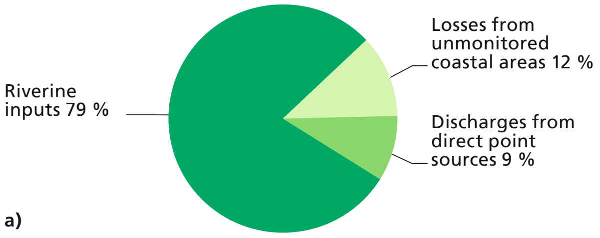
Figure 2-2 a,b Total water- and airborne inputs of a) phosphorus and b) nitrogen to the Baltic Sea by sub-basin in 2008. See notes in the caption of Figure 2-1 a-b.

3. Nutrient sources (2006)

HELCOM countries report, on an annual basis, their total waterborne loads of nitrogen and phosphorus from rivers, unmonitored and coastal areas as well as point sources discharging directly to the Baltic Sea. They also report emissions of nitrogen compounds to air as input for EMEP calculations of nitrogen deposition on the Baltic Sea. Although data on total nutrient input until 2008 was available for the PLC-5 project, this chapter is based on data for 2006. This is the latest year when sources have been quantified for source apportionment and monitoring carried out according to PLC-5 guidelines for the periodical (every 6 years) assessment.

In 2006, the total input of nitrogen to the Baltic Sea was 836,100 tonnes of which 637,900 tonnes entered the sea as waterborne loads and 198,200 tonnes via atmospheric deposition. The total waterborne input of phosphorus in 2006 was 28,400 tonnes and there is no estimate for airborne phosphorus deposition. The main pathway for inputs of nitrogen and phosphorus was riverine load, and the riverine input from small rivers also constitute the main source for losses from unmonitored and coastal areas (**figures 3-1 a, b**). Point sources such as municipalities, industries

Total phosphorus load in 2006:
28,400 tonnes



Total nitrogen load in 2006:
836,100 tonnes

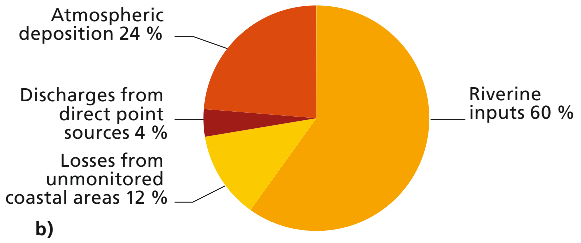


Figure 3-1 a,b Pathways of a) total phosphorus and b) total nitrogen inputs into the Baltic Sea in 2006. Atmospheric deposition of phosphorus is not estimated, but constitutes generally less than 5% of total phosphorus input to the Baltic Sea. *Note: the waterborne loads include transboundary loads.*

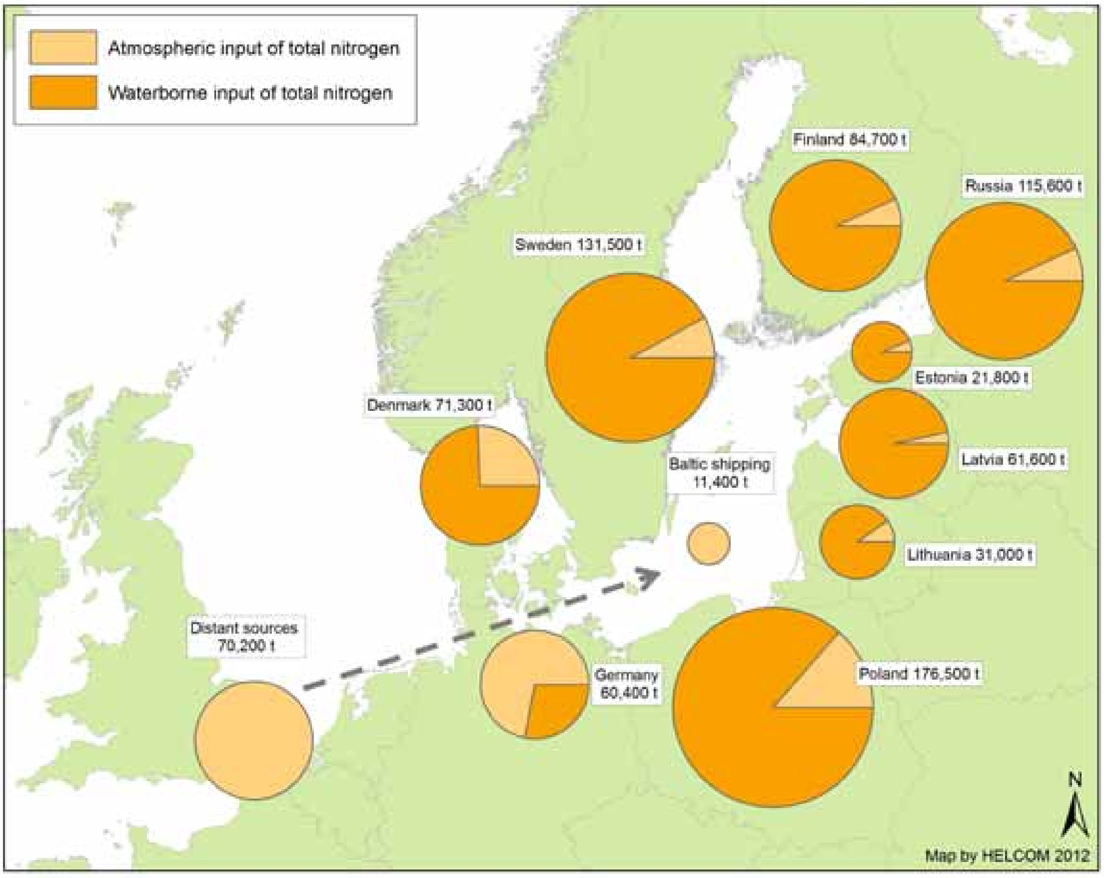


Figure 3-2 Total inputs of water- and airborne nitrogen from HELCOM countries, Baltic Sea shipping and distant sources to the Baltic Sea in 2006. *Note: the waterborne loads of Latvia, Lithuania, Poland and Sweden include transboundary loads.*

and fish farms discharging directly into the sea accounted for less than 10% of total phosphorus and 5% of total nitrogen loads in 2006, respectively. Total atmospheric deposition of nitrogen on the Baltic Sea accounts for nearly a quarter of total nitrogen supply, whereas atmospheric phosphorus deposition, although not calculated, is assumed to account for less than 5% of total phosphorus inputs.

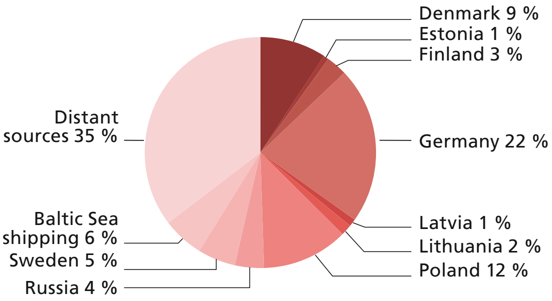


Figure 3-3 Contributions of HELCOM countries, Baltic Sea shipping and distant sources to the total atmospheric deposition of nitrogen to the Baltic Sea in 2006. (Data source: EMEP)

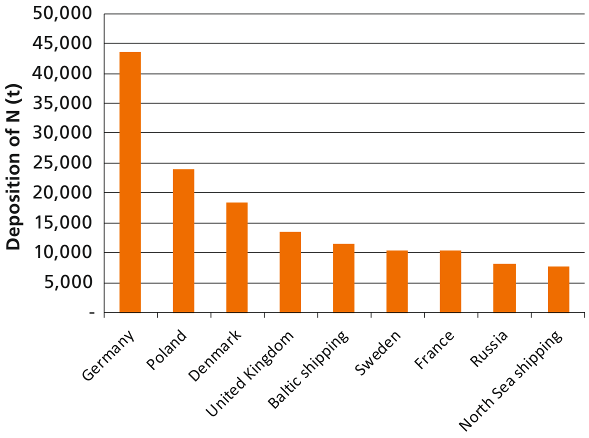


Figure 3-4 Top ten countries/sources with the highest contributions to the deposition of total nitrogen on to the Baltic Sea in 2006. (Data source: EMEP)

3.1 Sources of airborne inputs in 2006

Nitrogen compounds are emitted into the atmosphere as nitrogen oxides (NO_x) and ammonia (NH_3). Oxidized nitrogen (NOx) constitutes, in most years, the largest share of the total nitrogen deposited via the atmosphere to the Baltic Sea, up to around 55% on an annual basis. Combustion processes related to shipping, road transportation and energy combustion are the main sources of nitrogen oxides emissions in the Baltic Sea region, while agriculture generally contributes with 85-95% of the emitted ammonia (Bartnicki and Valiyaveetil 2009). While a major part of emitted nitrogen oxides are transported over long distances before being deposited, more ammonium is deposited relatively close to the emission source.

Of the 198,200 tonnes of nitrogen deposited to the Baltic Sea via the atmosphere in 2006, 59% originated from HELCOM countries (including areas in these countries not draining to the Baltic Sea), 6% originated from Baltic Sea shipping and 35% from distant sources outside the Baltic Sea region (**figure 3-3**). There is a southwest to northeast gradient in deposition, with the highest deposition in the southern and western part of the Baltic Sea due to dominant wind systems and the location of the main emission sources.

An assessment of the main contributors to the atmospheric deposition of total nitrogen to the Baltic Sea shows that Germany is by far the greatest contributor, followed by Poland and Denmark (**figure 3-4)**. The United Kingdom, a country outside the HELCOM region, was the fourth largest contributor of total atmospheric nitrogen deposited onto the Baltic Sea, followed by Baltic Sea shipping and Sweden. North Sea shipping was the tenth largest contributor.

3.2 Sources of waterborne inputs in 2006

In most countries the nutrient loads to inland waters are higher than the total waterborne input to the Baltic Sea. During transport from sources to the sea, processes in soils, groundwater and inland surface waters can retain, transform and release nutrients discharged from sources in the catchment. These processes are collectively called retention. Quantification of retention of nutrients in the catchment is necessary for evaluating the relative importance of nutrient sources discharging into inland surface waters. Furthermore, information on retention in the catchment, including retention in inland surface waters, is important for assessing the reduction of nutrient loads to the sea after implementation of mitigation measures directed towards inland sources.

Figures 3-5 a and **b** illustrate the retention (in %) of nitrogen and phosphorus in the gross riverine loads as reported by the HELCOM countries for the PLC-5 report. The reported retention figures refer to inland surface waters and in general they do not include retention in groundwater or soils. Therefore, in large catchments the total retention from losses from the root zone to the river mouth can be higher than those given in **figure 3-5** and as high as 90% for nitrogen. Overall, large catchments with a high percentage of lakes and wetlands and a high frequency of flooded river valleys generally have higher retention compared with small catchments, and those having high draining intensity and straightened river courses. Some lakes can have a net release of phosphorus due to former high loads of phosphorus to these lakes, and this is reflected e.g. by the negative Danish retention figures.

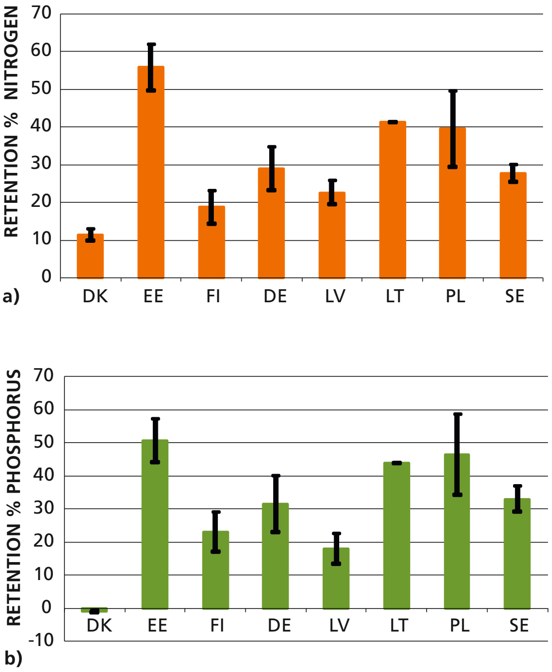
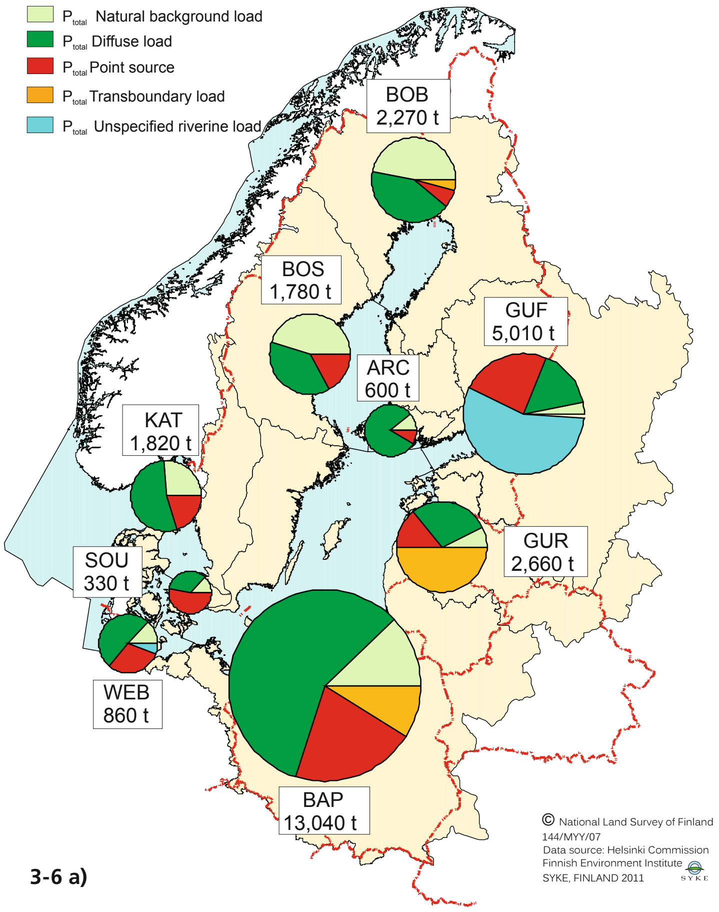


Figure 3-5 Retention (in %) of a) phosphorus and b) nitrogen in the gross riverine loads in 2006 by country. Average and maximum and minimum retention values reported by each country are shown. Retention is primarily estimated in inland surface waters.

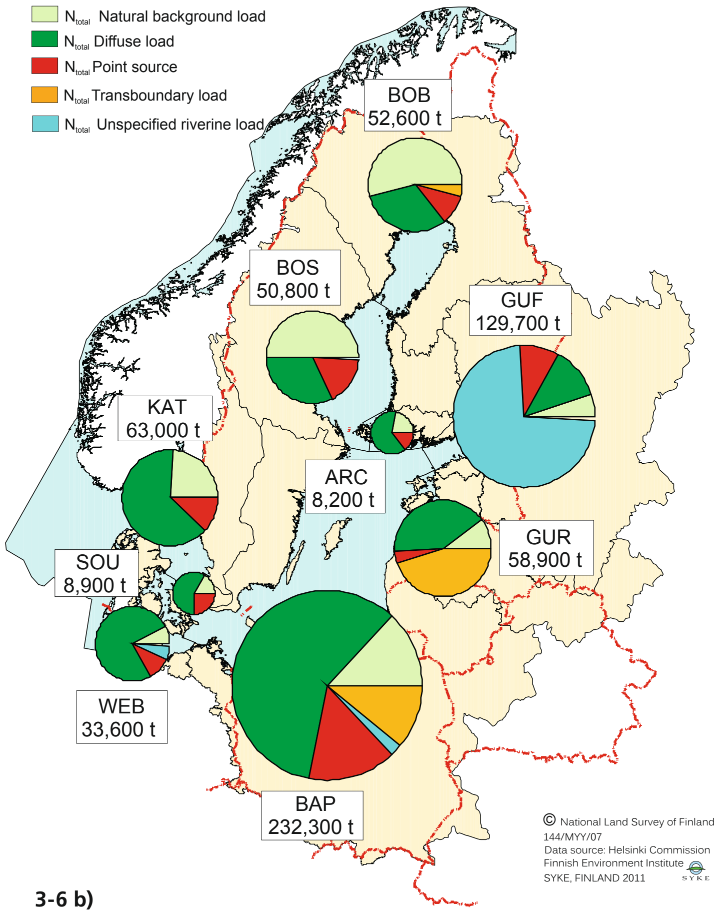
The results of riverine load apportionment indicate that in 2006 the largest share, at least 45% of the total inputs of both phosphorus and nitrogen into the Baltic Sea, originated from anthropogenic diffuse sources (**figure 3-6 a, b, 3-7 a, b** and **3-9 a, b**). Another diffuse source, the natural background load varies considerably among regions and countries, but constituted in average about 16% of the total phosphorus load and a bit more for nitrogen. It should be stressed that it is difficult to distinguish natural background sources from diffuse sources of anthropogenic origin, and thus the figures are considered uncertain. For parts of the Baltic Sea catchment no source apportionment is available (denoted as unspecified loads) and transboundary loads are also not source apportioned. For both these categories a major part of these loads is likely to originate from diffuse sources. Point sources discharged to inland waters and directly to the sea constituted less than 30% of the total waterborne phosphorus load, and less than 20% of the corresponding nitrogen load (**figure 3-9 a, b**).

The apportionment of anthropogenic diffuse sources performed for selected countries indicates that agriculture contributed on average about 60-70% of the reported total diffuse loads to the sea. In some countries, scattered dwellings, storm water and, for nitrogen, atmospheric deposition were also significant anthropogenic diffuse sources, although much smaller than agriculture (HELCOM 2011).

For both phosphorus and nitrogen, Poland contributed the largest portion of the waterborne inputs in 2006, with 36% and 24% of the total waterborne inputs respectively (**figures 3-8 a, b**) even though the Polish catchment (including transboundary catchment) constitutes only 18% of the whole Baltic Sea catchment (**figure 3-8c**). Sweden has 26% of the total Baltic Sea catchment area and 19% of total nitrogen and 13% of total phosphorus waterborne loads to the Baltic Sea, respectively. Germany, with the smallest



3-6 a)



3-6 b)

Figure 3-6 a, b Source apportionment of inputs of a) total waterborne phosphorus (P_{total}) and b) total waterborne nitrogen (N_{total}) (in tonnes) into the Baltic Sea by sub-region in 2006. Note that the figures for the Gulf of Finland (GUF) and the Western Baltic (WEB) also include unspecified riverine load.

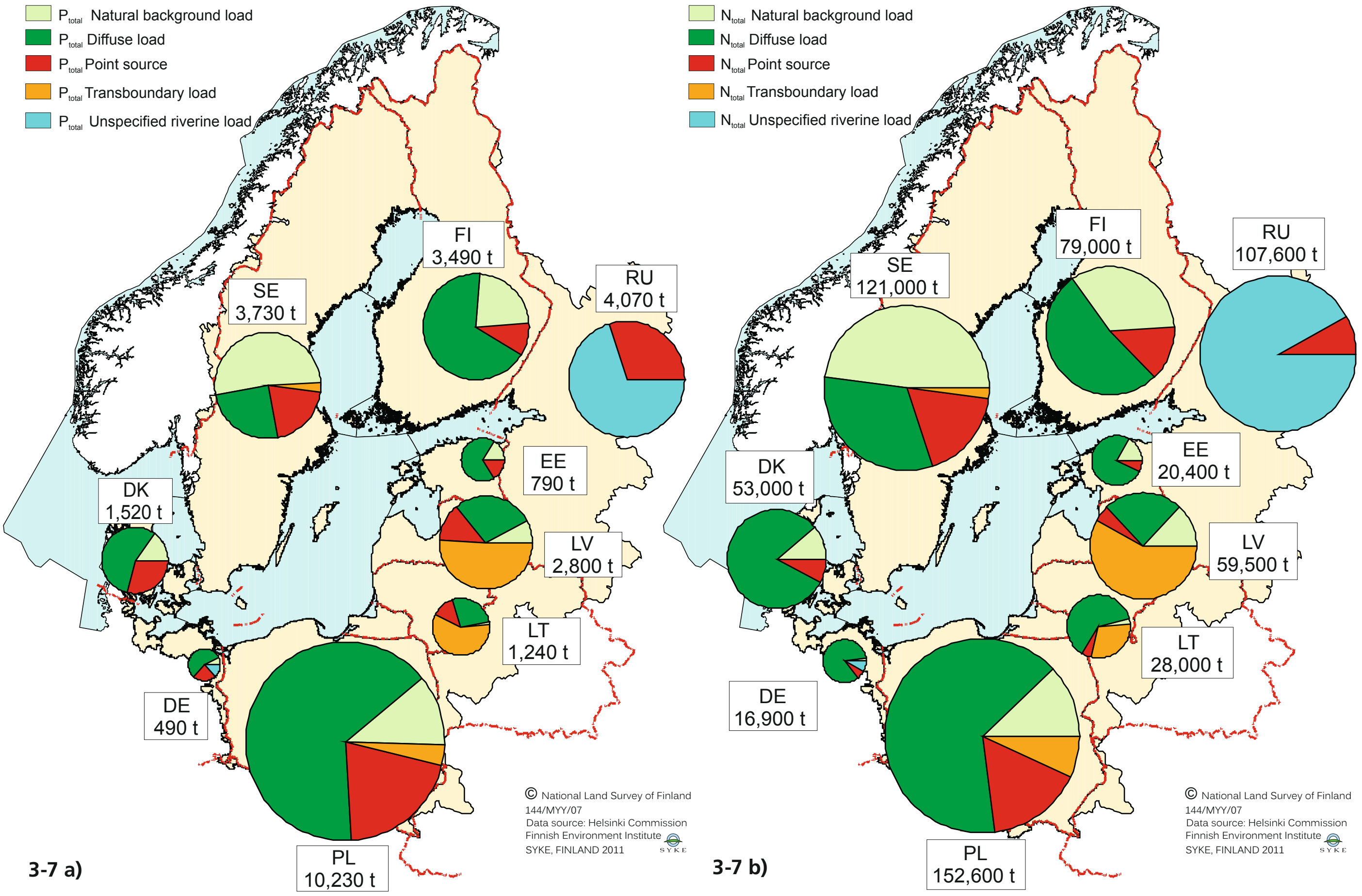


Figure 3-7 a, b Source apportionment of a) total waterborne phosphorus and b) total waterborne nitrogen loads (in tonnes) to the Baltic Sea by country in 2006. Note that the figures for Russia and Germany also include unspecified riverine loads.

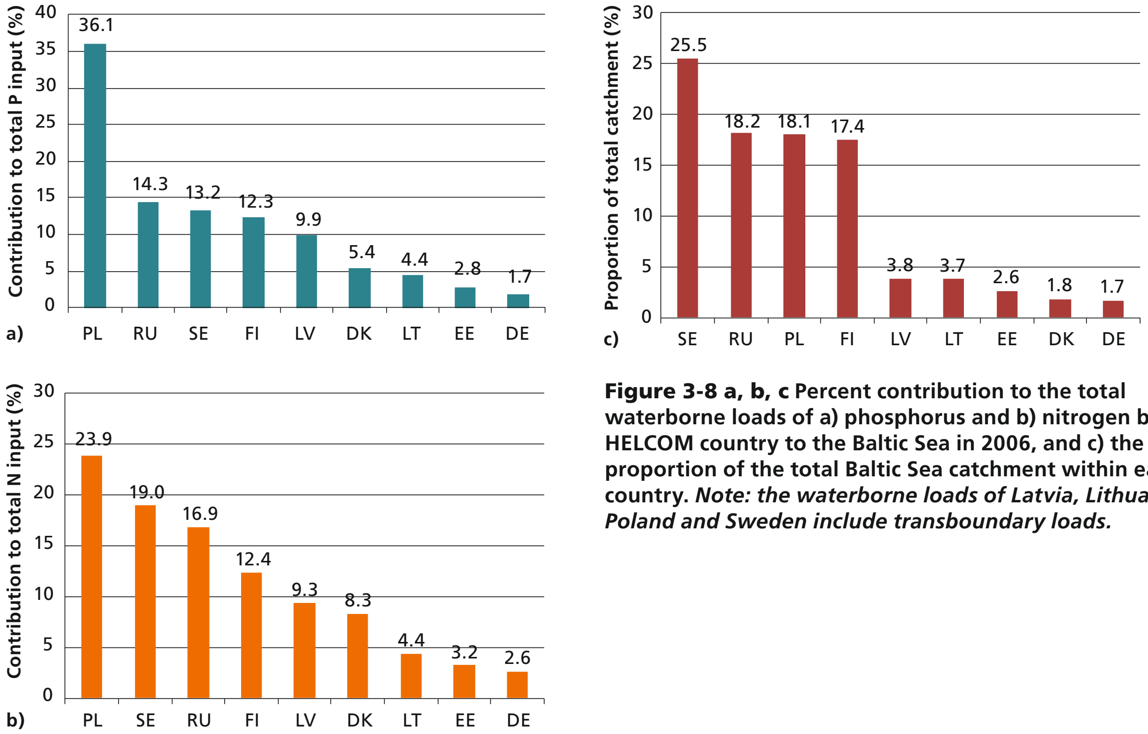


Figure 3-8 a, b, c **Percent contribution to the total waterborne loads of a) phosphorus and b) nitrogen by HELCOM country to the Baltic Sea in 2006, and c) the proportion of the total Baltic Sea catchment within each country.** ***Note: the waterborne loads of Latvia, Lithuania, Poland and Sweden include transboundary loads.***

proportion of the Baltic Sea catchment area, also contributed the smallest proportion of waterborne inputs of nutrients. Besides catchment size e.g. intensity of agriculture, population density, industrial activity, degree of wastewater purification, geology and hydrological conditions are important factors affecting the load from different sub-catchments and countries.

Point sources (wastewater from municipal treatment plants, industries and fish farms) are the second largest anthropogenic source of nutrients, with municipalities as the main source (90%) (**figure 3-9 a, b**). The transboundary load (mainly from Belarus) could not be divided into sources. HELCOM has estimated that the percentage of the total riverine load of nitrogen and phosphorus from Belarus to the HELCOM downstream countries is more than 5% of the total load to the Baltic Sea, without taking into account riverine retention (HELCOM 2005), but it is considerably less when taking into account retention.

The PLC-5 report also quantified the discharges and losses of nutrients from different sources into inland surface waters (gross load) in the Baltic Sea catchment area. Overall, the picture is similar for losses to inland surface waters per country and sub-region as for total waterborne loads to the sea. The largest nitrogen and phosphorus losses to inland waters were in Poland, Russia, Sweden and Finland. Transboundary load constituted the greatest proportion of inland sources in Latvia and Lithuania without taking into account retention. Considering all HELCOM countries, diffuse sources were the largest pathway, and agricultural activities accounted for the majority of the diffuse gross losses of nitrogen and phosphorus entering

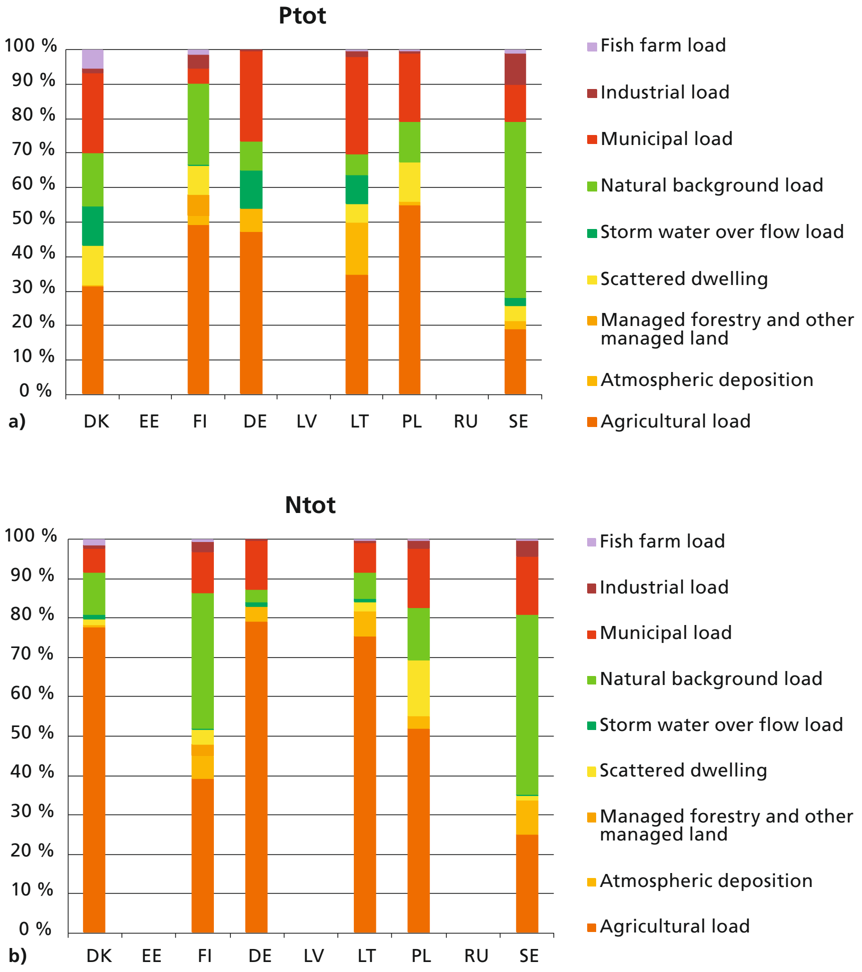


Figure 3-9 a,b Proportions of different sources contributing to the total waterborne inputs of phosphorus and nitrogen to the Baltic Sea in 2006.

inland surface waters. It should be stressed again that it can be difficult to distinguish natural background sources from other diffuse sources.

Area-specific nutrient loads, expressed as kg km^{-2}, make is possible to directly compare nutrient loads from different sub-regions and countries around the Baltic Sea, irrespective of the catchment size. Intensively cultivated sub-catchment areas with a relatively low proportion of wetlands have by far the highest area-specific diffuse losses of nitrogen into inland surface waters. High area-specific phosphorus loads are often related to high population densities (as in the Danish Straits catchment area) and extensive agricultural activity. Factors such as agricultural activity, soil type and geological features of the catchment areas (for example, around the Archipelago Sea), in combination with climatic factors and the occurrence of frozen soils and surface runoff, will also contribute to especially high area-specific phosphorus loads (**figures 3-10 a, b**). Further, the proportion of wastewater with efficient treatment and nutrient removal has a clear impact on the area-specific nutrient loads.

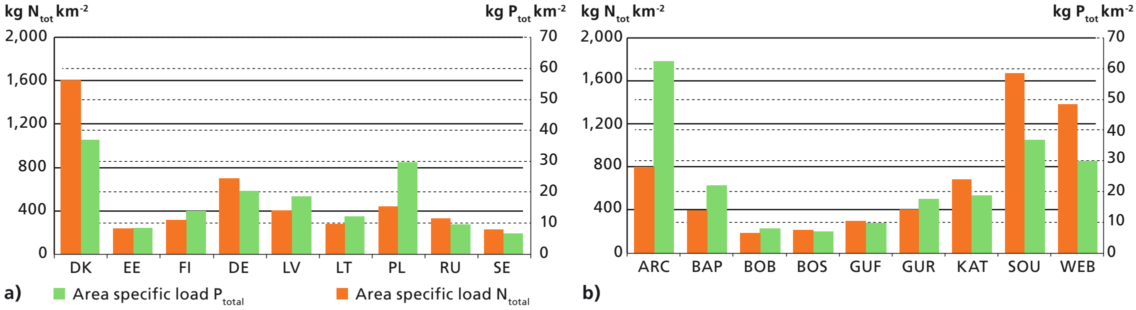


Figure 3-10 a-b **Area-specific load of nitrogen and phosphorus (kg km^{-2}) into the Baltic Sea by a) country and b) sub-region in 2006 (direct point sources not included).** ***Note: Phosphorus load of river Pregolya is missing. And the figures of Latvia, Lithuania, Poland and Sweden include transboundary loads.***

4. Long-term trends in emissions and inputs

As mentioned in the preface of this report, HELCOM Contracting Parties agreed, when adopting the HELCOM Baltic Sea Action Plan, to reduce their nutrient loads so that good environmental status of the Baltic Sea can be achieved by 2021 (HELCOM 2007). The maximum allowable nutrient inputs to the Baltic Sea sub-basins are shown in **table 4-1** and used as a basis to calculate provisional country-wise nutrient reduction allocations shown in **table 4-2.**

Table 4-1 The maximum allowable nutrient inputs (in tonnes per year) to each Baltic Sea sub-basin if good environmental status is to be reached and the corresponding necessary nutrient reductions as agreed upon in the HELCOM Baltic Sea Action Plan (BSAP). Note: P=phosphorus and N=nitrogen. Source: HELCOM 2007.

Sub-region	Maximum allowable input		Inputs in 1997-2003 according to BSAP 2007		Needed reductions	
	P	N	P	N	P	N
Bothnian Bay	2,580	51,440	2,580	51,440	0	0
Bothnian Sea	2,460	56,790	2,460	56,790	0	0
Gulf of Finland	4,860	106,680	6,860	112,680	2,000	6,000
Baltic Proper	6,750	233,250	19,250	327,260	12,500	94,000
Gulf of Riga	1,430	78,400	2,180	78,400	750	0
Danish straits	1,410	30,890	1,410	45,890	0	15,000
Kattegat	1,570	44,260	1,570	64,260	0	20,000
Total	**21,060**	**601,720**	**36,310**	**736,720**	**15,250**	**135,000**

Table 4-2 Country-wise provisional nutrient reduction requirements as agreed upon in the HELCOM BSAP. Source: HELCOM 2007.

Country	Phosphorus ($t\ a^{-1}$)	Nitrogen ($t\ a^{-1}$)
Denmark	16	17,210
Estonia	220	900
Finland	150	1,200
Germany	240	5,620
Latvia	300	2,560
Lithuania	880	11,750
Poland	8,760	62,400
Russia	2,500	6,970
Sweden	290	20,780
Transboundary Common pool*	1,660	3,780
Total	**15,020**	**133,170**

* In the BSAP, the HELCOM contracting parties agreed that "transboundary pollution originating in the non-contracting states Belarus and Ukraine should be addressed by initiating joint activities e.g. by bi- and/or multilateral projects and through other existing funding mechanisms as well as by international agreements such as the 1992 UNECE Convention on Transboundary Waters and Lakes, and the River Basin Management Plans of the EU Water Framework Directive for HELCOM Contracting States being also EU Member States."

Airborne nitrogen deposition was seen as a background load without any reduction targets.

In order to evaluate the progress of countries in reaching their nutrient reduction targets and to assess the effectiveness of measures to reduce nutrient loads, it is important to evaluate the long-term trends in emissions and inputs of nutrients.

4.1 Development in air emissions and atmospheric depositions of nitrogen

Annual nitrogen emissions from most HELCOM countries have decreased from 1995 to 2009, (**figure 4-1 and figure 4-2**) but it has not been tested if this decrease is statistically significant. The greatest reductions have been achieved by Denmark and Sweden, which 39 and 37% lower total nitrogen emissions to the air in 2009 compared to 1995, respectively. Estonia's, Finland's, Germany's, and Poland's emissions were 20-28% lower and the emissions from Latvia and Lithuania were about 10% lower than in 1995. Only emissions from Russia increased (4%) during the period 1995-2009, but this might partly be explained by the extension of the EMEP domain

within the Russian territory, which resulted in increased emissions after 2006 (Bartnicki 2011a). Further, it should be pointed out that the methodology of how emissions are calculated has changed between 1995 and 2009.

In 2008, approximately 60% of nitrogen emissions were in oxidized form (NO_x), mainly resulting from combustion processes and 40% were in reduced form (NH_x), mainly ammonia from the agricultural sector. Emissions of nitrogen from the shipping sector have increased with growing shipping traffic. Emissions from shipping (NO_x) have been increasing since 2000 and current estimates indicate systematic annual increase of these emissions in the range of 2-3% (Bartnicki 2011a).

Deposition of total nitrogen is affected by climatic conditions and inter-annual variation of meteorological conditions, such as dominating wind direction, precipitation (intensity, frequency, distribution, type), temperature, etc. To evaluate to which extent decreased emissions have resulted in lower atmospheric deposition, EMEP has (for this report) introduced a normalization calculation of the annual deposition to the Baltic Sea during 1995-2009 to smoothen the effect of inter-annual meteorological variation.[5] Increased nitrogen emissions since 2006 as compared with 2000-2005 are related to the inclusion of emissions from a larger part of Russia, but sources situated in these areas far east from the Baltic Sea give a very small contribution to the nitrogen deposition on the Baltic Sea. This partly explains why there is only a moderate correlation (R2 = 0.4032) between air emissions (which are not very sensitive to changes in weather conditions) and normalized depositions of total nitrogen (**figure 4-2**). It should be noted that roughly 40% of the deposition on the Baltic Sea originates from emissions outside the HELCOM countries.

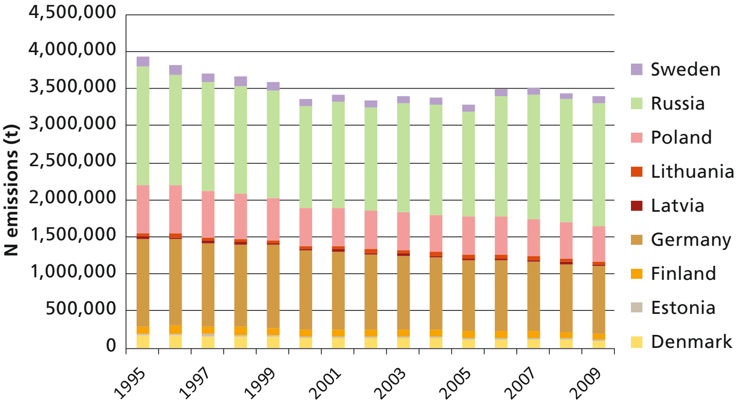


Figure 4-1 Annual atmospheric emissions of total nitrogen from individual HELCOM countries during the period 1995 – 2009. Note: the data cover emissions from the entire territories of the countries, except for Russia, where only emissions from the area covered by the EMEP domain are included. This area was significantly extended for 2007 and onward resulting in a large increase of nitrogen emissions from Russia. (Data source: Bartnicki 2011a)

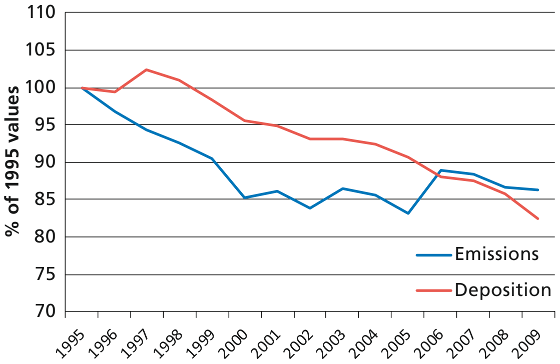


Figure 4-2 Comparison of relative annual normalized depositions of total nitrogen into the Baltic Sea basin and relative annual emissions of total nitrogen (nitrogen oxides + ammonia) from the HELCOM countries during the period 1995 - 2009. Units: 1995 = 100%. Note: total N emissions from HELCOM countries in 1995 were 3,933,400 tonnes and the normalized deposition of total nitrogen to the Baltic Sea in 1995 was 210,200 tonnes. The Russian area was significantly extended for 2007 and onward resulting in a large increase of nitrogen emissions from Russia. (Data source: Bartnicki 2011a and Bartnicki 2011b)

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[5] For each year in this period, annual deposition is modelled 15 times by using the meteorological condition for each year in the period and then taking an average of the 15 model runs (e.g. deposition for 1995 is calculated using meteorological conditions from 1995, 1996, 1997..., 2009, respectively, but using the same emission figures for each model run and then averaging the 15 estimates of 1995 deposition to a normalized figure).

A statistical test for trends in the total nitrogen deposition on the Baltic Sea and the corresponding deposition on the six main Baltic Sea sub-basins from 1995 to 2009 was done by the Danish Centre for Environment and Energy (DCE) **(figure 4-3)**. The statistical test shows no significant trends (decreases), although for Gulf of Bothnia there is a nearly significant decrease. But a test for trends on the normalized total nitrogen deposition to the Baltic Sea shows a statistically significant decrease and a corresponding decrease is seen for both oxidized and reduced nitrogen deposition. The decrease of total nitrogen deposition to the Baltic Sea is approximately 3 tonnes per year or 18% from 1995 to 2009. The total nitrogen emissions from the HELCOM countries decreased from 1995 to 2000, and have not changed considerably since then. The modeled and normalized nitrogen deposition was highest during 1997-1998 and has since then been decreasing. As noted above, more than one third of the total nitrogen deposition originates from other sources than HELCOM countries. Further, changed methodology makes it uncertain to compare developments in emissions and depositions of nitrogen or to draw conclusions on the development of total nitrogen deposition.

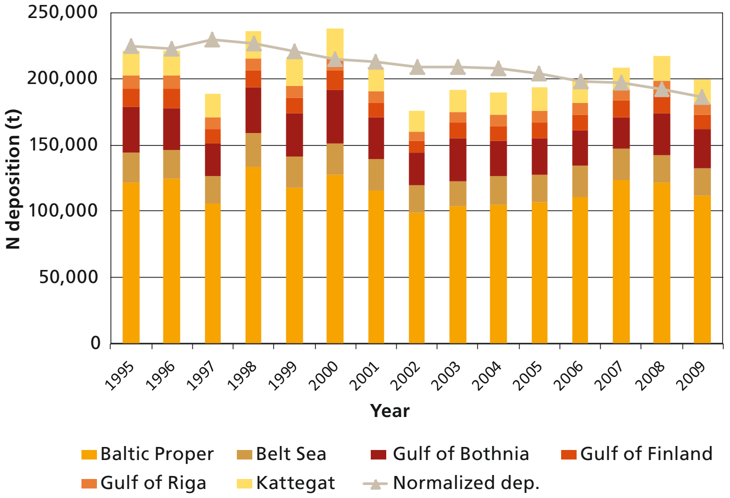

Figure 4-3 Modeled atmospheric deposition of total nitrogen to the different Baltic Sea sub-basins from 1995-2009 and normalized modeled nitrogen deposition. (Data source: Bartnicki 2011b)

4.2 Development in waterborne inputs of nutrients

When comparing riverine inputs into the Baltic Sea for different years, the controlling influence of climatic conditions, mainly on runoff, should be taken into account because there is a close correlation between runoff and nutrient loads. During years with heavy precipitation and associated high runoff, more nitrogen and phosphorus are leached and eroded from cultivated areas, and most probably also from natural background areas, resulting in higher riverine nutrient inputs to the Baltic Sea than in dry years. These variations in nitrogen and phosphorus loads make it difficult to compare loads from one year to another, as can be seen in **figure 4-4**.

Flow normalization of load data allows for a more correct evaluation of trends in the total waterborne inputs to the Baltic Sea as it, to some extent, can smooth out the annual variation caused by the weather conditions. The Baltic Nest Institute (BNI) carried out a flow normalization of annual total riverine inputs per country and per main Baltic Sea catchment sub-region. Subsequently, the Danish Centre for Environment and Energy (DCE) carried out a trend analysis in order to evaluate whether there are any statistically significant decreases or increases in waterborne nitrogen and phosphorus loads. Where there was a significant trend, the annual changes were deducted and a change from 1994 to 2008 was calculated. For more information about flow normalization and trend analysis, and detailed results of the calculations, see chapter 5 and Annex 2 of the PLC-5 report (HELCOM 2011).

The flow normalized total waterborne loads of nitrogen and phosphorus are shown in **figure 4-5**. Compared with **figure 4-4** it is quite obvious that flow normalization smoothens out inter-annual variation and therefore makes its easer to also visually evaluate for any trends in nutrient inputs to the Baltic Sea. The figure indicates a certain decrease in waterborne phosphorus load but no real changes for waterborne nitrogen load. Statistical analyses confirm these findings, with a significant decrease of 13% for total annual waterborne phosphorus load entering Baltic Sea from 1994 to 2008 (**table 4-3**). No significant trends are found for total waterborne nitrogen loads to the Baltic Sea.

Denmark, Germany and Sweden reduced significantly their (flow normalized) total waterborne loads of nitrogen (34%, 14% and 12%, respectively) and phosphorus (31%, 31% and 28%, respectively) from 1994 to 2008. Poland significantly decreased its waterborne phosphorus load (18%). Estonia shows a statistically significant increase in its waterborne nitrogen load (47%) while Latvia has a statistically significant increase in the corresponding phosphorus load (86%) (**table 4-3 a**).

For Kattegat, Danish Straits and Baltic Proper a statistically significant decrease for both waterborne (flow normalized) nitrogen and phosphorus loads are shown during the period 1994 to 2008. For phosphorus there is a significant decrease to Bothnian Sea and Bothnian Bay. There is also a significant increase in waterborne loads of nitrogen to Bothnian Bay (12%) and of phosphorus to the Gulf of Riga (67 %) (**table 4-3b**).

Direct discharges of phosphorus and nitrogen from coastal municipal wastewater treatment plants (MWWTPs), industry and fish farms into the Baltic Sea (**figures 4-6 and 4-7**) are generally independent of variations in precipitation, although some municipal wastewater treatment plants may allow untreated overflows during heavy storm water events. For all these sources, there is an overall significant decrease to the Baltic Sea during the period 1994 to 2008 for both nitrogen and phosphorus. All countries have a significant decrease in the direct point source load for phosphorus and all countries besides Poland and Russia for nitrogen (HELCOM, 2011).

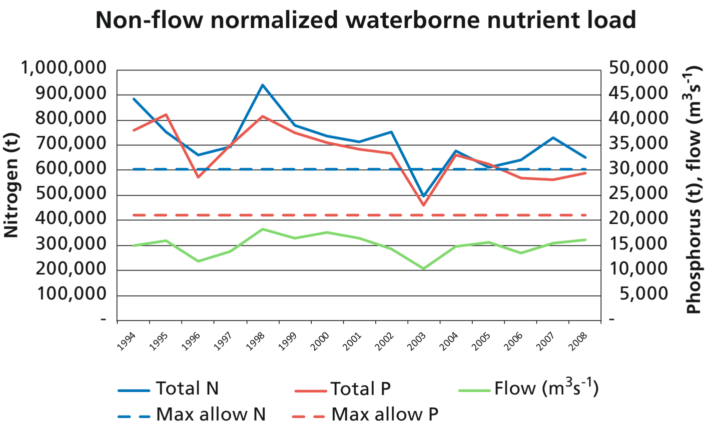

Figure 4-4 Annual variation in waterborne nitrogen and phosphorus inputs to the Baltic Sea (tonnes, without flow correction). The riverine flow has been given to show the yearly differences in flow. The dashed lines show the nutrient reduction targets for the entire Baltic Sea as agreed in the HELCOM Baltic Sea Action Plan.

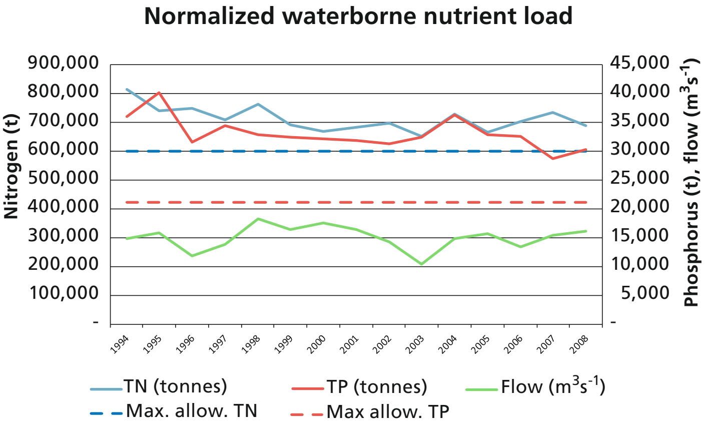

Figure 4-5 Total waterborne loads of nitrogen and phosphorus (normalized riverine flow and non-flow normalized direct coastal load) to the Baltic Sea from 1994 to 2008, indicating also the maximum allowable waterborne input as agreed in the HELCOM Baltic Sea Action Plan. (Source: HELCOM 2011)

Tables 4-3 a, b: A: Trend analysis of total waterborne annual loads (in t a^{-1}) for nitrogen and phosphorus from 1994 to 2008 by country. Statistically significant trends are marked with bold figures. Changes in loads indicate the estimated decrease (-) and increase (+) during the period. B: Same as table 4-3 a, but for the major Baltic Sea sub-basins.

Country	Estimated slope N (t a^{-1})	Change in N-load since 1994 (%)	Estimated slope P (t a^{-1})	Change in P-load since 1994 (%)
Denmark	**-1,844**	**-34**	**-67.7**	**-31**
Estonia	**766**	**47**	8.84	10
Finland	781	16	-36.7	-13
Germany	**-259**	**-14**	**-14.4**	**-31**
Latvia	1,553	22	**118**	**86**
Lithuania	-182	-6	13.9	7
Poland	-2,987	-16	**-172**	**-18**
Russia	171	3	-38.5	-12
Sweden	**-1,158**	**-12**	**-93.2**	**-28**
Total	-5,478	-9	**-339**	**-13**

Sub-basin	Estimated slope N (t a^{-1})	Change in N-load since 1994 (%)	Estimated slope P (t a^{-1})	Change in P-load since 1994 (%)
Kattegat	**-1435**	**-26**	**-27.3**	**-19**
Danish Straits	**-1463**	**-35**	**-59,6**	**-34**
Baltic Proper	**-4243**	**-16**	**-211**	**-17**
Gulf of Riga	-727	-11	**99,8**	**67**
Gulf of Finland	32	0	-58,6	-13
Bothnian Sea	355	10	**-47,3**	**-24**
Bothnian Bay	**428**	**12**	**-57,1**	**-26**
Baltic Sea	-5478	-9	**-339**	**-13**

For MWWTPs, the direct discharges during the period 2000 to 2005, especially for phosphorus, were higher than in both the preceding and subsequent years, which probably might be related to data errors/missing data for some countries. The direct point source phosphorus load to the Baltic Sea has decreased markedly, by 27% from 1994 to 2008, and the nitrogen load has decrease by 33% from 1994 to 2008. The real decrease might be higher, however, due to some missing data from the 1990s. It should be noted that municipal phosphorus and nitrogen loads

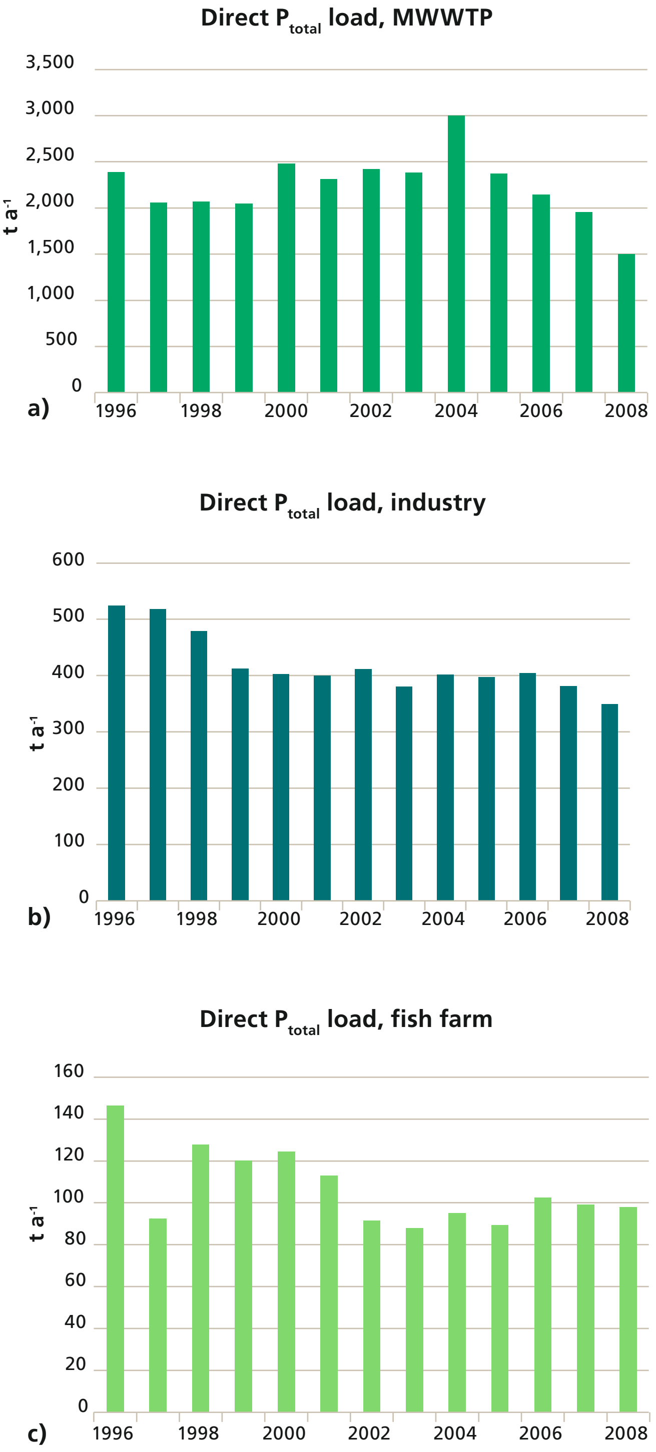

Figure 4-6 Direct phosphorus discharges (in tonnes per year) from three categories of point sources to the Baltic Sea from 1996 to 2008: a) MWWTPs, b) industry, and c) fish farms.

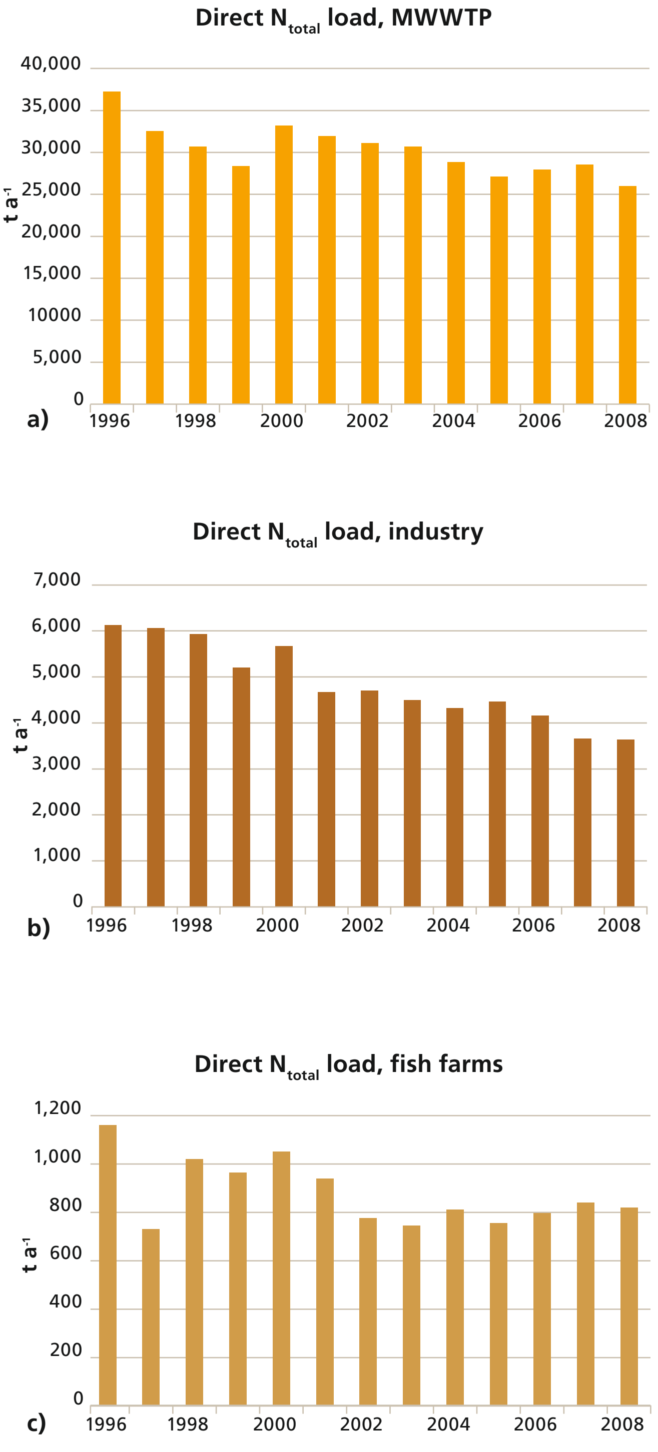

Figure 4-7 Direct nitrogen discharges (in tonnes per year) from three categories of point sources to the Baltic Sea from 1996 to 2008: a) MWWTPs, b) industry, and c) fish farms.

from the Nordic Contracting Parties and Germany decreased significantly already before the 1988 HELCOM Ministerial Declaration (HELCOM 1988) was agreed upon due to measures taken already during the 1970s and 1980s.

Since 1997-2003 was used as a reference period for the preliminary country-wise nutrient reduction requirements in the Baltic Sea Action Plan, the changes in waterborne nutrient loads to the Baltic Sea in comparison to the period 2006-2008 are assessed. Thus, the average flow normalized loads during 2006-2008 are compared with average flow normalized loads from 1997-2003 (**table 4-4**), but without testing whether the changes are statistically significant. The figures for average waterborne loads during 1997-2003 have changed compared with those used in BSAP 2007 due to flow normalization and updated and improved data. The new figures show an increase of total waterborne nitrogen loads (2%) but a decrease in corresponding phosphorus load (6%). There is a marked reduction in the waterborne nitrogen load from Denmark (21%) and Lithuania (12%) but a marked increase from Latvia (24%) and Estonia (19%). It should be stressed that it has not been evaluated whether these changes are significant. For phosphorus, marked decreases are seen from Russia (28%), Lithuania (25%) and Sweden (11%), but marked increases from Latvia (58%). This analysis was complicated by the occurrence of significant gaps in the available data sets from some countries to some Baltic Sea sub-basins, which make the results uncertain. For instance, the big changes in loads from Russia and Latvia might to some extent be explained by incomplete data and changed methodology. Further, it should be noted that the results cannot be directly compared with those of the trend analysis in **table 4-3 a,b**, where a different method and a longer time series were used.

In **table 4-5** the average of flow normalized average annual loads for the period 2006-2008 are compared with the maximum allowable inputs per major Baltic Sea sub-basin which were adopted in BSAP 2007. For the whole Baltic Sea, the flow normalized waterborne input of nitrogen was about 107,000 tonnes, or 18%, higher than the maximum allowable input, and for phosphorus the excess was 9,500 tonnes or 45%. The total atmospheric deposition of nitrogen during 2006-2008 was on average 201,000 tonnes, which is 5% lower than the 1997-2003 average of 212,000 tonnes. When looking at the nutrient loads at the sub-basin level, using the flow normalized annual average loads for 2006-2008, the Bothnian Sea was the only basin showing a total flow normalized waterborne load of nitrogen that is lower than the maximum allowable input. For phosphorus the corresponding loads to Bothnian Bay, Bothnian Sea and the Danish Straits were lower than the maximum allowable inputs (**table 4-5**).

Table 4-4 Total flow normalized waterborne annual loads of nitrogen and phosphorus (in t a^{-1}) during 1997-2003 and 2006-2008, respectively. The loads are expressed as annual averages for the periods (tonnes per year) and relative changes (%) between the two periods. The loads from 1997-2003 has been corrected since BSAP 2007 according to available data used in the PLC-5 report (HELCOM 2011). Negative percentages indicate decrease in the flow normalized waterborne loads from 1997-2003 to 2006-2008.*

	1997-2003		2006-2008		Change from 1997-2003 to 2006-2008	
Country	**N (t a^{-1})**	**P (t a^{-1})**	**N (t a^{-1})**	**P (t a^{-1})**	**N (%)**	**P (%)**
Denmark	58,612	1,841	46,475	1,710	-21	-7
Estonia	30,256	1,235	36,046	1,206	19	-2
Finland	73,965	3,483	79,600	3,471	8	0
Germany	20,243	539	19,608	492	-3	-9
Latvia	74,670	2,073	92,837	3,284	24	58
Lithuania	49,684	2,588	43,599	1,944	-12	-25
Poland	188,798	11,972	190,985	11,469	1	-4
Russia	77,439	4,921	82,813	3,528	7	-28
Sweden	122,350	3,856	117,102	3,428	-4	-11
Baltic Sea	696,017	32,509	709,064	30,532	2	-6

* These changes should be interpreted taking into account missing data (see chapter 6.4.2 of the PLC-5 report)

Table 4-5 Total flow normalized annual waterborne load of nitrogen and phosphorus (in t a^{-1}) averaged for 2006-2008 compared with the maximum allowable inputs according to BSAP 2007.

	Maximum allowable input		Flow normalized load 2006-2008		Difference	
	N (t a^{-1})	**P (t a^{-1})**	**N (t a^{-1})**	**P (t a^{-1})**	**N (t a^{-1})**	**P (t a^{-1})**
Bothnian Bay	51,440	2,580	54,613	2,341	3,173	-239
Bothnian Sea	56,790	2,460	55,937	2,226	-853	-234
Gulf of Finland	106,608	4,860	117,740	4,879	11,132	19
Gulf of Riga	78,400	1,430	96,389	3,287	17,989	1,857
Baltic Proper	233,250	6,750	289,327	14,922	56,077	8,172
Danish Straits	30,890	1,410	38,482	1,302	7,592	-108
Kattegat	44,260	1,570	56,577	1,576	12,317	6
Total Baltic Sea	**601,638**	**21,060**	**709,064**	**30,533**	**107,426**	**9,473**

5. Nutrient reduction potential

Water management in the Baltic Sea catchment has improved during the last ten years and in the Nordic countries and Germany since the 1970s, resulting in a considerable decrease of phosphorus load to most sub-basins. For nitrogen, the development has been less positive and the total loads to the sea have remained virtually unchanged. Although progress has been made, it is obvious that the BSAP nutrient reduction targets have not been fully reached.

In order to reach the overall eutrophication goal for the Baltic Sea, nutrient loads should not exceed the BSAP defined maximum allowable inputs of nitrogen and phosphorus to the Baltic Sea sub-basins **(table 4-1)**. As shown in Chapter 4, the average annual loads to the whole Baltic Sea are still clearly above the targets of the BSAP. The situation differs between sub-basins, but the analysis by the PLC-5 project was made for the whole Baltic Sea. As noted in chapter 4, for the whole Baltic Sea there remains a reduction need of about 107,000 tonnes of nitrogen and up to 9,500 tonnes of phosphorus (**table 4-5**). These figures describe nutrient load reduction to the sea, which implies even higher reductions at sources due to the retention in the catchment, including inland surface waters. Nutrient loads to the Bothnian Bay and Bothnian Sea have not changed significantly since the period 1997-2003 and still remain close to targets, and thus the remaining reduction requirements refer to the other parts of the Baltic Sea.

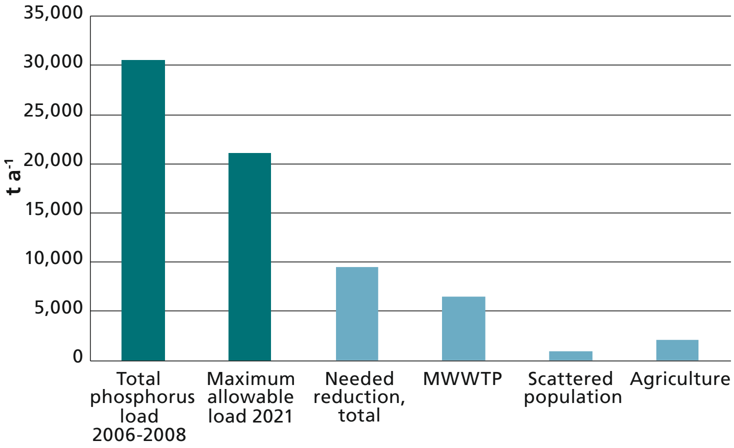

Figure 5-1 Total phosphorus load (flow normalized) (in t a^{-1}) into the Baltic Sea in 2006-2008, the maximum allowable input and the phosphorus reduction potential for municipal wastewater (MWWTP) and scattered population. The reduction requirement for agriculture = remaining.

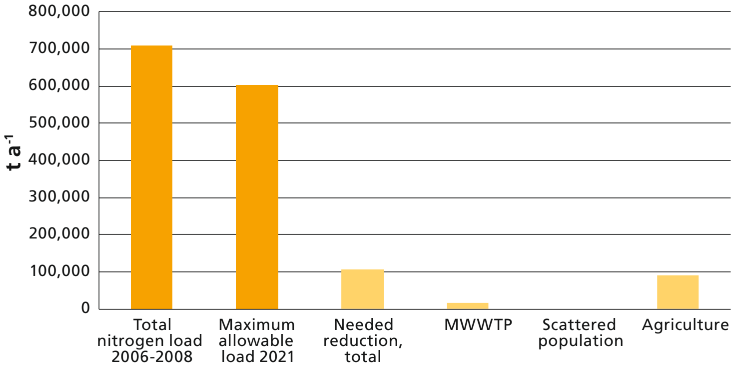

Figure 5-2 Total nitrogen load (flow normalized) (in t a^{-1}) into the Baltic Sea in 2006-2008, the maximum allowable input and the nitrogen reduction potential for municipal wastewater (MWWTP) and scattered population. The reduction requirement for agriculture = remaining.

Urban areas are important sources of nutrient loads and further reductions are needed in order to fulfill HELCOM Recommendation 28E/5 for wastewater treatment plants > 2,000 PE. In order to meet the requirements of this Recommendation by 2021, an annual reduction of roughly 10,000 tonnes of nitrogen and 4,000 tonnes of phosphorus to the Baltic Sea is needed (**figures 5-1 and 5-2**). These levels refer to the situation in 2007-2009. The greatest potential for phosphorus reductions are seen in Poland, Russia and Belarus, while Denmark, Finland, Sweden and Germany have already reached the required levels. For nitrogen, all countries except Denmark and Germany display some reduction potentials, although for Finland and Sweden they mainly occur in the Bothnian Bay and Bothnian Sea catchments. Further measures, including upgrading all wastewater treatment plants to 70% nitrogen removal, would increase the reduction potential by an additional 7,000 tonnes per year. Upgrading all plants to 90% removal of phosphorus would add another 2,500 tonnes of phosphorus per year to the reduction potential.

The total reduction potential for unconnected households is more difficult to assess, since detailed information about location and treatment techniques is not available. About 21 million people live in houses not connected to municipal wastewater treatment, many of which have improper treatment efficiency if compared with the requirements of HELCOM Recommendation 28E/6. By applying different scenarios for treatment level, it was estimated that the reduction potential is

between 1,000-3,000 tonnes of phosphorus per year. The potential for nitrogen reduction was not estimated, but is comparatively lower.

No reduction potentials have been calculated for forestry operations or storm water constructions, because statistics and data on those sources are poor in many countries. These sources are not insignificant, but it is likely that the nutrient reduction potentials for these sources are lower than for scattered dwellings.

A rough estimate is that agriculture accounts for 30-40% of the total loads of nitrogen and phosphorus to the Baltic Sea, or at most 350,000 tonnes of nitrogen and 10,000 tonnes of phosphorus per year. Considering the relatively low efficiency of measures implemented so far in the agricultural sector, it seems quite unlikely that this sector could contribute with the remaining reduction requirement of 80,000-90,000 tonnes of nitrogen to the Sea. The remaining gap to the phosphorus target is 2,000 tonnes per year, which would imply a reduction of 20%. This also appears to be a very challenging task, although not an impossible one. The future EU common agriculture policy will be of vital importance in this working towards these reduction targets.

The annual atmospheric deposition of nitrogen has decreased with about 10%, or about 20,000 tonnes, over the last decade. If this reduction continues at the same pace until 2020, it will contribute with a significant share of the remaining reduction target of 90,000 tonnes. Thus, it is of great importance for the health of the Baltic Sea to implement measures to reduce emissions of nitrogen oxides and ammonia to the atmosphere from HELCOM countries, shipping as well as the rest of Europe.

In conclusion, it is unlikely that the preconditions for good environmental status of the Baltic Sea can be achieved by 2021 if the nutrient reduction targets from only municipal wastewaters are fulfilled. Furthermore, the long residence time for nutrients in the catchment area implies that even if sufficient measures were implemented for various other diffuse and point sources of nutrients during the next five years, the targeted input reduction to the Baltic Sea will probably not be reached by 2021.

6. Conclusions

The following conclusions are based on results from the PLC-5 report as well as on an additional assessment, in the present report, of airborne nutrient inputs to the Baltic Sea.

The waterborne nutrient input to the Baltic Sea in 2008 was estimated to be 652,100 tonnes of nitrogen and 29,000 tonnes of phosphorus. Total nitrogen supply to the Baltic Sea via atmospheric deposition was 207,400 tonnes, or 24% of the total water- and airborne supply to the Baltic Sea, which in 2008 was 859,600 tonnes. Atmospheric deposition of phosphorus has not been measured but constitutes usually less than 1-5% of the total phosphorus supply. The Baltic Proper received the largest amounts of nutrients with 41% of total nitrogen and 39% of total phosphorus input followed by the Gulf of Bothnia (18% of total nitrogen and 20% of total phosphorus inputs). The main countries contributing to the nitrogen inputs were Poland (19%), Sweden (15%), and Finland (12%). The largest loads of phosphorus originated from Poland (28%), Finland (18%), Russia (12%) and Sweden (12%). The area-specific load of nitrogen into the Baltic Sea was typically highest in sub-regions with intensive agricultural activity and high population density such as to the Sound (1,700 kg N km^{-2}), Western Baltic Sea (1500 kg N km^{-2}), Kattegat (800 kg N km^{-2}) and Archipelago Sea (800 kg N km^{-2}). For phosphorus the highest area-specific losses were found in catchment areas with high population density, many industries, and high agricultural activity such as to the Archipelago Sea (65 kg P km^{-2}), the Sound (35 kg P km^{-2}), and Western Baltic Sea (30 kg P km^{-2}). Furthermore, geology, climate, wastewater treatment efficiency, frequency of surface runoff and snow/ice cover have an impact on area-specific loads of nutrients.

The most updated source apportionment data is from 2006. The main part of waterborne inputs enters the Baltic Sea via rivers (approximately 95% of nitrogen and 92% of phosphorus). Further, the source apportionment indicates that the largest sources of nitrogen and phosphorus, with at least 45% of the total inputs to the Baltic Sea, originated from diffuse sources. Point sources contributed to the total load with 12% for nitrogen and about 20% for phosphorus. The proportion of natural background load varied considerably among countries (between 5% and 50%), but constituted on average 16% of the total phosphorus load and somewhat higher for nitrogen. There are uncertainties in applied methodology and missing data resulting in major uncertainties regarding the importance of diffuse sources.

Agriculture contributed with approximately 70% to over 90% of the anthropogenic diffuse riverine nitrogen load and 60-80% of the corresponding diffuse phosphorus load. Agriculture thus contributed on average 60-70% of the reported total diffuse inputs to the sea. In some countries, scattered dwellings, storm water, and atmospheric nitrogen deposition were also significant sources, although much smaller than agriculture. The second largest anthropogenic source of nutrients originated from point sources, with municipalities as the main source (90%). Unspecified riverine load relates mainly to Russia, which did not perform any riverine load apportionment.

Sources of airborne loads have also been quantified for 2006. The primary emissions source is combustion processes (NO_x), as in energy consumption, transport sector, and industrial processes as well as emissions from agriculture (NH_x). Total emissions from the HELCOM countries in 2006 were 2,076,200 tonnes NO_x and 1,422,200 tonnes NH_3 and emissions from Baltic Sea shipping was 94,130 tonnes NO_x. Approximately 105,000 tonnes of NO_x and 93,200 tonnes NH_x were deposited on the Baltic Sea in 2006. The percentage of the individual countries' emissions of total nitrogen deposited on the Baltic Sea in 2006 was low, with between 11-15% (Sweden and Denmark) to less than 1% for Russia. Of the Baltic Sea ship traffic emissions, approximately 12% is deposited on the Baltic Sea. Germany, Poland and Denmark are the three largest contributors of total nitrogen deposition to the Baltic Sea, but amongst the top ten contributors are also the United Kingdom, France, as well as shipping on the Baltic and North Seas, meaning that approximately 40% of the nitrogen deposition on the Baltic Sea arrives from emissions outside the HELCOM countries.

Based on non-normalized figures for airborne deposition of total nitrogen it was not possible to detect any statistically significant changes neither for the Baltic Sea nor for the sub-basins of the Baltic Sea during 1995-2009, although for Gulf of Bothnia there has been a nearly significant decrease. By normalizing total nitrogen deposition for 1995-2009, there is a statistically significant decrease in total nitrogen deposition to the Baltic Sea with about 18% decrease from 1995 to 2009.

During the period 1994 to 2008, waterborne inputs from point sources discharging directly to the Baltic Sea decreased significantly for both nitrogen and phosphorus, with an average annual reduction of 1,170 tonnes of nitrogen and 80 tonnes of phosphorus. Direct nitrogen inputs decreased significantly for Germany, Denmark, Finland, Lithuania and Sweden, but significantly increased for Latvia. For direct coastal inputs of phosphorus, there was a significant decrease from Germany, Denmark, Finland, Lithuania and Sweden. Estonia and Latvia had a non-significant increase in these inputs. The direct coastal inputs of nitrogen decreased significantly to all main sub-basins except the Gulf of Riga, where it increased significantly. For phosphorus the same tendency was found, except for the Gulf of Finland, where the decrease was not significant.

Flow normalization of riverine load was performed before assessing progress towards the BSAP nutrient reduction targets and before statistical analysis of temporal trends in loads to smoothen out the impact of changing runoff from year to year on riverine, and thus also nutrient, loads. Statistical trend tests showed that Germany, Denmark and Sweden have a significant decrease of total waterborne nitrogen input during 1994-2008, while there was a significant increase from Estonia. Furthermore, for Finland, Latvia and Russia the total nitrogen load increased, and for the whole Baltic Sea decreased but not statistically significantly. The corresponding phosphorus loads showed a statistically significant decrease for Germany, Denmark, Poland, Sweden, and for the whole Baltic Sea, but a significant increase for Latvia. A statistically non-significant increase was seen for Estonia, and Lithuania. Total waterborne loads of nitrogen to the Kattegat, Danish Straits and Baltic Proper significantly decreased during 1994-2008, but increased significantly for the Bothnian Bay. Regarding phosphorus, a statistically significant decrease was observed for all main sub-regions except for the Gulf of Riga, which had a significant increase, and the Gulf of Finland, which had a non-significant decrease.

When comparing the most recent period of available waterborne data (2006-2008) with the 1997-2003 reference period, seven countries showed a decrease in total flow normalized waterborne phosphorus loads, although the trends were not always statistically significant. For nitrogen only four countries showed a decrease in total waterborne loads. Flow normalized waterborne nitrogen loads for the whole Baltic Sea was nearly 13,000 tonnes higher (2%) in 2006-2008 compared with 1997-2003 and the corresponding figure for phosphorus was 2,000 tonnes lower (6%).

Based on the flow normalized average annual load during 2006-2008, the required load reduction needed to reach the BSAP 2007 maximum allowable amounts to about 107,000 tonnes of nitrogen and nearly 10,000 tonnes of phosphorus. These are lower than the reduction values given in BSAP 2007 (135,000 tonnes nitrogen and 15,200 tonnes phosphorous), and the changes are mainly due to flow normalization. However, the situation differs between the sub-basins and for nitrogen a positive development was seen for the Kattegat, Danish Straits, Baltic Proper and Bothnian Sea. For phosphorus, the development was positive for the Danish Straits, Baltic Proper, Bothnian Sea and Bothnian Bay, although only the Baltic Proper has a reduction requirement according to the BSAP. Nevertheless, the average total waterborne annual load to the whole Baltic Sea in 2006-2008 was clearly above the preliminary nutrient reduction targets of the BSAP.

A summary of an assessment of the reduction potential on different sources is given below. This assessment does not take into account the specific situation in individual sub-basins and should therefore be considered a rough estimate. If wastewater treatment levels required by HELCOM Recommendation 28E/5 are fulfilled by 2021, an annual reduction of roughly 10,000 tonnes of nitrogen and 4,000 tonnes of phosphorus would take place. Minor reductions could be achieved by measures to improve unconnected households, forestry operations and storm water constructions, but most of the remaining part would fall on agriculture, as well as on sectors causing large amounts of atmospheric deposition onto the

Baltic Sea, such as shipping, traffic and combustion in industries. For the agricultural sector the reduction requirements would be about 80,000-90,000 tonnes of nitrogen per year and 2,000 tonnes of phosphorus per year. Because the efficiency of measures implemented in the agricultural sector has been fairly low, this will evidently be a very difficult task and it is unlikely that the total reduction targets will be fulfilled by 2021.

It is important to note that there can be a considerable time lag from implementing measures in the catchment area before the reduction in waterborne loads to coastal areas and further to the open sea is obtained, e.g. in areas situated at long distances from the sea or where the pathways of nutrients pass groundwater, where they can be stored for years or several decades. Further, in some catchments, retention in soils, groundwater and inland surface waters are so high that it can require up to five to ten times higher reductions in losses from diffuse sources to obtain a given reduction to the Baltic Sea.

The PLC-5 report identified various limitations in the PLC water data. There were significant data gaps and missing data from some areas in reported data, as well as data which were evaluated as not being valid. Some of these problems were so serious that they complicated trend analysis, the relative importance of different sources and the evaluation of progress on fulfilling BSAP 2007 reduction targets.

The PLC-5 report emphasized that for the future, it is very important to focus on data completeness and consistency and to improve the comparability of data between countries. The new HELCOM expert group on follow-up of national progress towards reaching BSAP nutrient reduction targets (HELCOM LOAD), which will focus on methodologies for load assessments, is seen as a useful platform to further this work as well.

The PLC-5 report also identified several issues to be addressed in order to improve the situation as concerns PLC data (HELCOM 2011).

7. Acknowledgements

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9. List of definitions and abbreviations

Airborne	Nutrients carried or distributed by air
Anoxic condition	A situation with no oxygen available for organisms
Anthropogenic	Caused by human activities
Atmospheric deposition	Airborne nutrients or other chemical substances originating from emissions to the air and deposited from the air on water surfaces
BSAP	Baltic Sea Action Plan
Benthic organism	An organism, that live in, on, or near the bottom of aquatic environments. Also called benthos
Catchment area	The area of land bounded by watersheds draining into a body of water (river, basin, reservoir, sea), in this report the Baltic Sea (also referred to as drainage area)
Contracting Parties	Signatories of the Helsinki Convention
Diffuse losses	Nutrients or other compounds lost to surface water from diffuse sources
Diffuse sources	Activities spread over an area with no discrete points of emission or loss of substances, e.g. agriculture, forest land, urban areas, atmospheric deposition and precipitation
EMEP	Co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe
Emissions	Airborne compounds emitted from traffic, other combustion or industrial processes, agriculture etc.
Eutrophication	Condition in an aquatic ecosystem where increased nutrient concentrations stimulate the excessive growth of algae, which leads to an imbalanced function of the ecosystem
Flow normalization	A numerical method that adjusts a data time series to smooth and adjust and remove this influence variations imposed by water flow, when you want to investigate for development in e.g. nitrogen or phosphorus load. This means e.g. if nitrogen loads have decreased in a flow normalized data series, this decrease in not due to a decrease in the water flow
Gross load	Discharges and losses of nutrients from different sources into inland surface waters
Inland surface waters	All inland waters, except soil and groundwater, and including wetlands, rivers and lakes
ISO and EN Standards	Internationally validated and standardized methods developed by the International Standard Association (ISO) or by the European standardization bodies CEN, CENELEC and ETSI
Maximum allowable input	The maximum annual amount of a substance that a Baltic Sea sub-basin may receive and still fulfill HELCOM's ecological objectives for a Baltic Sea unaffected by Eutrophication
MWWTP	Municipal wastewater treatment plant
Natural background losses	Refers to natural losses of substances from unmanaged areas as well as losses from different land categories irrespective of human activities
Non-contracting parties	Countries that is not a partner to the Helsinki Convention 1992, but that has an indirect effect on the Baltic Sea contributing with inputs of nutrients or other substances via water and air
Nitrogen oxides	Atmospheric pollutants, mainly NO and NO_2, collectively denoted NO_x (main sources is combustion processes)
Point source discharges	Discharges from municipalities and industries as well as fish farms to inland surface waters or directly to the sea
Retention	The amount of a substance lost/retained during transport in soil and/or water including groundwater from the source to a recipient
Riverine loads	The amount of a substance being carried by rivers

Scattered dwellings	Individual houses in rural areas without common wastewater treatment and not connected to a wastewater treatment plant
Statistically significant	In statistics, a result is called “statistically significant” if it is unlikely to have occurred by chance. The degree of significance is expressed by the probability, P. P< 0.05 means that the probability for at result to occur by chance is less than 5%
Sub-basins	Subdivision units of the Baltic Sea Basin, e.g. Baltic Proper, Gulf of Finland and Kattegat. See Figure 1-1
Transboundary load	Amount of a substance that is transported across a country border. Usually it is used regarding inputs from countries that are not Contracting Parties to HELCOM but have discharges to the Baltic Sea, such as Ukraine, Belarus, Slovakia, Czech Republic and Norway regarding waterborne loads
Waterborne	Nutrients carried or distributed by water

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