Baltic Sea Environment Proceedings No. 145

Baltic Marine Environment Protection Commission

Updated Fifth Baltic Sea Pollution Load Compilation (PLC-5.5)

Published by:
Helsinki Commission
Katajanokanlaituri 6 B
FI-00160 Helsinki, Finland
http://www.helcom.fi

Authors: Lars M. Svendsen[1] (Project Manager), Jerzy Bartnicki[2], Susanne Boutrup[1], Bo Gustafsson[3], Waldemar Jarosinski[4], Seppo Knuuttila[5], Pekka Kotilainen[5], Søren E. Larsen[1], Minna Pyhälä[6], Tuija Ruoho-Airola[7], Lars Sonesten[8], Håkan Staaf[9]

[1] DCE - Danish Centre for Environment and Energy
[2] Meteorological Synthesizing Centre-West of EMEP
[3] Baltic Nest Institute, Stockholm University
[4] Institute of Meteorology and Water Management, National Research Institute, Poland
[5] Finnish Environment Institute
[6] Secretariat of the Helsinki Commission
[7] Finnish Meteorological Institute
[8] Swedish University of Agricultural Sciences
[9] Swedish Agency for Marine and Water Management

For bibliographic purposes this document should be cited as:
HELCOM, 2015. Updated Fifth Baltic Sea pollution load compilation (PLC-5.5). Baltic Sea Environment Proceedings No. 145

Design and Layout: Bitdesign, Vantaa, Finland
Cover photo: Seppo Knuuttila
Number of pages: 143
ISSN 0357-2994

Updated Fifth Baltic Sea Pollution Load Compilation (PLC-5.5)

Table of Contents

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 inputs of nutrients to the sea. Through coordinated monitoring, HELCOM has, since the mid-1980s been compiling information about the magnitude and sources of nutrient inputs into the Baltic Sea. By regularly compiling and reporting data on pollution loads, HELCOM is able to follow the progress towards reaching politically agreed nutrient reduction input goals.

In 2007, the HELCOM Baltic Sea Action Plan (BSAP) was adopted by the Baltic Sea coastal countries and the European Community (HELCOM 2007). The BSAP has the overall objective of reaching a Baltic Sea in good environmental status by 2021, by addressing the issues of eutrophication, hazardous substances, biodiversity and maritime activities. The BSAP included for the first time ever a nutrient reduction scheme based on maximum allowable inputs (MAI) of nutrients to achieve good status in terms of eutrophication derived through modelled calculations by the Baltic Nest Institute (BNI) Sweden. The plan also adopted provisional country-wise allocation of reduction targets (CART) to fulfil MAI through which the responsibility to reach these nutrient reductions targets is shared on the polluter pays principles.

The 2013 HELCOM Copenhagen Ministerial Declaration (HELCOM 2013a) agreed on revised MAI and new CARTs that were calculated based on improved eutrophication targets and models, more complete data on nutrient inputs (the one produced by the PLC-5.5 project) and allocation principles. For more information on the nutrient reduction scheme, see HELCOM 2013b.

According to the revised nutrient reduction scheme 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 21,700 tonnes of phosphorus and 792,200 tonnes of nitrogen. Necessary nutrient reductions have been calculated also to the sub-basin level (see **Table 5.8**). Based on nutrient inputs during the reference period 1997-2003 and the share of pollution from different countries and other sources, nutrient reduction targets were allocated (HELCOM 2013a).

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 water- and airborne inputs of nutrients, and hence eutrophication, this can only be done if the sources of nutrients reaching the Baltic Sea and magnitude of nutrient inputs are known. This is why HELCOM pollution load compilation (PLC) data is of such great importance. High quality, complete, consistent and comparable 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.

The Review of Fifth Baltic Sea Pollution Load Compilation for 2013 HELCOM Ministerial Meeting was submitted as a supporting document to the ministerial meeting, presenting the main results of the PLC-5.5 project. The report was published in December 2013 (HELCOM 2013c). This Updated Fifth Baltic Sea Pollution Load Compilation is a more complete version of the above mentioned “Review” report, providing tables and graphs with information for all countries and sub-basins (the “Review” report presented some main results as well as a few more detailed examples).

The PLC-5.5 report is a further step forward in quantifying waterborne and air-borne inputs to the Baltic Sea by providing an updated, corrected and more complete data set on nutrient inputs to the Baltic Sea. The report is based on the Fifth Baltic Sea Pollution Compilation (called PLC-5 report) on waterborne data from 1994-2008 (HELCOM 2011, HELCOM 2012) updated with new data for 2009 and 2010. Further, data gaps were filled in and suspicious data corrected, in order to obtain a dataset as complete and correct as possible. Besides the waterborne loads to the Baltic Sea 1994-2010, the report also covers data on atmospheric inputs during 1995-2010, 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. This report does not include updated information on all sources of nutrient inputs (the latest complete source apportionment was elaborated for the PLC-5 report on 2006 data), but includes updates on inputs from e.g. direct point sources discharging to the Baltic Sea and for airborne emissions. The PLC-5.5 data set was closed in July 2013 (no updated or corrected data was accepted from Contracting Parties after that) as normalization and statitistical trend analysis had to be ready for the Copenhangen Ministerial Meeting in October 2013. Hence it was not possible to include data for 2008-2010 which was received from Latvia in 2014 in this assessment.

The report evaluates changes and trends in country- and sub-basin-wise nutrient inputs from 1994 to 2010. It does not include an evaluation on progress towards MAI and CART, but does present detailed results of trend analyses (1994-2010) and comparison of normalized average input during 2008-2010 with the reference period 1997-2003.

The main focus in the PLC-5.5 project was to update the waterborne nutrient input data, and to include data on atmospheric nitrogen deposition. Hence, heavy metal inputs to the Baltic Sea have not been included in this work. Also, the inconsistency in monitoring and reporting of heavy metal input data makes it a challenge to properly assess the reported inputs. For proper future heavy metal input assessments these obstacles need to be resolved

Summary

The scope and methodological considerations

This report provides updated, corrected and more complete information on pollution loads to the Baltic Sea, based on the PLC-5 report waterborne data from 1994-2008 (HELCOM 2012) as well as new data for 2009 and 2010.

The report is based on the so far most complete, consistent and quality assured PLC data set, covering waterborne and airborne inputs to the Baltic Sea from 1994 to 2010. The completion of the data set required filling in of some data gaps, as for some catchments no monitoring or modelling results were available or provided to HELCOM. The PLC-5.5 data set has been approved by all the Contracting Parties for use in the PLC-5.5 report, although Russia has not accepted that the filled in data gaps can be included in the official PLC-Water database. Waterborne transboundary inputs from other Contracting Parties and non-Contracting Parties are included in the inputs from the Contracting Party where these inputs enter the Baltic Sea.

In addition to the waterborne inputs to the Baltic Sea 1994-2010, the data set covers also atmospheric inputs for 1995-2010, which are calculated based on emissions data submitted by countries to the European Monitoring and Evaluation Programme of the Long Range Transboundary Air Pollutants in Europe (EMEP). EMEP compiles the emission data and their models calculate the atmospheric input to the Baltic Sea. The atmospheric inputs data set was also updated, recalculated and amended since the PLC-5 Executive Summary report (HELCOM 2012).

To reduce the effects of changing weather conditions, riverine data have been flow normalized. Furthermore, EMEP has developed methodology and calculated normalized nitrogen deposition data and the PLC project has compiled a revised phosphorus deposition rate for the whole Baltic Sea. Input from direct point sources, to the Baltic Sea, has not been normalized, as it is generally not affected by weather conditions.

Total nutrient inputs in 2010

In 2010, the total waterborne and airborne inputs of nitrogen and phosphorus to the Baltic Sea were 977,000 tonnes and 38,300 tonnes, respectively. However, after normalization for weather conditions, the total normalized nitrogen and phosphorus inputs in 2010 were considerably lower: 802,000 tonnes of nitrogen (18% less) and 32,200 tonnes of phosphorus (16% less).

The total waterborne inputs of nitrogen and phosphorus in 2010 were 758,000 tonnes and 36,200 tonnes, respectively. Out of this, the input originating from point sources, discharged directly to the Baltic Sea was 30,500 tonnes for nitrogen, and 1,700 for phosphorus, which represented 4%, and 5% of the total waterborne inputs of those nutrients, respectively.

In 2010, it was estimated that the transboundary waterborne nutrient inputs originating from five non-HELCOM countries (Belarus, Czech Republic, Norway, Slovakia and Ukraine) constituted 3% of total nitrogen and 5% of total phosphorus inputs to the Baltic Sea. These inputs played a considerably greater role in some basins, for example for phosphorus inputs to the Gulf of Riga.

Atmospheric deposition of nitrogen amounted to 219,000 tonnes or 22% of the total nitrogen input. Based on new monitoring data from the Contracting Parties, an estimated deposition of 5 kg phosphorus km^{-2} was used as an annual average rate for the Baltic Sea, resulting in a total of 2,100 tonnes of atmospheric phosphorus deposited to the Baltic Sea annually, constituting nearly 5% of the total phosphorus input to the Baltic Sea.

In 2010, 62% of the total nitrogen deposition to the Baltic Sea originated from HELCOM countries (including the areas which are outside the catchment areas that drains to the Baltic Sea, e.g. in Denmark, Germany and Russia), 6% from Baltic Sea shipping, 18% from the 20 EU countries which are not HELCOM Contracting Parties, and the remaining 14% from other countries and distant sources outside the Baltic Sea region. The normalized nitrogen atmospheric deposition equalled 193,000 tonnes, or 24% of the total normalized nitrogen input to the Baltic Sea.

The seven largest rivers entering to the Baltic Sea (Daugava, Göta älv, Kemijoki, Nemunas, Neva, Odra, and Vistula) cover 51% of the catchment area. Fifty-three per cent of total waterborne nitrogen and 54% of phosphorus inputs entered the Baltic Sea in 2010 via these rivers, but only 46% of the total river flow.

Trends

Analysis of trends in inputs has been carried out for the period 1995-2010 for airborne inputs and for 1994-2010 for waterborne inputs. The difference in period is due to availability of data. For the total waterborne + airborne inputs, trends are carried out for the period 1994-2010 using an estimate for the airborne inputs in 1994.

In the period of 1995-2010 the total normalized airborne and flow normalized waterborne nitrogen inputs to the Baltic Sea was reduced significantly by 16%. Denmark (35%), Germany (23%), Poland (20%) and Sweden (15%) have significantly reduced their combined airborne and waterborne inputs. The direct point source inputs of nitrogen and phosphorus to the Baltic Sea have decreased significantly by 43% and 63%, respectively, from 1994 to 2010. The majority of the Contracting Parties had significant reductions during this period.

During the period 1994-2010, total flow normalized waterborne nitrogen input to the Baltic Sea was reduced by 17%. Several countries, including Denmark, Germany, Poland and Sweden, reduced their total flow normalized waterborne nitrogen input considerably (36%, 19%, 26% and 15%, respectively). Also Latvia and Lithuania reported significant decreases, but the confidence of those estimates was lower partly due to data variability and uncertainty (Latvian data).

In the period of 1995-2010, the reduction of normalized annual nitrogen atmospheric deposition to the Baltic Sea was 24% (more than 50,000 tonnes of nitrogen). The highest relative reduction (40%) was in Denmark, but also Finland, Germany, Poland, Sweden and the EU20 showed marked reductions of 23-34%. Atmospheric total nitrogen deposition from Russia and Baltic Sea shipping increased significantly, with 34% and 44% respectively, during the period. The contribution from Russia increased partly because the area in Russia from which emissions are included in EMEP deposition estimates markedly expanded after 2006, but Russian emissions near the Baltic Sea also increased according to EMEP (www.ceip.at/webdab-emission-database).

Between 1995 and 2010, the total normalized atmospheric deposition of nitrogen decreased significantly to all seven Baltic Sea sub-basins (18-27%). The Kattegat, the Danish Straits and the Baltic Proper also show a statistically significant decrease for both, flow normalized riverine (21-29%) and waterborne (22-39%) nitrogen inputs from 1994 to 2010, while all sub-basins, except the Bothnian Sea and the Gulf of Riga, show a significant reduction in total normalized nitrogen inputs from 1994 to 2010.

During the period of 1994-2010 the total flow normalized waterborne phosphorus inputs to the Baltic Sea was reduced by 20%. Reduction of phosphorus inputs to the sea was observed in all Contracting Parties, except for Latvia where these inputs were significantly increasing (69%). The highest reductions of total flow-normalized waterborne phosphorus inputs between 1994 and 2010 were reported for Denmark (34%), Lithuania (38%) and Poland (25%). Flow normalized riverine phosphorus inputs have decreased by approximately 5,700 tonnes (16%) since 1994, accounting for more than 70% of the total reduction in normalized phosphorus inputs to the Baltic Sea. Phosphorus inputs from direct point sources have decreased by 68%, or about 2,000 tonnes.

For total normalized waterborne phosphorus inputs, significant decreases were calculated for the Bothnian Sea (28%), the Baltic Proper (26%), the Danish Straits (40%), and the Kattegat (22%). For the Bothnian Bay the decrease was similar (21%), but with a lower statistical confidence level. On the other hand, waterborne phosphorus inputs increased with nearly 50% to the Gulf of Riga (note that data for Latvia are uncertain, especially for 2008-2010) and no significant trends were observed for the Gulf of Finland (there are shortcomings and uncertainties in the Russian data).

The trend analysis quantifies an overall significant reduction in total air and waterborne inputs to the Baltic Sea of approximately 165,000 tonnes of nitrogen and 7,600 tonnes of phosphorus from 1994 to 2010. This indicates that the measures taken before and after 1994 to improve wastewater treatment, to reduce air emissions from combustion processes and losses from diffuse sources (agriculture and forestry) have led to a significant decrease in nutrient inputs to the Baltic Sea.

The report gives further details on the results of trend analysis for each Contracting Party and the sub-basins to which they have nutrient inputs to.

Of the seven largest rivers, Daugava (6%), Göta älv (24%) and Vistula (36%) had significant decreases in riverine nitrogen inputs from 1994 to 2010. For corresponding riverine phosphorus input only Odra (42%) and Nemunas (36%) had a significant decrease while Daugava had a significant increase (6%).

Reductions since the reference period

When adopting HELCOM Baltic Sea Action Plan the HELCOM Contracting Parties agreed to reduce their nutrient inputs to achieve good environmental status of the Baltic Sea by 2021 (HELCOM 2007). A set of provisional maximum allowable inputs (MAI) of nitrogen and phosphorus was agreed upon, and the provisional reduction requirements were determined by deducting MAI from reference inputs and using a set of allocation principles. The reference input was defined as the average annual waterborne input in the period 1997-2003, based on the available PLC data set in 2007. With the updated and more complete and consistent PLC-5.5 data set, reference inputs have been updated, calculated as the average of normalized airborne and flow normalized waterborne inputs during 1997-2003. Revised MAI and new country allocated reduction targets (CART) based on revised allocation principles were decided by the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a).

The revised MAI is 792,209 tonnes of nitrogen and 21,716 tonnes of phosphorus, leading to a total reduction requirement of 118,134 tonnes of atmospheric and waterborne nitrogen inputs and 15,178 tonnes waterborne inputs of phosphorus, as compared with the reference period (1997-2003).

The average total normalized inputs during 2008-2010, were approximately 829,000 tonnes of nitrogen and 33,100 tonnes of phosphorus, with 197,000 tonnes of the nitrogen inputs from atmospheric deposition (24%). The atmospheric deposition of phosphorus remains at 2,100 tonnes, calculated using the same deposition rate (5 kg P km^{-2}) for all years. The average normalized total nitrogen and phosphorus input to the Baltic Sea during 2008-2010 decreased with approximately 10%, or about 81,000 tonnes of nitrogen, and 9%, or nearly 3,800 tonnes of phosphorus, compared to the corresponding inputs during the reference period. It has not been tested whether these reductions are statistically significant. More than 30,000 tonnes of the total nitrogen reduction was due to the reduction in the atmospheric deposition, of which 15,500 tonnes have been reduced by non-Contracting Parties (mainly the EU20 countries). However, the deposition from Baltic Sea shipping increased with 15%, or more than 1,700 tonnes of nitrogen, compared to the reference period.

For the Kattegat the average total atmospheric and waterborne nitrogen reductions in 2008-2010 were three times more than the reduction requirements (more than 12,500 tonnes nitrogen has been reduced; the requirement is 4,761 tonnes). For nitrogen inputs to the Baltic Proper and Gulf of Finland more than one third of the needed reduction requirement was obtained during 2008-2010, and for phosphorus the corresponding figures were 22-25%. On the other hand, total phosphorus inputs to the Gulf of Riga increased during 2008-2010 with approximately 380 tonnes since the reference period and, consequently, the remaining reduction requirement has more than doubled as compared to the requirements in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a).

Photo by Seppo Knuuttila

1. Introduction

1.1. Eutrophication of the Baltic Sea

Eutrophication is a major problem in the Baltic Sea. Since the beginning of the 20th century, the Baltic Sea has changed from an oligotrophic clear-water sea into a highly eutrophic marine environment (Larsson 1985).

Eutrophication in the Baltic Sea is to a large extent driven by anthropogenic inputs of the nutrients nitrogen and phosphorus, resulting in nutrient over-enrichment and/or changes in nutrient ratios causing elevated levels of macrovegetation, increased turbidity, oxygen depletion in bottom waters, changes in species composition and increase or nuisance blooms of microscopic algae. According to a recent HELCOM assessment of eutrophication status during 2007-2011, nearly the entire Baltic Sea is considered to be affected by eutrophication (HELCOM 2014a). This indicates that despite measures taken to reduce external inputs of nitrogen and phosphorus to the sea, good water quality status has not yet been reached.

The total inputs of nutrients to the Baltic Sea have decreased since the late 1980s and currently inputs levels equal those in the early 1960s. Despite the reduced inputs, the concentrations of nutrients in the sea have not declined accordingly (**Figures 1.1 and 1.2**). The long residence time of water in the open Baltic Sea as well as feedback mechanisms such as release of phosphorus from anoxic sediments, and the prevalence of nitrogen-fixing cyanobacteria blooms in the sub-basins of the Baltic Sea are processes that slow down the recovery from the eutrophied state (HELCOM 2014a, Vahtera et al. 2007).

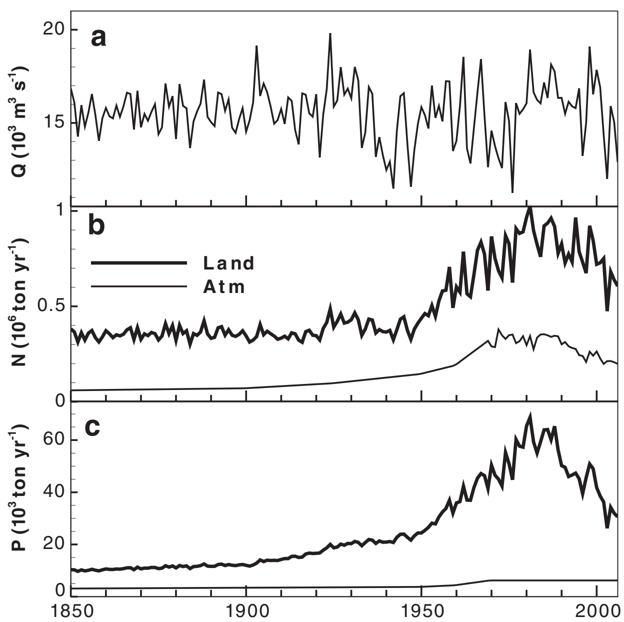


Figure 1.1. Long-term time series of a) annual average total river flow (Q), b) nitrogen (N), and c) phosphorus (P) loads from land and atmosphere to the whole Baltic Sea. (Source: Gustafsson et al. 2012)

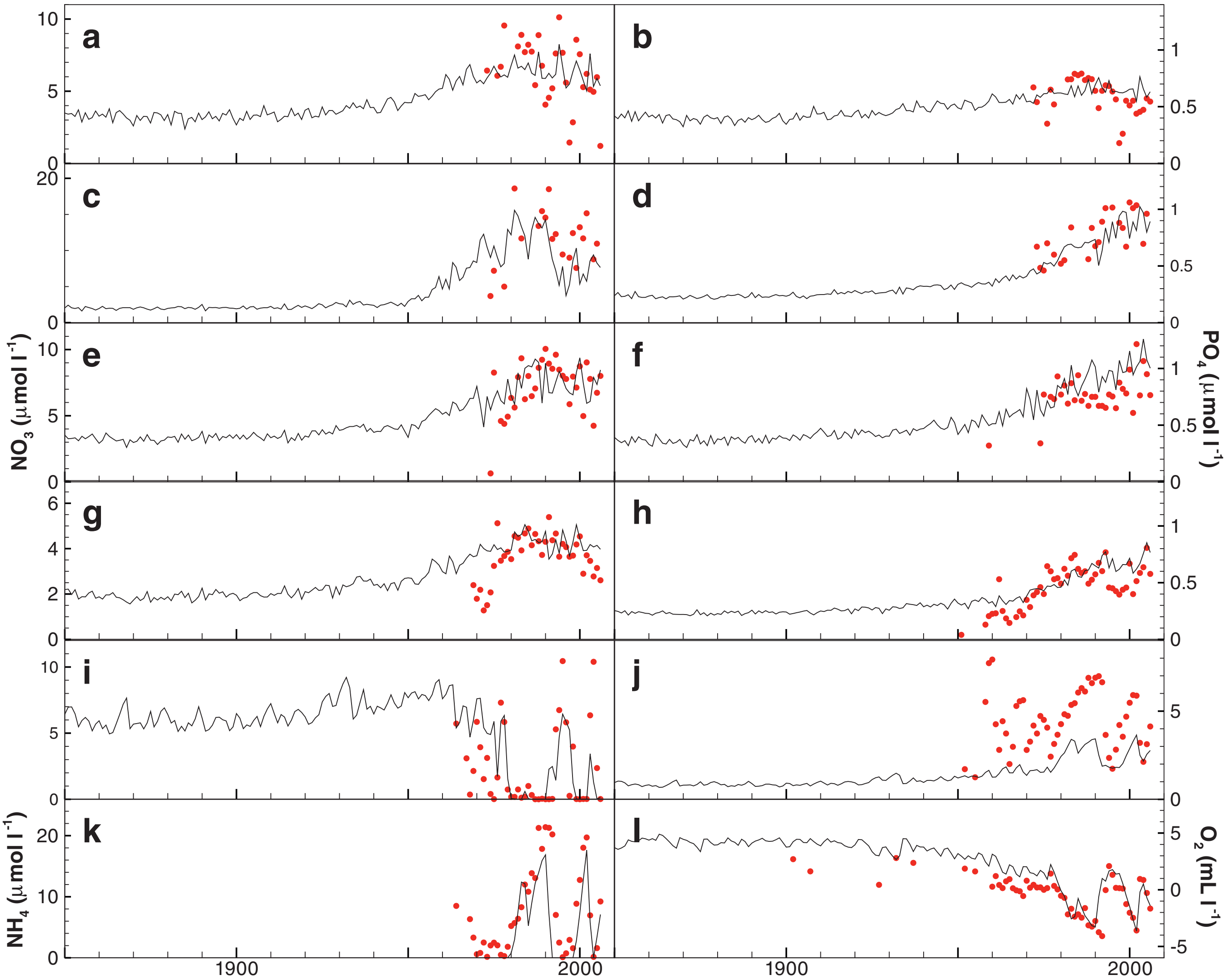


Figure 1.2. Winter average surface nitrate and phosphate concentrations in southern Kattegat (a, b), Gulf of Riga (c, d), Gulf of Finland (e, f), and Gotland Sea (g, h). Annual average nitrate (i), phosphate (j), ammonia (k), and oxygen (l) concentrations at 200 m depth in Gotland Sea. Lines are modelled and red dots are averages made from observations. Oxygen concentrations before 1950 are averaged over 5-year periods because of few available data. (Source: Gustafsson et al. 2012)

1.2. Objectives of the PLC

In order to implement the objectives of the Helsinki Convention (HELCOM 1974, HELCOM 1992), and the Baltic Sea Action Plan (BSAP) nutrient reduction scheme (HELCOM 2007, HELCOM 2013a), the Helsinki Commission (HELCOM) needs reliable data on nutrient inputs to the Baltic Sea. Pollution load compilations (PLCs) aim to quantify waterborne inputs from land-based sources in order to assess the effectiveness of measures taken to abate the pollution in the Baltic Sea catchment area, to follow-up on progress towards reaching BSAP nutrient reduction targets as well as to be able to identify further cost-effective measures for reducing pollution.

In March 2005, the Helsinki Commission adopted HELCOM Recommendation 26/2, which recommends that the quantified waterborne discharges from point sources and losses from non-point sources of pollution as well as the quantified natural background losses into surface waters in the catchment area of the Baltic Sea located within the borders of the Contracting Parties should be reported every six years, as specified in PLC guidelines.

To assess the total nutrient inputs entering the Baltic Sea also the atmospheric depositions of nutrients are included in the present report.

1.3. Previous PLC reports

Pollution load compilations have been performed on a regular basis since the late 1980s.

The *First Pollution Load Compilation (PLC-1)* was a first attempt to compile all available data on pollution loads from Contracting Parties (HELCOM 1987). The *Second Pollution Load Compilation (PLC-2)* covered inputs in 1990 (HELCOM 1993), the *Third Pollution Load Compilation (PLC-3)* covered 1995 inputs (HELCOM 1998) and the *Fourth Pollution Load Compilation (PLC-4)* was focused on inputs in 2000 (HELCOM 2004).

Table 1.1. Overview of past HELCOM pollution load compilation reports.

PLC No.	Year(s) covered	Main content/new information	Year published	Reference	Comments/data quality
1	Not specified	First attempt to compile the various types of data concerning inputs of nutrients and organic matter previously submitted to the Commission.	1987	BSEP 20	Data were often preliminary, background information or rough estimates, different methodologies were used and there were many data gaps.
2	1990	Total nutrient from rivers, direct inputs from urban areas and industries to the different Baltic Sea sub-basins.	1993	BSEP 45	Special set of guidelines for PLC-2 were developed, providing a unified methodology for measurements, calculations and reporting. Data set rather incomplete, use of different methodologies, many direct sources missing etc.
3	1995	Riverine and land-based waterborne pollution of BOD_7, nutrients and heavy metals.	1998	BSEP 70	A set of guidelines was prepared, including reporting requirements and a quality assurance system was established and an interlaboratory comparison test was performed. There were still many shortcomings, missing data and uncertainties in the amount of total inputs.
4	2000	Total waterborne nutrient inputs and partial estimates of inputs on heavy metals. PLC-4 guidelines were to some extent also harmonized with OSPAR HARP guidelines and included quantification of major sources of nitrogen and phosphorus using two approaches: source-oriented approach and load-oriented approach.	2004	BSEP 93	Another step forward in terms of quality, but there were still some missing data and problems with methodologies applied for part of the catchment area.
5	1994-2008	Total waterborne nutrient inputs and partial estimates of inputs on heavy metals and including source apportionment. Based mainly on data from the year 2006 but included also assessment of trends in loads between 1994 and 2008. Introduced flow-normalization and statistical trend analysis of nutrient load data. The Executive Summary also included atmospheric inputs.	2011 2012	BSEP 128 BSEP 128A (Executive Summary)	Significant gaps in the reported data were identified. Some of these are so serious that they complicate the interpretation of, for example, the trend analysis and the relative importance of different sources.
5.5	1994-2010	Based on PLC-5 but updated with nutrient input data up to 2010. Includes also atmospheric inputs of nitrogen and phosphorus. Estimates of changes in inputs since 1994 and comparison of inputs 2008-2010 with reference period 1997-2003.	2013	BSEP 141 (Review for 2013 Ministerial Meeting)	Estimate of total inputs improved by filling in of data gaps by experts, hence also improving assessment of trend and changes in nutrients inputs.

The *Fifth Pollution Load Compilation (PLC-5)* was published in 2011, and based mainly on data from the year 2006, but it also included trend assessments of annual inputs between 1994 and 2008 (HELCOM 2011). The PLC-5 introduced for the first time flow-normalization as well as statistical trend analysis of nutrient input data with the objective to smooth out the effects of variations in meteorological conditions on river flow, to better determine long-term trends and to allow for assessing whether HELCOM countries were achieving the provisional nutrient reduction targets that they had agreed upon in the HELCOM BSAP in 2007. During the compilation of the PLC-5 report, significant gaps and inconsistencies in the reported data for some sub-basins were identified that complicated the interpretation of, for example, the trend analysis and the relative importance of different sources.

For further details on the PLC history, see **Table 1.1** above and Chapter 1.2 in the PLC-4 report (HELCOM 2004) and Chapter 1.5 of the PLC-5 report (HELCOM 2011).

1.4. Main focus of the PLC-5.5 report

The 35th meeting of the HELCOM Heads of Delegation in 2011 agreed that a report on nutrient inputs to the Baltic Sea should be produced for the HELCOM ministerial meeting in 2013, updating the Fifth Baltic Sea Pollution Load Compilation (PLC-5) report (HELCOM 2011, HELCOM 2012) with the latest available data (up to 2010).

The report *Review of the Fifth Baltic Sea Pollution Load Compilation for the 2013 HELCOM Ministerial Meeting* was submitted to the Ministerial Meeting in October 2013 and published in the HELCOM Baltic Sea Environment Proceeding (No. 141) in December 2013 (HELCOM 2013a). This report is a more comprehensive assessment based on the exactly same data set.

The focus of the PLC-5.5 report is to:

- quantify and describe the total waterborne inputs to the Baltic Sea (from rivers, unmonitored and coastal areas as well as point sources discharging directly to the sea)
- quantify and describe the total atmospheric deposition of nutrients to the Baltic Sea and its sub-basins, including contribution from non-HELCOM sources and shipping
- evaluate changes and trends in the pollution loads since 1994/1995
- assess changes and trends in country- and sub-basin-wise nutrient inputs to the sea in relation to the reference period 1997-2003 that was agreed on in the BSAP nutrient reduction scheme.

The PLC-5.5 report is based on data collected by the HELCOM Contracting Parties and reported to the HELCOM PLC-Water database host Finnish Environment Institute (SYKE) and the European Monitoring and Evaluation Programme (EMEP), under the Convention on Long-range Transboundary Air Pollution (CLRTAP), which acts as HELCOM data consultant concerning atmospheric pollution loads.

Due to gaps and uncertainties in some data reported by the Contracting Parties, it has been necessary for the authors of this report to fill in and correct parts of the data set.[1] A complete data set is essential for evaluating trends in nutrient inputs and the effectiveness of measures to combat pollution. A description of the methods used to fill in data gaps is given in Chapter 3.4 of this report.

1 The complete PLC-5.5 data set and documentation on how it was compiled are available via the PLC-5.5 project page on the HELCOM website

2. Description of the Baltic Sea catchment area

The total Baltic Sea catchment area comprises 1,729,500 km², of which nearly 93% belongs to the HELCOM Contracting Parties and the remaining 7% lies within the territories of Non-Contracting Parties.

2.1. Division of the Baltic Sea catchment area

The division of each of the sub-basins of the catchment area between Contracting Parties and Non-Contracting Parties is illustrated in **Figure 2.1** and presented in **Table 2.1.**

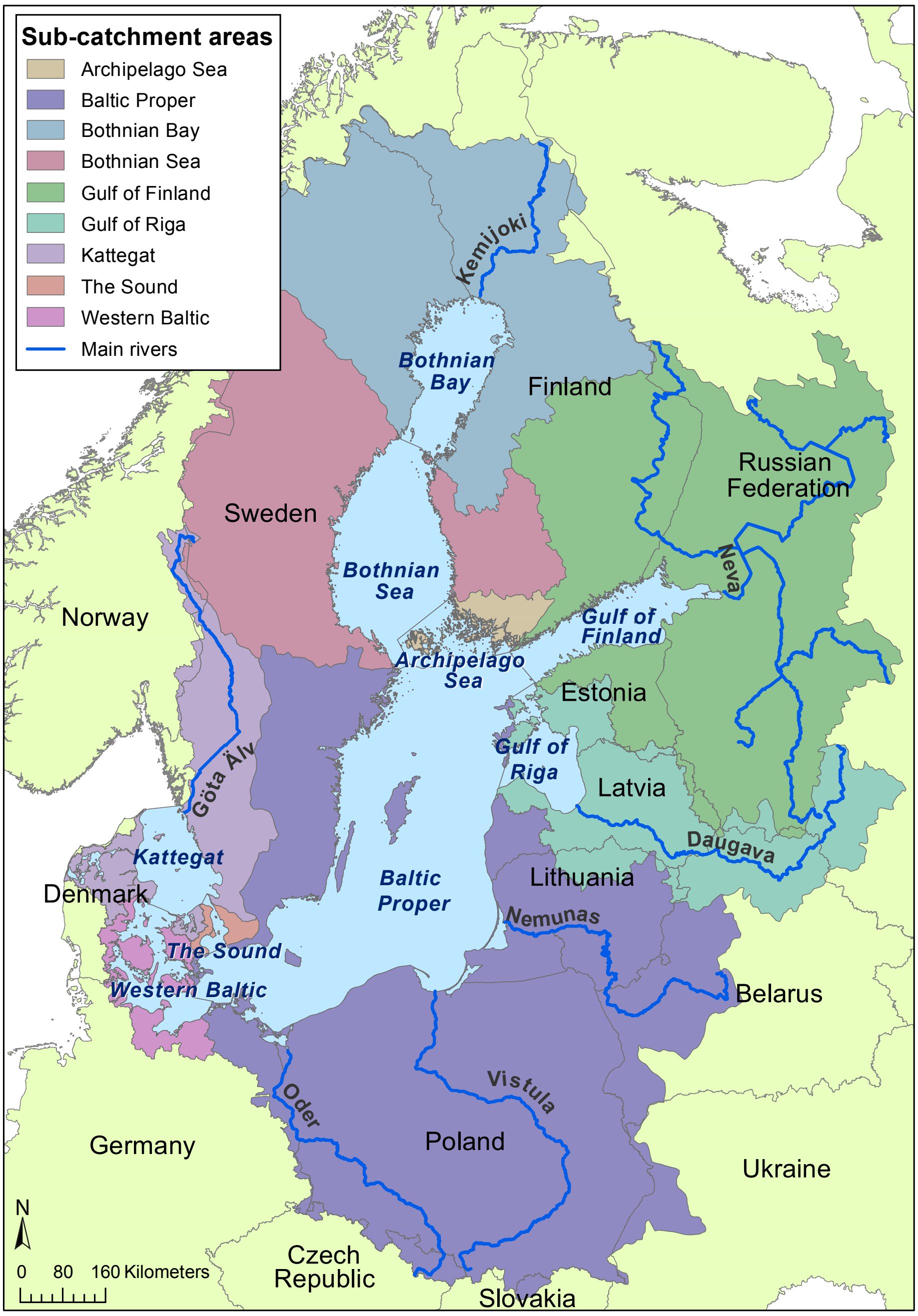


Figure 2.1. The Baltic Sea catchment area and sub-basins as defined for PLC-Water. Further the seven largest rivers discharging to the Baltic Sea are shown.

The sub-basin catchment areas of the Baltic Proper and the Gulf of Finland are the largest, covering 572,050 km² (33%) and 422,580 km² (24%), respectively. The Archipelago Sea and the Sound have the smallest catchment areas. Sweden possesses the largest portion of the Baltic Sea catchment area, 440,050 km² (25%). The next largest national catchment areas are those of Poland, Russia and Finland, all of which are larger than 300,000 km². Germany has the smallest proportion of the catchment area of all the HELCOM countries, at 28,600 km² (1.7%). The total catchment area outside the borders of the Contracting Parties is 125,030 km², mostly within Belarus.

A more detailed description of the Baltic Sea catchment area and its specific sub-catchments can be found in Chapter 2 of the Fourth Baltic Sea Pollution Load Compilation (PLC-4) report (HELCOM 2004).

The catchment areas of the seven largest rivers that discharge into the Baltic Sea take up 51% of the total Baltic Sea catchment area (**Table 2.2**).

Table 2.1. Division of the Baltic Sea catchment area between Contracting Parties and non-Contracting Parties for each sub-basin, in km².

Sub-basins/ country	Gulf of Bothnia			Gulf of Finland	Gulf of Riga	Baltic Proper	Belt Sea		The Kattegat	Total
	Bothnian Bay	Bothnian Sea	Archi-pelago Sea				Western Baltic	The Sound		
Contracting Parties										
Finland	146,000	39,300	8,950	107,000	-	-	-	-	-	301,250
Russia	-	-	-	285,580	18,500	12,500	-	-	-	316,580
Estonia	-	-	-	26,400	17,600	1,100	-	-	-	45,100
Latvia	-	-	-	3,600	49,600	11,400	-	-	-	64,600
Lithuania	-	-	-		11,140	54,160	-	-	-	65,300
Poland	-	-	-	-	-	311,900	-	-	-	311,900
Germany	-	-	-	-	-	18,200	10,400	-	-	28,600
Denmark	-	-	-	-	-	1,200	12,340	1,740	15,830	31,110
Sweden	113,620	176,610	-	-	-	83,230	-	2,890	63,700	440,050
Total	**259,620**	**215,910**	**8,950**	**422,580**	**96,840**	**493,690**	**22,740**	**4,630**	**79,530**	**1,604,490**
Non-Contracting Parties										
Belarus					33,300	58,050				91,350
Ukraine						11,170				11,170
Czech Republic						7,190				7,190
Slovakia						1,950				1,950
Norway	1,060	4,860							7,430	13,350
Total Baltic Sea catchment areas including Contracting Parties and Non-Contracting Parties										
Total	**260,680**	**220,770**	**8,950**	**422,580**	**130,140**	**572,050**	**22,740**	**4,630**	**86,960**	**1,729,500**

Table 2.2. Division of river catchment areas among Contracting and Non-Contracting Parties for the seven largest rivers discharging into the Baltic Sea.

Rivers / country	Neva	Vistula	Nemunas	Daugava	Odra	Göta älv	Kemijoki	Total
Long-term mean flows during 1981-2010 for the seven largest rivers discharging into the Baltic Sea								
in m^3/s	2,501	1,023	516	683	516	595	575	6,409
Length of the seven largest rivers								
in km	74[1]	1,047	937	1,020	854	756[2]	600	-
Catchment areas in Contracting Parties in km²								
Finland	56,200						49,470	105,670
Russia	224,800[3]		3,170	27,000			1,610	256,580
Estonia				1,340				1,340
Latvia			90	23,700				23,790
Lithuania			46,700	10,820				57,520
Poland		168,700	2,510		106,060			277,270
Germany					5,590			5,590
Denmark								
Sweden						42,470		42,470
Catchment areas in Non-Contracting Parties in km²								
Belarus		12,600	45,450	33,300				91,350
Ukraine		11,170						11,170
Czech Republic					7,190			7,190
Slovakia		1,950						1,950
Norway						7,430		7,430
Total catchment areas of the seven largest rivers, including Contracting and Non-Contracting Parties								
Total	**281,000**	**194,420[4]**	**97,920**	**96,160**	**118,840**	**49,900**	**51,080**	**889,320**

[1] length of the Neva from Lake Ladoga

[2] length of the Göta älv + Klarälven River (Göta älv from Lake Vänern to the sea is 93 km)

[3] the size of the catchment area of Neva is being reassessment and may change for future assessments

[4] without delta areas

2.2. Land use in the Baltic Sea catchment area

Over 84 million people live in the Baltic Sea catchment area, of which 64% are in the catchment of the Baltic Proper sub-basin. Forty-five percent of the total population living in the entire Baltic Sea catchment area live in Poland. The highest population densities are in the southern parts of the catchment area (**Figure 2.2**, **Table 2.3** and **Table 2.4**). Cities with large human populations and intense industrial activities are considered major point sources, although effective wastewater treatment can significantly reduce pollution inputs. Rural populations, with little or no treatment of sewage discharges can also have a significant impact on nutrient inputs.

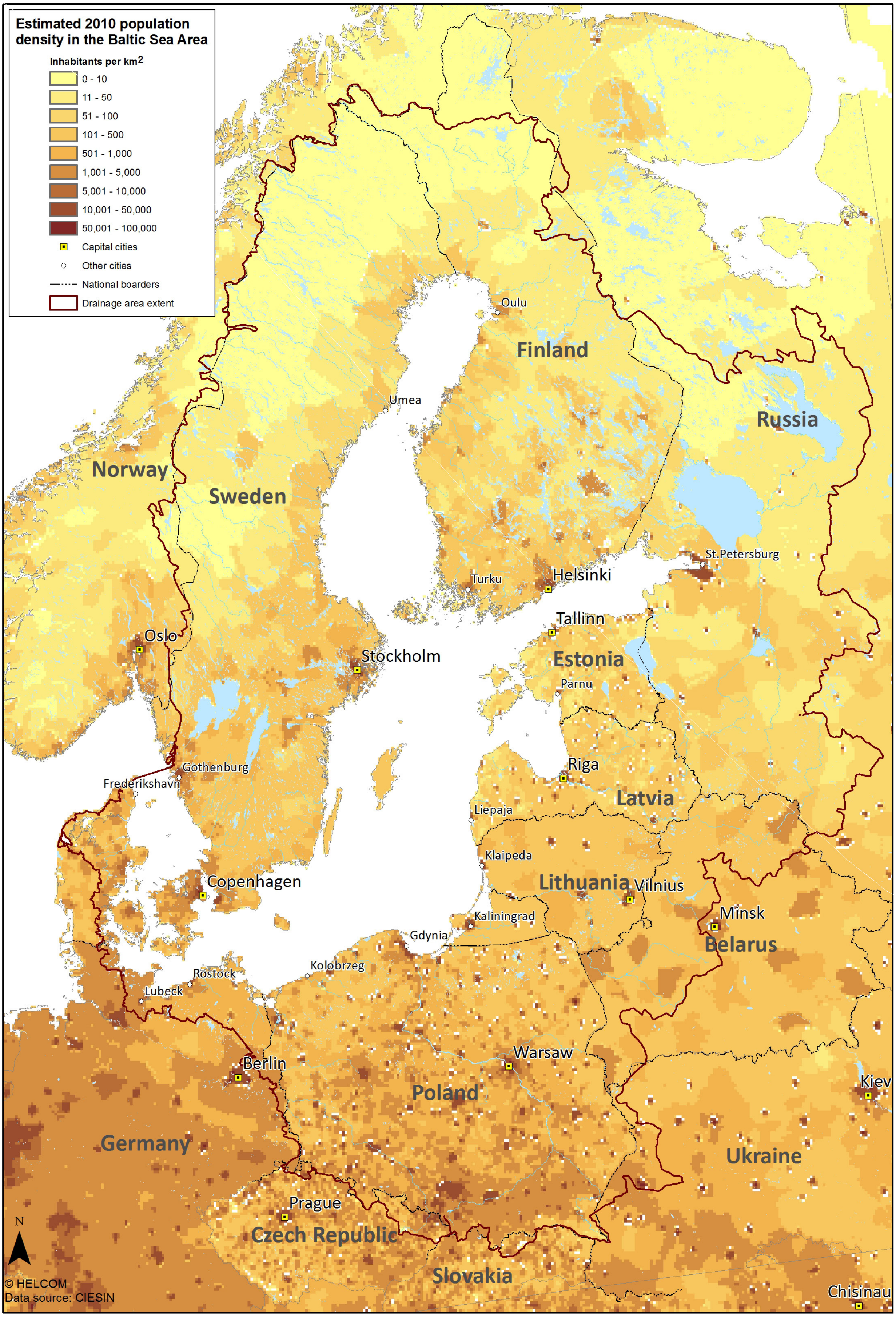


Figure 2.2. Estimated average population density in the Baltic Sea catchment area in 2010. (Data source: Center for International Earth Science Information Network – CIESIN)

Table 2.3. Population size and population density for the parts of countries that are within the Baltic Sea catchment area. The total country areas, including parts outside the catchment, are also given for comparison. (Data sources: UNEP 2005; FAOSTAT 2011; Federal Statistical Service of Russia 2009; National Statistical Committee of the Republic of Belarus 2010, National Statistical Bureaus).

Country	Country Area (km^2)	Baltic Sea catchment area (km^2)	Total population (in thousands) in the catchment in 2010	Catchment population density (persons km^{-2}) in 2010
		Contracting Parties		
Poland	312,700	311,900	38,200	122
Russia	17,098,200	304,080	9,200	30
Sweden	450,300	440,050	9,400	21
Finland	338,400	301,400	5,400	18
Denmark	43,100	31,100	4,500	145
Lithuania	65,300	65,300	3,300	51
Germany	357,100	28,600	3,100	108
Latvia	64,600	64,600	2,300	36
Estonia	45,100	45,100	1,300	29
		Non-Contracting Parties		
Belarus	207,600	91,350	4,000	44
Ukraine	603,700	11,170	1,800	161
Czech Republic	78,900	7,190	1,600	223
Slovakia	49,000	1,950	200	103
Norway	323,900	13,370	20	2

Table 2.4. Population and surface areas of the Baltic Sea catchment area and sub-regions in 2010 and average river flow 1994-2010.

Sub-region	Population (thousands)	Terrestrial surface area (km^2)	Marine surface area (km^2)	Average river flow 1994-2010 ($m^3 s^{-1}$)	Average runoff 1994-2010 ($l s^{-1} km^{-2}$)
Bothnian Bay	1,400	260,680	36,200	3,311	12.7
Bothnian Sea	2,300	220,770	63,400	2,843	12.9
Archipelago Sea	500	8,950	14,400	90	10.1
Gulf of Finland	12,100	422,580	30,000	3,408	8.1
Gulf of Riga	3,700	130,140	18,600	1,090	8.4
Baltic Proper	53,700	572,050	209,300	3,607	6.3
Western Baltic	4,400	22,740	18,600	186	8.2
The Sound	2,400	4,630	2,300	44	9.5
Kattegat	3,800	86,980	23,600	1,092	12.6
Total	**84,300**	**1,729,520**	**416,400**	**15,670**	**9.1**

Information about land cover can also help to interpret nutrient inputs originating from different parts of the Baltic Sea catchment. As illustrated in **Figure 2.3** the northern parts of the catchment area are dominated by forest and woodland, whereas large parts of Germany, Denmark and Poland consist of agricultural land.

Figure 2.3. Land cover in the Baltic Sea catchment area. (Source: CORINE land cover 2006)

According to a study by Hong et al. 2012, there is a north-south gradient in the net anthropogenic input of nutrients in the Baltic Sea catchment area (**Figure 2.4).**

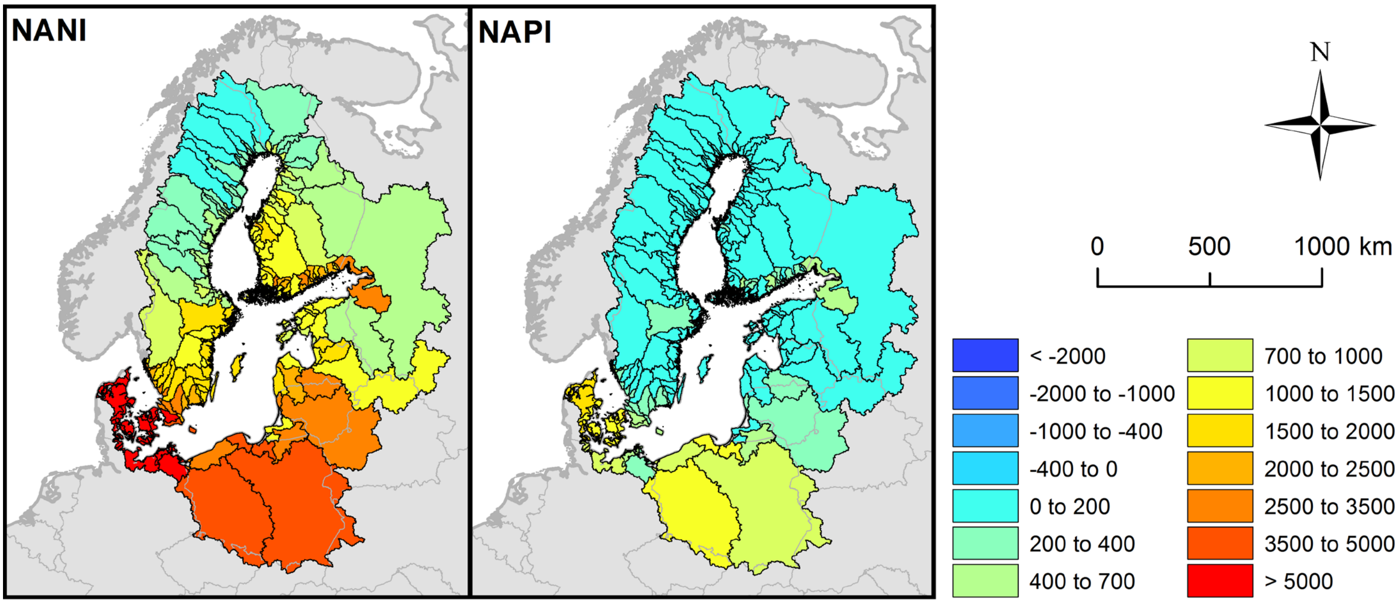


Figure 2.4. Net anthropogenic nutrient inputs for nitrogen (NANI, left panel, kg N km^{-2} yr^{-1}) and phosphorus (NAPI, right panel, kg P km^{-2} yr^{-1}) for the catchments. (Source: Hong et al. 2012)

Information on the application of nitrogen and phosphorus with fertilizer and manure by the HELCOM countries in 2010, expressed as kilograms per hectare agricultural land, indicates that the highest nitrogen application rates are in Germany and Denmark and the corresponding for phosphorus (mineral fertilizers only) are in Poland and Finland (**Table 2.5**). Livestock intensity, expressed in life stock units per hectare, is highest in Denmark and Germany and lowest in the Estonia, Latvia and Lithuania. The table is compiled from different sources, where the definition of agricultural land might differ and there can also be at least 5-10% variation in the application of nitrogen and phosphorus for a given year.

Table 2.5. Agricultural land (1,000 hectare), application of mineral fertilizer and manure of nitrogen and phosphorus and application of potassium (all in kg ha^{-1} agricultural land), as well as amount of livestock in cattle, pigs and total (expressed in livestock units per hectare agricultural land). Data are for the entire country in 2010, although manure (nitrogen) is an average from 2008-2011. Russia informed (Natalia Oblomkova, pers. comm.) that in 2010 for Kaliningrad, Leningrad, Novgorod, Pskov regions and Republic of Karelia 22,125 tonnes N of mineral based fertilizer and 714,590 tonnes N of manure based fertilizer were applied. n.a. = not available. (Data source: Russian Federal Statistical Service, Rosstat)

	DK	DE	EE	FI	LV	LT	PL	RU	SE
Agricultural area (1,000 ha)	2,700	16,700	950	2,300	1,800	2,800	15,500	n.a.	3,100
	Nitrogen: kg N ha^{-1} agricultural land								
Mineral fertilizer	73	107	39	62	26	51	70	9.8	57
Manure	84	76	15	43	17	27	31	n.a.	32
	Phosphorus: kg P ha^{-1} agricultural land								
Mineral fertilizer	3.9	5.6	2.1	6.3	2.2	4.1	8.6	3.6	2.5
Manure	14	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Potassium: kg K ha^{-1} agricultural land								
Total application	15	22	7.4	14	6.7	13	24		6.8
	Livestock units ha^{-1} agricultural land								
Cattle	0.42	0.54	0.19	0.29	0.17	0.21	0.28	n.a.	0.35
Pigs	1.30	0.38	0.09	0.14	0.05	0.07	0.24	n.a.	0.12
Total livestock	1.82	1.07	0.32	0.49	0.26	0.32	0.67	n.a.	0.57

The amounts of water- and airborne nutrient inputs to the sea are also affected by hydrological and meteorological conditions, which affect precipitation patterns (i.e. frequency and type) and temperature. During wet and warmer years (with less snow and ground frost) there are generally greater inputs of nutrients from diffuse sources. **Figure 2.5** shows long-term variations in precipitation, temperature, water resources and flood magnitude in Sweden, indicating an overall increase in temperature and precipitation during the last 100 years (HELCOM 2013).

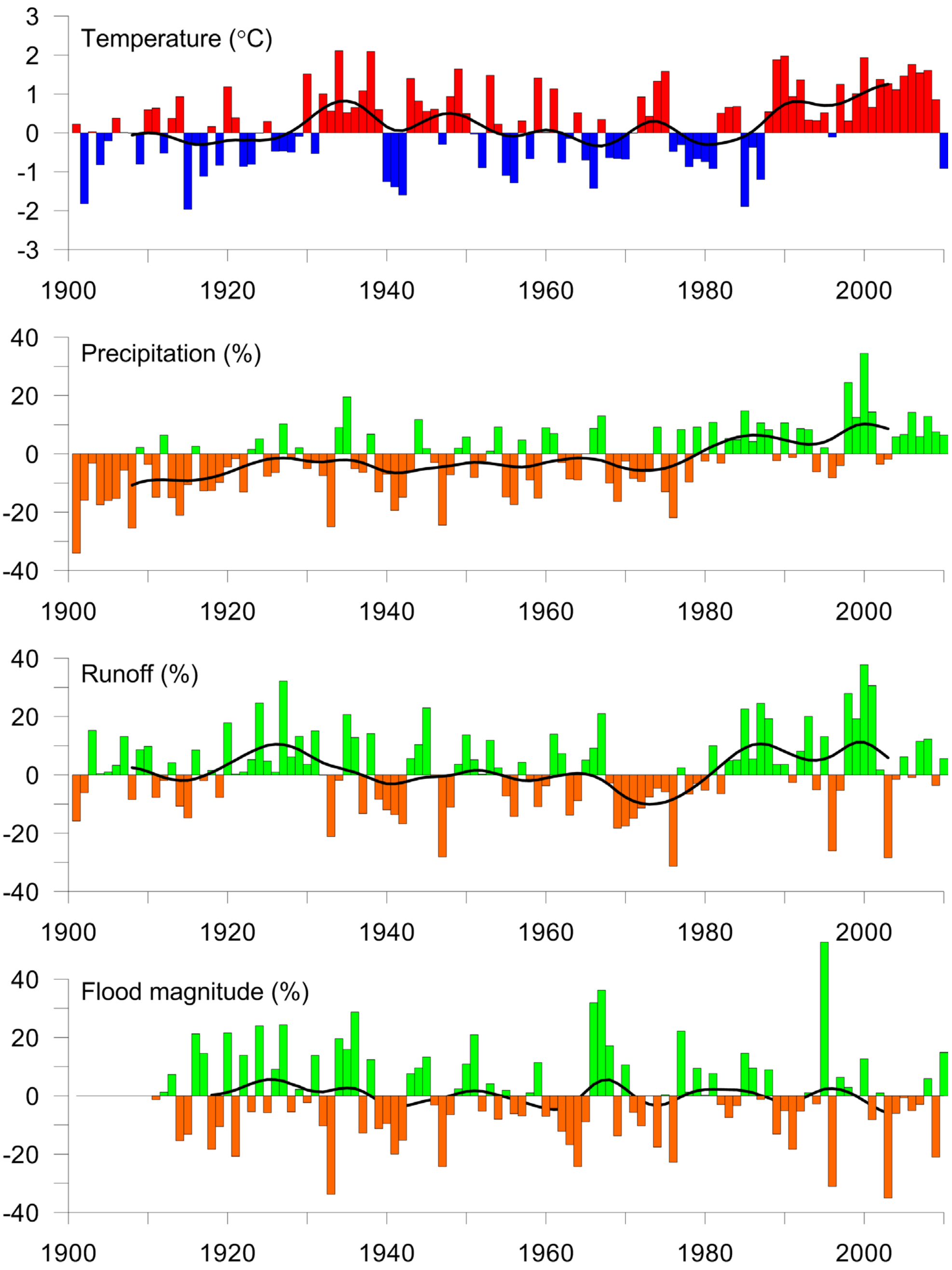


Figure 2.5. Annual anomalies (vs. 1961-1990) and long-term variations in precipitation, temperature, water resources and flood magnitude in Sweden, for the period 1901-2010. For flood magnitude, the years before 1911 were omitted due to data scarcity. (Source: From Hellström & Lindström 2008, updated until 2010 in HELCOM 2013d)

Atmospheric inputs to the sea (atmospheric deposition) are also largely affected by precipitation and meteorological conditions. Precipitation varies from year to year in different parts of the Baltic Sea. In 2010 the southern part of the Baltic Sea received more precipitation that northern parts (Figure 2.6). Further, areas with mountains and at higher elevation (especially on the windward side) receive substantially more rain than areas sheltered by mountains.

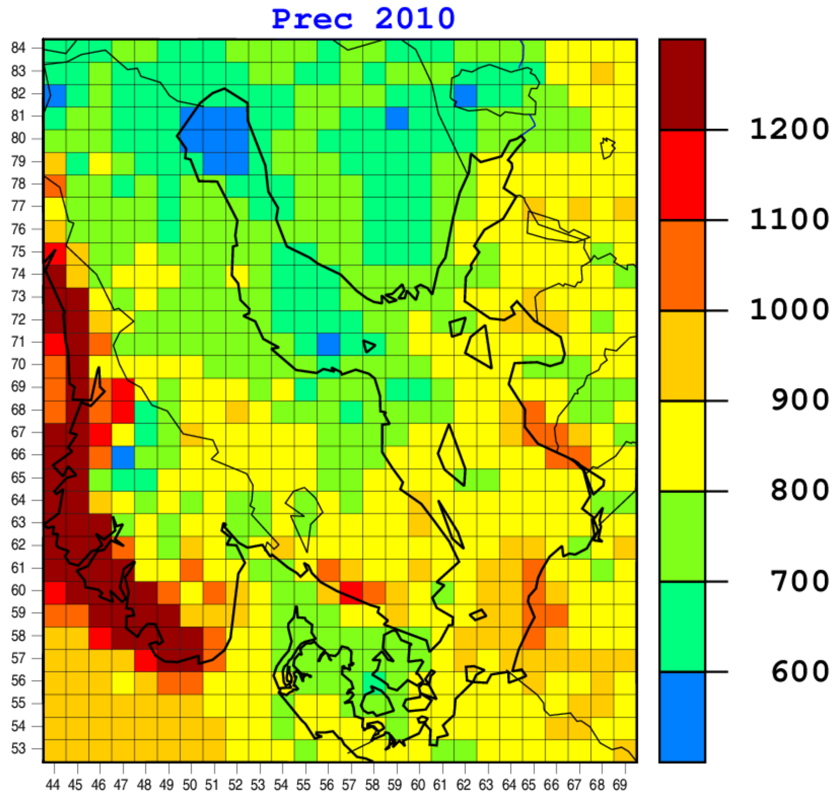


Figure 2.6. Annual precipitation in 2010 (unit: mm yr^{-1}) provided by EMEP (Bartnicki).

For more information about population, level of sewage treatment in the HELCOM countries, land use, fertilizer consumption and mean hydrological conditions in the Baltic Sea area, see Chapter 2 of the Fifth Baltic Sea Pollution Load Compilation, PLC-5 (HELCOM 2011).

3. Methodology and quality assurance

3.1. Classification of inputs

Land-based nutrient inputs enter the Baltic Sea either air- or waterborne (**Figure 3.1**). The main *pathways* of nutrient input to the Baltic Sea are:

- Riverine inputs of nutrients to the sea - nutrients entering inland surface waters within the Baltic Sea catchment area and transported by rivers to the sea.
- Point sources discharging directly to the sea.
- Direct atmospheric deposition on the Baltic Sea water surface.
- The net flux 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 fertilizer applications, animal manure and husbandry. Atmospheric emissions of airborne phosphorus are mainly emitted from combustion of coal and straw, and as a minor input combustion of oil and gas, while natural sources are wind suspended dust from soil, biological material as airborne algae, pollen, small plant fragments
- Point sources including inputs from municipalities, industries and fish farms both discharging into inland surface waters and directly into the Baltic Sea.
- Anthropogenic 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.
- 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.

As indicated in **Figure 3.1** nutrients enter inland waters by different pathways and are thereafter affected by a variety of processes in rivers and lakes. The amount of rainfall and the resulting water flow in rivers, 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 and surrounding land before they enter the sea, this is also called retention in inland surface waters.

A part of the nutrient input to the Baltic Sea originates from outside the HELCOM area (cf. Chapter 4.7). Distant sources contribute with a significant portion of atmospheric inputs of nitrogen.

Phosphorus enters the Baltic Sea mainly as waterborne input and to a lesser extent as atmospheric deposition. Based on monitoring information from the HELCOM countries compiled by the PLC-5.5 project, it is estimated that atmospheric deposition of phosphorus to the Baltic Sea in average is maximum 5 kg P km^{-2} or in total about 2,100 tonnes of phosphorus per year as compared to former estimates in the BSAP of 6,300 tonnes. This figure should be seen as a preliminary estimate based on results from land-based and coastal monitoring stations (HELCOM 2014b).

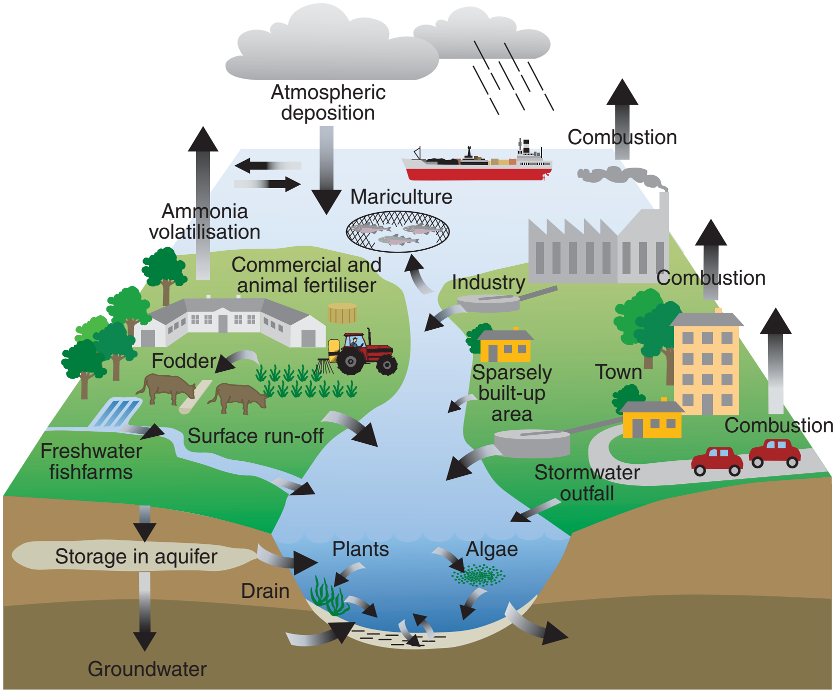


Figure 3-1. Different sources of nutrients to the sea and examples of nitrogen and phosphorus cycles. The flow related to ammonia volatilization shown in the figure applies only to nitrogen. In this report, also combustion and atmospheric deposition deal only with nitrogen. Emissions of phosphorus to the atmosphere by dust from soils are not shown in the figure. (Source: Ærtebjerg et al. 2003)

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 are considered in this report.

Annex 5 contains a list of definitions and abbreviations.

3.2. Methodology used for quantifying water- and airborne inputs, normalization of inputs, and trends analysis

The methodology used to quantify the water- and airborne inputs of nutrients and their sources is only briefly summarized in this report. For a comprehensive review of the methods please refer to the PLC guidelines, the PLC-5 report (especially source apportionment of nutrients), and the review of PLC-5 (PLC-5.5 report) (HELCOM 2006, 2011, 2013c, respectively).

3.2.1. Quantification of airborne inputs

The deposition of the nitrogen compounds to the Baltic Sea is calculated using data on emissions from several components, meteorology and land use together with the EMEP model for the nitrogen computations. The model also includes deposition of nitrogen originating from several countries outside of the HELCOM area. The model is calibrated against monitored nitrogen deposition.

A detailed description of the method for the calculation of atmospheric nitrogen deposition is presented in Annex 9.3.

Deposition of phosphorus is not modelled as there is no collection of emission data. Based on available monitored phosphorus deposition data, a fixed annual rate of 5 kg P km^{-2} is used (HELCOM 2014b).

3.2.2. Quantification of waterborne inputs

The annual PLC data reporting consists of riverine inputs and point sources discharging directly to the Sea. The riverine inputs are calculated based on measurements in monitored river systems and estimates from unmonitored areas. Typically, water samples are taken in the monitored rivers on a monthly basis, whereas the river flow often is based on daily observations. Generally, the nutrient concentrations are interpolated or modelled to daily estimates, and together with the daily river flow, daily loads are calculated. These loads are summed to annual totals, which are the prime interest for the PLC assessments. The load estimates from unmonitored areas are generally based on modelled data or from area-specific inputs from adjacent and similar monitored river systems. The inputs from directly discharging point sources are based on a multitude of monitoring schedules, largely depending on the size of the point source or its input, i.e. the larger the source the more often the outlet is monitored. Hence, the sampling frequency may vary from a few occasions per year to daily sampling at significant point sources.

3.2.3. Normalization of inputs

Hydrological normalizations of riverine inputs are performed to reduce the impact of interannual variability in weather conditions. This is done to allow for trend analysis of inputs that are more comparable to each other and to make it easier to detect trends and effects of measures taken in the catchment areas that would otherwise be hidden among the usually large variation in river flow. The empirical hydrological normalization method used is based on the linear relationship between the log-transformed annual river flow and the log-transformed annual nutrient input. Further details are given in Annex 4, Chapter 9.4.

Atmospheric deposition is normalized to reduce the influence of meteorology on computed annual nitrogen depositions. EMEP runs their model with the same emissions from one particular year, but with all available different meteorological years, and then calculate the median deposition for the years that will be used as the estimated normalized deposition. For simplification EMEP have used the source-receptor matrices and depositions as defined in Annex 3, Chapter 9.3 (equations 5 and 6) and calculated for each of 16-year period 1995-2010 with available EMEP model runs. For each year in the period 1995-2010 the “normalized” depositions to the Baltic Sea were calculated for oxidized, reduced and total nitrogen. Further details are given in Annex 9.3.

3.2.4. Trend analysis

The Mann-Kendall non-parametric test of monotone trends is used to statistically test for potential trends in nutrient inputs, and the slope of statistically significant trends are estimated by the Theil-Sen method for linear trends (Hirsch et al., 1982). The trend analyses are performed on normalized inputs to ensure low impact of interannual variation in river flow. Further details are given in Larsen & Svendsen (2013). The results of the trends analysis are given in Chapter 5.5.

3.3. Analytical methods for water analyses

The PLC-5 guidelines contain recommended analytical methodology for the different substances in river water and wastewater. These are well tested and documented European or international methods (EN or ISO) or methods based on these standards, and the countries are highly recommended to follow these standard methods. However, it has not been specified as mandatory to use the recommended methods since none of the parameters are dependent on the analytical method. Further, the PLC-5 guidelines include instructions to avoid potential errors.

The PLC-5 guidelines state that Contracting Parties are responsible for the quality assurance of the data submitted to HELCOM PLC-Water database. Participating laboratories are encouraged to endeavour official accreditation for variables on which they report data in accordance with PLC guidelines. For accredited laboratories it is usually a requirement to follow EN ISO/EC 17025. If the laboratories do not have the recommended accreditation the analytical methods should be validated and documented according to EN ISO/EC 17025 or similar, and the laboratory should have a quality assurance system according to the requirements of the EN ISO/IEC 17025. Besides, all laboratories should participate in regular interlaboratory comparison tests and appropriate reference materials should regularly be used. The quality assurance procedures within the PLC-5.5 project are further elaborated in Annex 2, Chapter 9.2, which also includes an overview of the limits of quantification (LOQ) and limits of detection (LOD) for chemical analysis of river water and wastewater given by the Contracting Parties.

3.4. Data basis

3.4.1. Data reporting

The HELCOM Contracting Parties annually report inputs from rivers and direct point sources to Baltic Sea sub-basins. Compared to the Fifth Pollution Load Compilation (HELCOM 2011), which included waterborne data from 1994 to 2008, this assessment includes also data from 2009 and 2010. Additionally, most Contracting Parties have updated or revised old PLC data covering the period 1994-2008, e.g. by providing missing data and/or correcting previously reported data. The PLC-5.5 data set is based on data provided by Contracting Parties until July 2013; data reported after that has not been included in the data set used for this assessment. Further, as part of the PLC-5.5 project, the HELCOM LOAD Core Group and BNI Sweden have made great efforts to fill in data gaps/missing data and provide proposals for correcting suspicious data as described in the review of the PLC-5 report and in a separate report on the preparation of the PLC-5.5 data (HELCOM 2013c and HELCOM 2013e).

Hence, the most complete, consistent and quality assured PLC data set ever has been developed covering the 1994-2010 waterborne inputs to the Baltic Sea. All changes, including filling in data gaps, have been discussed with the Contracting Parties, and the PLC-5.5 data set was approved by all the HELCOM Contracting Parties for use in the PLC-5.5 report and for revised calculations of the BSAP maximum allowable nutrient inputs (MAI) and the new country-wise allocation of reduction targets (CART) (HELCOM 2013a)[2].

In general, the updating of older data, filling in data gaps and removing or correcting outliers increased annual waterborne total nitrogen, total phosphorus and the total water flow to the Baltic Sea, but for some years, such as 2003 and

2 Russia has not accepted to include the present Russian PLC-5.5 data in the PLC-Water database as official Russian data

2004 for total nitrogen and 1995 for total phosphorus, it decreased (**Figure 3.2**). In the updated PLC-5 data set, total annual water flow increased for most years with 2-5% while total waterborne nitrogen and total phosphorus for most years increased with 2-15% and 4-15%, respectively. When comparing the PLC-5.5 data set with the PLC-5 data set, the main changes can be seen for waterborne inputs to the Gulf of Finland, Gulf of Riga and southern parts of the Baltic Proper, while only minor changes are seen for the remaining parts of the Baltic Sea.

Figure 3.2. Comparison of total annual water flow (top), annual waterborne inputs of total nitrogen (middle) and total phosphorus (bottom) during 1994-2008 to the Baltic Sea using the data set in the PLC-5 report (HELCOM 2011 and HELCOM 2012) and the updated data set for PLC-5.5 report (HELCOM 2013c).

Data on atmospheric inputs covers 1995-2010, where 1995-2008 have also been updated and recalculated since the last PLC assessment (HELCOM 2012). Data on 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. More information is given in Annex 3, Chapter 9.3.

3.4.2. Filling in data gaps, removing outliers and updating data

The most important data gaps and challenges that had to be solved to obtain a complete and consistent PLC-5.5 data set are summarized below (further details are given in HELCOM 2013e).

Data gaps that have been filled in/estimated by the PLC-5.5 project:

- Flow: e.g. all water flows from Latvia from 2009-2010 and unmonitored areas from 1994-2003 and 2007-2010. All Russian water flows from unmonitored areas and 17 small rivers.
- Nitrogen: e.g. all Latvian data from 2009-2010 and unmonitored areas from 1994-2003 and 2007-2010. All Russian data from rivers from 1994-1999 to the Gulf of Finland and from 1994-2003 and 2007-2010 to the Baltic Proper as well as all data from unmonitored areas and 17 small rivers.
- Phosphorus: e.g. all Latvian data from 2009-2010 and all Russian data from unmonitored areas and 17 small rivers.
- Some countries are missing data from direct wastewater treatment plants and direct industry partly or fully for one or several years (water flow, nitrogen, phosphorus).

The following main challenges have been dealt with in order to complete the PLC-5.5 data set (details on how it was handled are described in HELCOM 2013e):

- Some countries only monitored and reported inorganic (dissolved) nutrient fractions for some years (i.e. no total amounts were monitored/reported).
- Nemunas 1994: Nitrogen and phosphorus inputs were exceptionally high. Further, it has been clear that inputs from Matrosovka (a channel from the River Nemunas that enters from Lithuania into the Kaliningrad region) were included in the total Nemunas inputs for some years, but not in other years.
- There was no obvious explanation for very high inputs for some years in some rivers (e.g. the Odra and Vistula in Poland and the Neva in Russia).
- Monitored rivers: Data on total nitrogen and total phosphorus was missing for River Pregolya for 1994-2005 and 2007-2010. For 2004-2006, only the inorganic fractions of nitrogen and phosphorus are available. Total nitrogen was missing for River Neva for 1997-1998 and for River Seleznevka for 1994-2010. Total nitrogen and total phosphorus for the River Luga were missing for 1994-2000. Further, phosphorus inputs seemed to be very low until 2008 in River Luga. For River Neva, River Seleznevka and River Luga dissolved nitrogen and phosphorus (fractions) were reported for the years where total data on nitrogen and total phosphorus were missing.
- The monitored nitrogen inputs from the Neva for 1994-1999 were missing and the monitored phosphorus inputs seemed to include only the dissolved phosphorus fractions.

- Direct point source inputs are included in unmonitored or coastal inputs for some years; the reporting of direct point sources in many cases does not cover all point sources. Further, some countries sometimes include direct inputs in unmonitored areas/coastal areas or even in monitored inputs. This has not been solved completely, which mainly affects the statistical analyses on trends on direct inputs from some countries to some Baltic Sea sub-basins, but does not affect total waterborne inputs.

3.4.3. Transboundary inputs

Waterborne transboundary inputs from other Contracting Parties and non-Contracting Parties are included in the inputs from the Contracting Party where these inputs enter the Baltic Sea. For example, the waterborne inputs to Gulf of Riga at the outlet of Daugava (in Latvia) include transboundary inputs from Russia and Belarus, and a minor contribution from Lithuania and Estonia; however, the inputs are included as part of the waterborne values from Latvia. The Lithuanian inputs to the Baltic Proper are based on the reported Lithuanian data and estimated inputs from the Matrosovka Canal, calculated by the PLC-5.5 project. The estimated net transboundary waterborne inputs from non-Contracting Parties and Contracting Parties, taking into account retention within surface waters, are included in **Tables 4.7a** and **4.7b**).

3.5. Uncertainties in modelled and calculated data

3.5.1. Atmospheric deposition

The deposition of nitrogen compounds to the Baltic Sea is calculated using emissions from several components, meteorology and land use data together with the EMEP model for the nitrogen computations. A detailed description of the method for the calculation is presented in Annex 3, Chapter 9.3.

Countries participating in the EMEP programme annually report their emission inventory data to the EMEP Centre of Emission Inventories and Projections (CEIP, http://www.ceip.at) using standard formats in accordance with the EMEP reporting guidelines. In the modelling of the nitrogen deposition to the Baltic Sea at the MSC-W, expert estimates for the emissions are used when data is missing or unrealistic. This reduces the risk for large anomalies in the calculations of the depositions and source-allocation budgets in case of substantial errors in the emissions estimates. CEIP also regularly audits the emission estimates. Increased quality of the emissions and land use data has gradually improved the deposition estimates.

In this report, the modelling results of nitrogen deposition originating from ship emissions are calculated by EMEP MSC-W based on ship traffic emissions derived from the IIASA ship emission estimates for the years 2005 and 2010 with a linear interpolation between the years. In a more detailed estimate of Baltic Sea shipping emissions, based on the information from the automatic identification system (AIS), which enable the positioning of ships with a high spatial resolution (Jalkanen et al., 2013), the NO_x emissions were 17% higher than the EMEP estimates (Bartnicki et al., 2011).

The estimated phosphorus deposition in this report is based on a constant deposition rate based on data collected by Contracting Parties (HELCOM 2014b) with no temporal or spatial change. The reason is that only a limited number of measurements from the HELCOM countries and no emission data for the modelling work were available for evaluation. For most countries, measurements only covered wet deposition and there was a lack of data on particulate or dry deposition.

EMEP estimates that the modelled atmospheric deposition deviates on average with about 20% from monitored deposition rates (Jerzy Bartnicki, pers. comm.).

3.5.2. Waterborne inputs

The total uncertainty of total waterborne input is a sum of a number of different uncertainty components (Larsen & Svendsen 2013):

- Uncertainty due to field sampling (uncertainty from field water sampling, how often, uncertainty from measurements of water velocity and stage, etc.).
- Laboratory uncertainty (uncertainty caused by laboratory analysis processes).
- Uncertainty deriving from the sampling set-up (how often, where and when, sampling location, time) and the methods for calculating water flow (either stage-discharge relationship or other methods) and input (based on combined concentrations and river flow).
- Uncertainty from estimation of unmonitored inputs (bias from omitting unmeasured inputs and uncertainty of the methods applied for estimating unmonitored inputs).
  - Uncertainty of inputs from direct point sources, including sampling, analytical errors, etc.

and probably several other contributing components.

Further variation introduced by year-to-year differences in weather conditions (amount, type, and distribution of rainfall), as well as changes in accumulated pools of snow/ice, soil and groundwater must be taken into account.

Uncertainty consists of two components, precision and bias, but is often given as one value. The uncertainties for many of the components listed above are not quantified or estimated, but the uncertainty on individual water flow quantifications are well known and should in most cases be lower than ± 5% (Herschy 2009 and WMO 2008). The precision of daily water flow depends on the number of discharge observations. For open gauging stations in stream channels in Denmark the uncertainty ranges from 8% (given as standard deviation) with 10 annual discharge observations (measurements of discharge), to about 6% with 12 measurements and less than 1% with more than 40 annual measurements (Kronvang et al. 2014). For modelled water flow the uncertainty might be higher. For chemical analysis the requirement in Denmark is that the total (expanded) uncertainty for total nitrogen and total phosphorus should be less than 15% (or 0.1 mg N l^{-1} and 0.01 mg P l^{-1} at low concentrations in freshwater, respectively 5 mg N l^{-1} and 1 mg P l^{-1} at low concentrations in wastewater).

The uncertainty of the total waterborne nutrient inputs to the Baltic Sea, per country or sub-basin, is the result of uncertainty estimates from several monitoring stations, unmonitored areas, and direct inputs. Denmark has estimated bias and precision for different catchment scales pending on sampling frequency (**Table 3.1**), and it is rather obvious that the uncertainty is reduced with higher aggregation level (bigger catchment size). The uncertainty of total Danish waterborne nitrogen inputs is 2.1% and 3.4% for phosphorus (Kronvang et al. 2014).

In general, countries have not assessed the total uncertainty of their nutrient inputs. The PLC-5.5 project roughly estimates an uncertainty of 15-25% for annual total waterborne nitrogen and 20-30% on total phosphorus inputs to Kattegat, Western Baltic, the major part of Baltic Proper, Bothnian Bay and Bothnian Sea, and for the remaining part of the Baltic Sea up to 50% uncertainty. The uncertainty for annual water flow to the above listed sub-basins is estimated to 5-10% for most sub-basins and 10-20% for the remaining ones.

Table 3.1. Danish uncertainty estimates (Bias and precision) on total waterborne phosphorus loads in three rivers and on Danish national scale for total waterborne inputs of nitrogen and phosphorus. After Kronvang et al., 2014. StDev = standard deviation.

Sampling Frequency	Small scale (10 km^2) Gelbæk River Total P	Medium scale (100 km^2) Gjern River Total P	Larger scale (500 km^2) Odense River Total P	Danish national scale	
				Total N	Total P
Accuracy (Bias)				-2.0%	-3.0%
Monthly	-18%	-6.1%	-3.0%		
Fortnightly	-16%	-4.8%	-2.0%		
Precision (StDev)				0.5%	1.6%
Monthly	22%	16%	12%		
Fortnightly	12%	9.3%	6.7%		

For the next PLC assessment (PLC-6), Contracting Parties are urged to collect and report information on the uncertainty for the main uncertainty sources mentioned above and to provide estimates on the total uncertainty of national data sets on total water flow and nutrient inputs to the sub-basins of the Baltic Sea.

Photo by Seppo Knuuttila

4. Water flow and inputs of nutrients in 2010

This chapter concerns total air- and waterborne nutrient inputs to the Baltic Sea in 2010 per sub-basin and per country. The majority of the results are given as the actual[3] inputs. However, to facilitate comparison with inputs from former years and to remove some of the interannual annual variation caused by weather conditions also some normalized nutrient input data are presented. Methods of normalization are described in Annex 3, Chapter 9.3 (airborne inputs) and Annex 4, Chapter 9.4 (waterborne inputs).

4.1. Total nutrient inputs to the Baltic Sea in 2010

HELCOM countries report their total waterborne inputs of nitrogen and phosphorus from rivers, unmonitored and coastal areas as well as point sources discharging directly to the Baltic Sea on an annual basis. They also report emissions of nitrogen compounds to air to the Convention on Long-Range Transboundary Air Pollution (LRTAP), which are used by EMEP to calculate nitrogen deposition to the Baltic Sea.

Source apportionment of waterborne inputs of nutrients was last assessed using 2006 data in the PLC-5 report (HELCOM 2011). The next source inventory and assessment will be part of the PLC-6 project and mainly based on 2014 data. Sources of atmospherically deposited nitrogen are comprehensively described in the annual report by EMEP to HELCOM (EMEP 2012). The present report will only include some few examples of sources.

The annual nutrient inputs to the sea are often reported as total amounts by country and sub-basin. 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 to the sea. Inorganic forms of nitrogen and phosphorus are normally readily available for algae, whereas organic nitrogen leached from coniferous forest areas, for example, is considered to have low direct bioavailability. Another aspect to consider is that considerable amounts of waterborne nutrients may be retained or transformed in coastal waters and thus do not reach the open sea directly, as opposed to nitrogen deposited from the atmosphere.

The contributions of actual waterborne and airborne inputs from HELCOM countries, Baltic Sea shipping and distant sources to the Baltic Sea in 2010 are presented in **Figures 4.1a** and **4.1b**.

3 Actual inputs are the inputs that have not been flow normalized (riverine) or normalized (airborne).

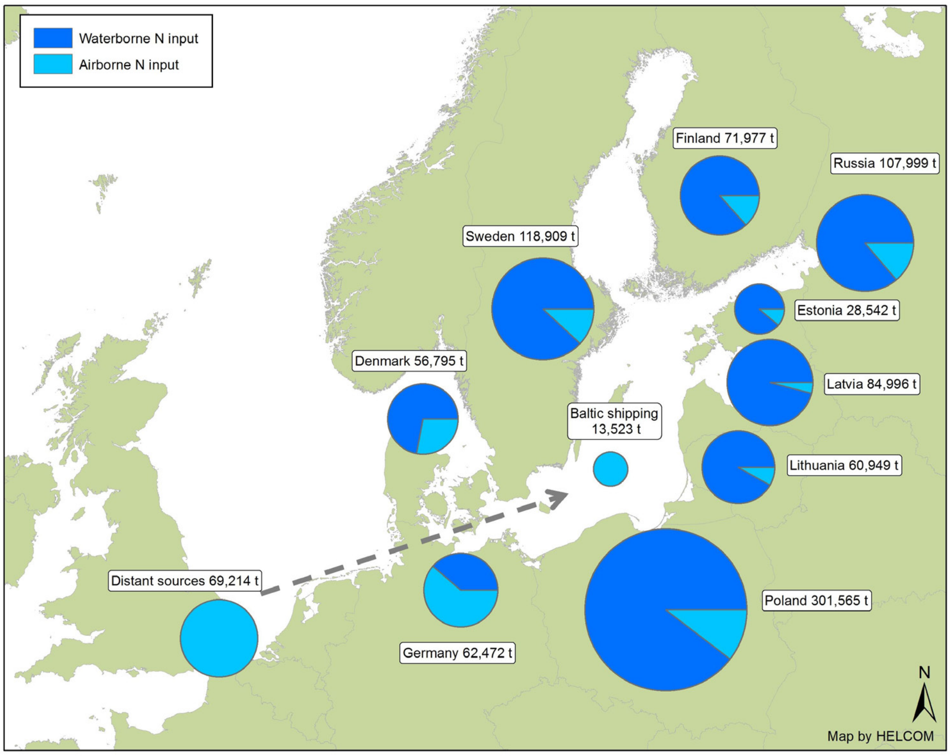


Figure 4.1a. Total actual inputs of water- and airborne nitrogen from HELCOM countries, Baltic Sea shipping and distant sources to the Baltic Sea in 2010. *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

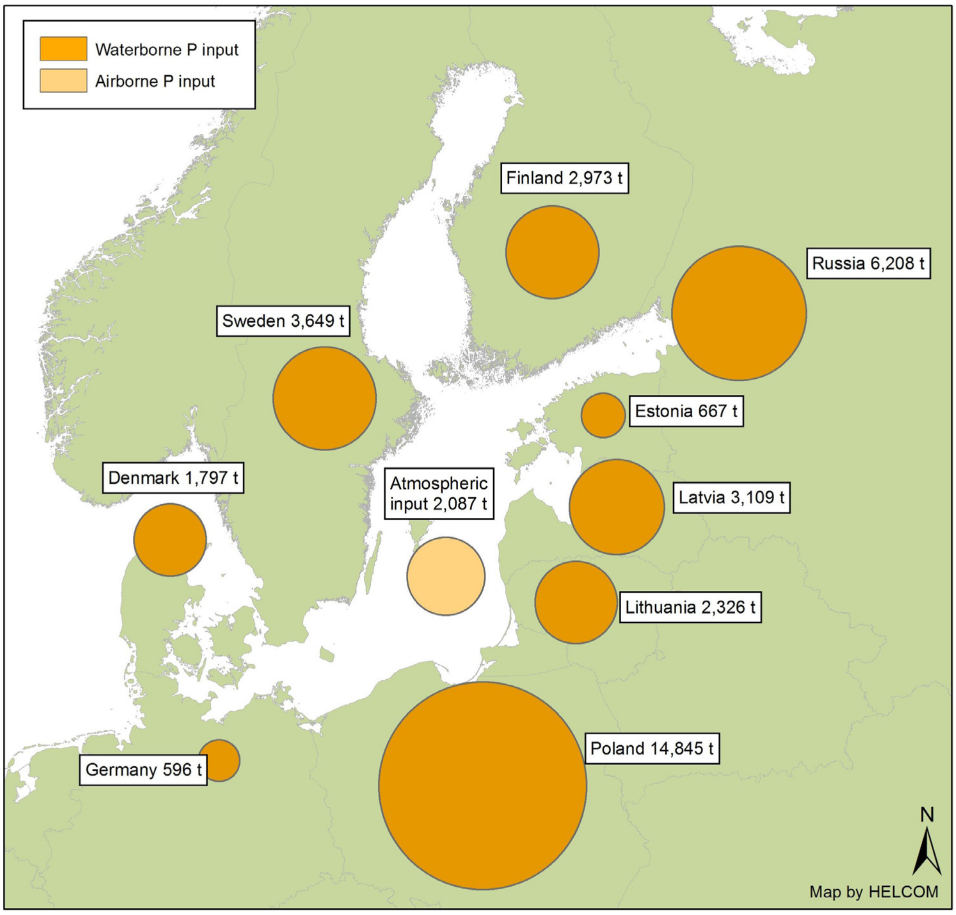


Figure 4.1b. Total actual inputs of water- and airborne phosphorus from HELCOM countries to the Baltic Sea in 2010. *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

The total nutrient input to the Baltic Sea can vary significantly depending on whether it is a wet or dry year. For example, 2010 was a very wet year in the southern part of the Baltic Sea catchment area and the actual (not normalized) nutrient input figures presented in this report are therefore very high for some countries. Further, the actual atmospheric nitrogen deposition was also rather high in 2010.

In 2010, the total water- and airborne inputs of nitrogen and phosphorus to the Baltic Sea were 977,000 tonnes of nitrogen and 38,300 tonnes of phosphorus (**Tables 4.1a** and **4.1b)**. Atmospheric nitrogen deposition amounted to 218,600 tonnes (22%) of the total nitrogen input. Atmospheric phosphorus deposition, which is assumed to be the same every year (or nearly 2,100 tonnes), constituted 5% of the total phosphorus input to the Baltic Sea. To eliminate as far as possible the influence of weather conditions, the flow normalized waterborne and normalized airborne inputs to the Baltic Sea have also been calculated (**Tables 4.2a** and **4.2b**). The total normalized nitrogen and phosphorus inputs in 2010 were considerably lower than the actual inputs (802,000 tonnes of nitrogen (18% lower) and 32,200 tonnes of phosphorus (16% lower)). The normalized nitrogen atmospheric deposition was 193,000 tonnes nitrogen or 24% of the total nitrogen input to the Baltic Sea. Normalized total nitrogen inputs, especially from Poland, Lithuania and Russia, were considerably lower than the actual total inputs, while they were higher for Finland. See also note to Table 4.1a regarding the preconditions on the PLC-5.5 data set.

Tables 4.1a and **4.1b.** Water flow as well as actual (non-normalized) waterborne and airborne inputs of phosphorus and nitrogen to the Baltic Sea in 2010 by a) country and b) sub-basin. EU20 = non-HELCOM EU countries; 'other air' and 'atmospheric phosphorus sources' = other countries and sources contributing to atmospheric deposition on the Baltic Sea. *Note: The PLC-5.5 data set was approved by HELCOM HOD 38/2012 for the development of the revised MAI, the new CART and the PLC-5.5 report; however, Russia has not accepted them as official data to be included in the PLC-Water database. The data include transboundary inputs (waterborne and airborne) to the Baltic Sea.*

Table 4.1a

Country	Flow (m^3s^{-1})	Nitrogen (t)			Phosphorus (t)		
		Waterborne	Airborne	Total	Waterborne	Airborne	Total
Denmark	313	40,881	15,914	56,795	1,797		1,797
Estonia	452	25,362	3,180	28,542	667		667
Finland	2,326	62,255	9,722	71,977	2,973		2,973
Germany	128	24,145	38,327	62,472	596		596
Latvia	1,369	81,539	3,457	84,996	3,109		3,109
Lithuania	790	55,980	4,969	60,949	2,326		2,326
Poland	2,880	270,287	31,278	301,565	14,845		14,845
Russia	3,577	93,186	14,813	107,999	6,208		6,208
Sweden	5,863	104,702	14,207	118,909	3,649		3,649
Baltic Shipping			13,523	13,523			
EU20			39,987	39,987			
Other air			29,227	29,227			
Atmos. P sources						2,087	2,087
Total	**17,698**	**758,337**	**218,604**	**976,941**	**36,168**	**2,087**	**38,255**

Table 4.1b

Country	Flow (m^3s^{-1})	Nitrogen (t)			Phosphorus (t)		
		Water-borne	Airborne	Total	Water-borne	Airborne	Total
Bothnian Bay	3,136	43,267	9,140	52,407	2,618	181	2,799
Bothnian Sea	2,926	46,247	26,143	72,390	1,861	394	2,255
Gulf of Finland	4,068	108,347	13,600	121,947	6,220	150	6,370
Gulf of Riga	1,372	78,602	9,973	88,575	2,790	93	2,883
Baltic Proper	4,784	395,568	122,843	518,411	19,806	1,046	20,852
Danish Straits	238	38,110	19,341	57,451	1,433	105	1,538
Kattegat	1,173	48,197	17,564	65,761	1,442	118	1,560
Total	**17,698**	**758,337**	**218,604**	**976,941**	**36,168**	**2,087**	**38,255**

Tables 4.2a and **4.2b.** Flow normalized waterborne and normalized airborne inputs of phosphorus and nitrogen to the Baltic Sea in 2010 by a) country and b) sub-basin. EU20 = non-HELCOM EU countries; 'other air' and 'atmospheric phosphorus sources' = other countries and sources contributing to atmospheric deposition on the Baltic Sea. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Table 4.2a

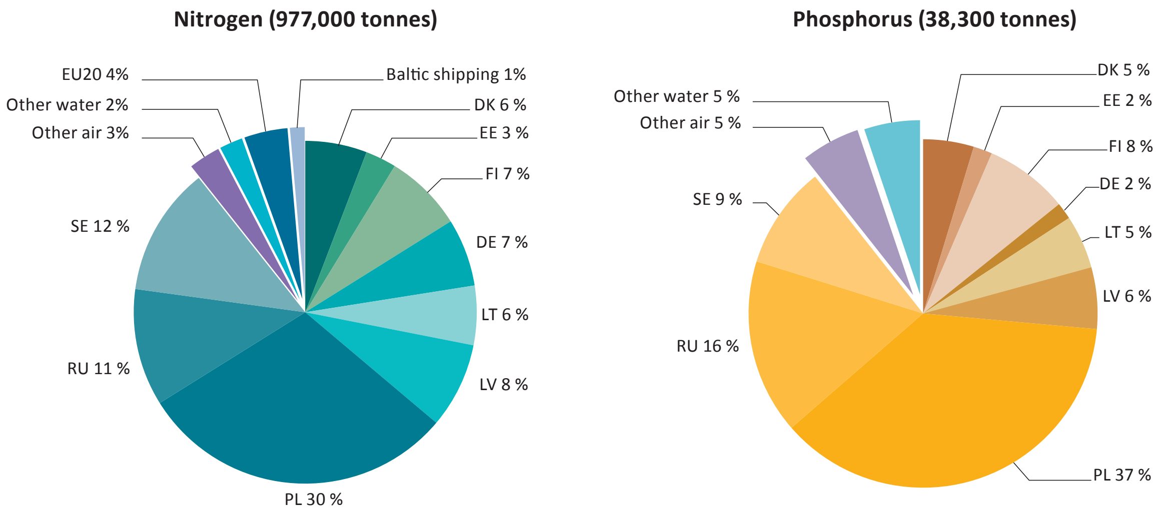
Country	Flow (m^3s^{-1})	Nitrogen (t)			Phosphorus (t)		
		Water-borne	Airborne	Total	Water-borne	Airborne	Total
Denmark	313	38,095	15,334	53,429	1,706		1,706
Estonia	452	22,491	1,993	24,484	612		612
Finland	2,326	67,213	6,411	73,624	3,297		3,297
Germany	128	21,991	35,090	57,081	564		564
Latvia	1,369	67,315	2,165	69,480	2,548		2,548
Lithuania	790	38,428	3,233	41,661	2,015		2,015
Poland	2,880	175,475	24,396	199,871	9,842		9,842
Russia	3,577	81,182	11,491	92,673	6,050		6,050
Sweden	5,863	97,713	11,330	109,043	3,527		3,527
Baltic Shipping			13,840	13,840			
EU20			42,046	42,046			
Other air			25,226	25,226			
Atmos. P sources						2,087	2,087
Total	**17,698**	**609,903**	**192,555**	**802,458**	**30,161**	**2,087**	**32,248**

Table 4.2b

Country	Flow (m^3s^{-1})	Nitrogen (t)			Phosphorus (t)		
		Water-borne	Airborne	Total	Water-borne	Airborne	Total
Bothnian Bay	**3,136**	**44,582**	**7,258**	**51,840**	**2,748**	**181**	**2,929**
Bothnian Sea	**2,926**	**48,635**	**21,347**	**69,982**	**2,045**	**394**	**2, 439**
Gulf of Finland	**4,068**	**95,536**	**12,015**	**107,551**	**6,114**	**150**	**6,264**
Gulf of Riga	**1,372**	**66,240**	**8,691**	**74,931**	**2,303**	**93**	**2,396**
Baltic Proper	**4,784**	**271,695**	**106,589**	**378,284**	**14,190**	**1,046**	**15,236**
Danish Straits	**238**	**36,955**	**20,091**	**57,046**	**1,369**	**105**	**1,474**
Kattegat	**1,173**	**46,260**	**16,564**	**62,824**	**1,392**	**118**	**1,510**
Total	**17,698**	**609,903**	**192,555**	**802,458**	**30,161**	**2,087**	**32,301**

The contributions of the HELCOM Contracting Parties to the actual total inputs of nitrogen and phosphorus to the Baltic Sea in 2010 are given in **Figure 4.2a** and **4.2b** with Poland as the greatest contributor of both nitrogen and phosphorus. The shares are markedly affected by the unusually high amount of precipitation in the Polish catchment in 2010, which gives Poland a high proportion of total actual inputs in 2010. Calculated as normalized inputs, Poland's contribution of nitrogen and phosphorus input to the Baltic Sea is 24% and 30%, respectively, compared to 30% and 37%, respectively for the actual inputs.

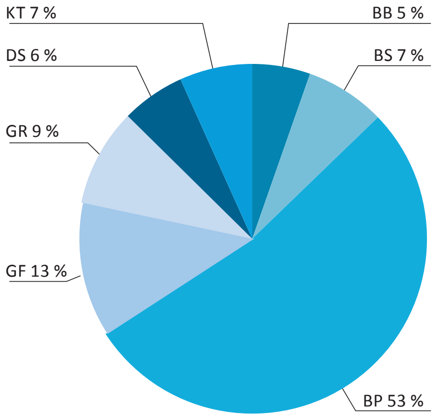
Transboundary inputs from non-Contracting Parties constituted about 10% of the total nitrogen inputs to the Baltic Sea in 2010, with 80% of these inputs being airborne **(Figure 4.2a)**. Five percent of total air- and waterborne phosphorus inputs in 2010 were transboundary waterborne inputs from non-Contracting Parties (**Figure 4.2b**). For phosphorus, however, it is not possible to divide atmospheric deposition by different sources as no emission sources have been quantified. Chapter 4.7 provides further information on transboundary air- and waterborne inputs of nitrogen and phosphorus originating from non-HELCOM countries.

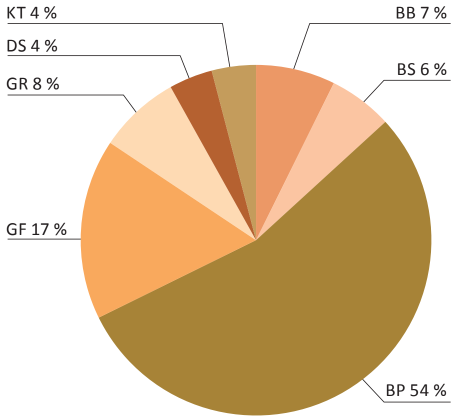


Figures 4.2a and **4.2b.** Total actual water- and airborne inputs of a) nitrogen and b) phosphorus to the Baltic Sea in 2010 by HELCOM Contracting Parties and other sources. Atmospheric nitrogen deposition is divided into Baltic shipping, EU20 (the 20 non-HELCOM EU countries) and 'other air' (other non-HELCOM countries and other distant sources such as North Sea shipping) and for phosphorus all atmospheric sources. 'Other water' is transboundary waterborne inputs from non-HELCOM Contracting Parties entering the Baltic Sea (see Table 4.1a). *See also note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set***.**

In 2010, the Baltic Proper received a much higher proportion of total nitrogen and phosphorus inputs (53% and 54%, respectively) than the share of the catchment area to this sub-basin (33%) of the total Baltic Sea catchment area (**Figures 4.3a** and **4.3b** and **Table 4.3**). This is partly explained by exceptionally high river flow and high nutrient inputs, for example from Poland, caused by floods (according to normalized 2010 data, the share of nitrogen and phosphorus inputs to the Baltic Proper was 47%).

The Danish Straits is the sub-basin that received the highest proportion of nitrogen and phosphorus compared with its share of the total Baltic Sea catchment. This is a reflection of the high population density and human activity in both the sub-catchment of the Danish Straits and the Baltic Proper. On the other hand, the Bothnian Bay and the Bothnia Sea received a lower share of total inputs to the Baltic Sea compared to their proportion of the total catchment area, which also corresponds with the low population density and lesser agricultural activities in these catchment areas at least in the Swedish part of these catchments.





Figures 4.3a and **4.3b.** Total actual water- and airborne inputs of a) nitrogen and b) phosphorus to the Baltic Sea by sub-basin in 2010. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Table 4.3. The inputs of total nitrogen and phosphorus to the Baltic Sea sub-basins in 2010 as a proportion of the total input, the proportion of the sub-basin catchment area of the total Baltic Sea catchment area and the proportion of the sub-basin's marine surface area of the total Baltic Sea surface area. *See also note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Country	Total input N (%)	Total input P (%)	Catchment area (%)	Marine area (%)
Bothnian Bay	5.4	7.3	15.1	8.7
Bothnian Sea	7.4	5.9	13.4	18.9
Gulf of Finland	12.5	16.7	24.0	7.2
Gulf of Riga	9.1	7.5	7.4	4.5
Baltic Proper	53.1	54.5	33.4	50.2
Danish Straits	5.9	4.0	1.6	5.0
Kattegat	6.7	4.1	5.1	5.7
Total	100	100	100	100

4.2. Total atmospheric deposition to the Baltic Sea

Nitrogen compounds are emitted into the atmosphere as nitrogen oxides (NO_x) and ammonia (NH_3). Oxidized nitrogen (NO_x) constitutes, in most years, the largest share of the total nitrogen deposited via the atmosphere to the Baltic Sea, around 55% on an annual basis (see **Figure 4.4**). Combustion processes related to shipping, road transportation and energy production are the main sources of nitrogen oxide emissions in the Baltic Sea region, while agriculture generally contributes with 85-95% of the emitted ammonia (Bartnicki & Valiyaveetil 2008). While a major part of emitted nitrogen oxides are transported over long distances before being deposited, ammonium is deposited relatively close to the emission source.

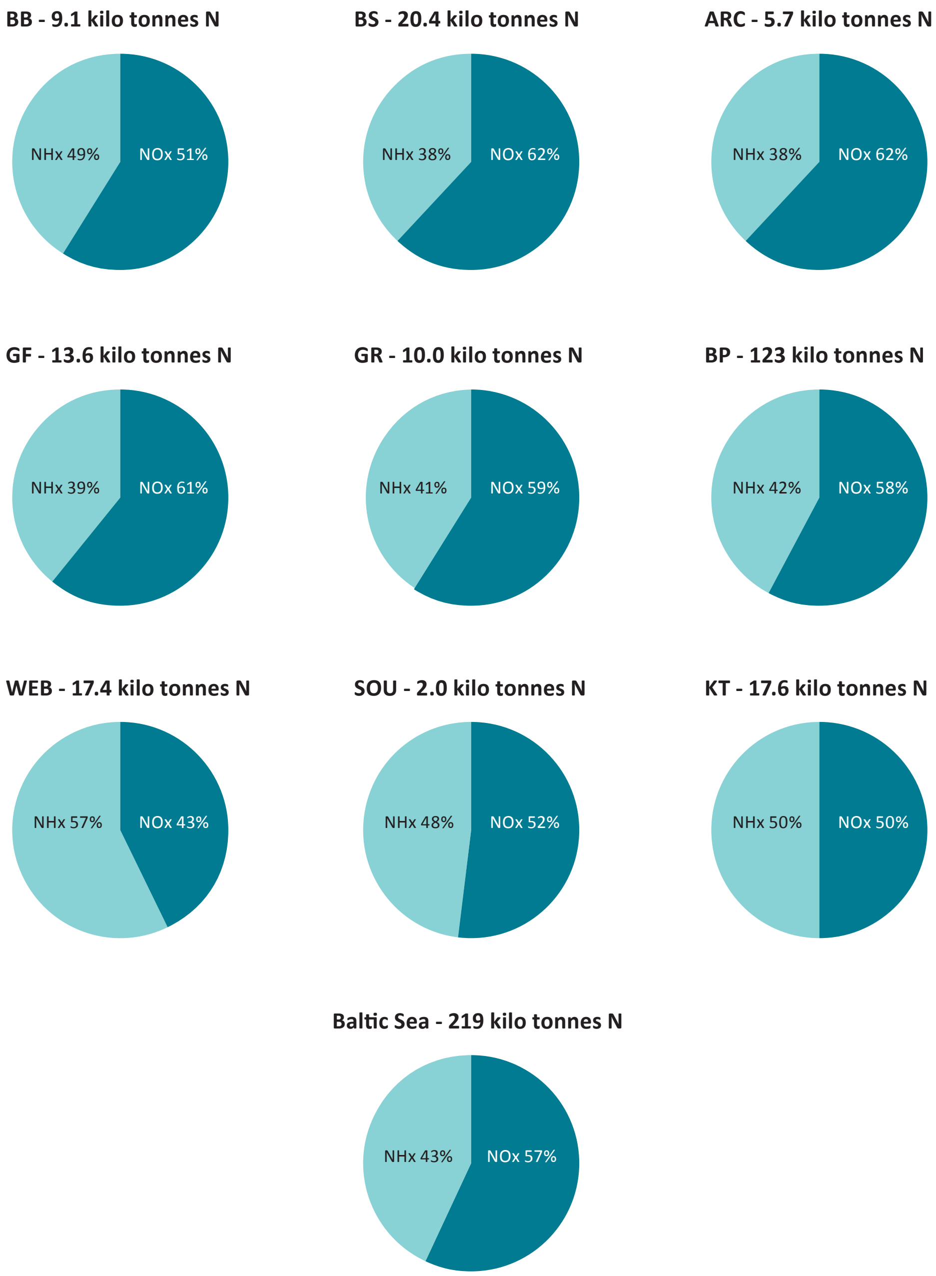


Figure 4.4. Actual atmospheric total nitrogen deposition to the nine sub-basins of the Baltic Sea and to the Baltic Sea as a whole in 2010 divided into the oxidized (NO_x) and reduced (NH_x) compartments.

In 2010, the total atmospheric deposition of nitrogen to the Baltic Sea was 218,600 tonnes, of which 62% originated from HELCOM countries (including emissions from areas in these countries – such as Germany and Russia - which are not part of the catchment area that drains to the Baltic Sea); 6% from Baltic Sea shipping; 18% from the 20 EU countries that are not HELCOM Contracting Parties; and 13% from other countries and distant sources outside the Baltic Sea region (including North Sea shipping) (**Figure 4.5**). Germany (18%) and Poland (14%) are the two HELCOM Contracting Parties with the highest shares of the total atmospheric nitrogen input to the Baltic Sea. There is a southwest to northeast gradient in deposition, with the highest deposition in the southern and western parts of the Baltic Sea due to dominant wind systems and the location of the main emission sources (Bartnicki et al. 2012).

Based on new information from monitoring data of Contracting Parties, it is estimated that an annual average of 5 kg phosphorus km^{-2} is deposited to the Baltic Sea each year (HELCOM 2014b). Calculated with this estimate, the Baltic Sea receives annually 2,087 tonnes airborne phosphorus, which constituted about 5% of total annual phosphorus inputs to the Baltic Sea in 2010. In the 2007 Baltic Sea Action Plan (HELCOM 2007), a rate of 15 kg phosphorus km^{-2} was used to calculate atmospheric deposition, while the new estimate 5 kg phosphorus km^{-2} has been used for the calculation of revised inputs during the reference period (**Table 4.1b**).

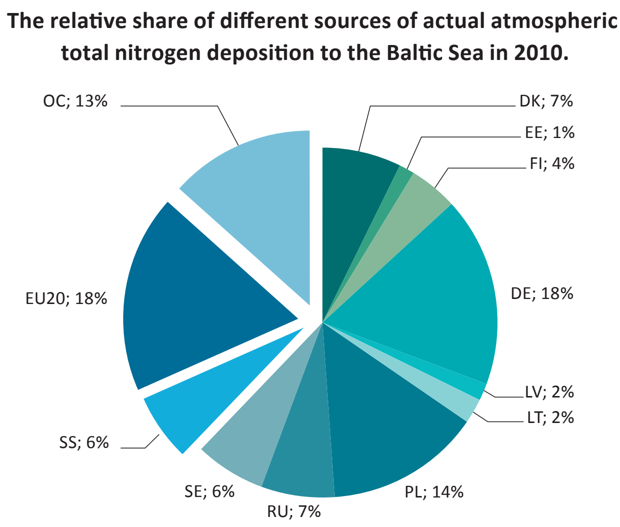


Figure 4.5. The relative contribution of different sources to the actual total atmospheric nitrogen deposition to the Baltic Sea in 2010 (SS=Baltic Sea shipping, OC= other countries and sources).

The Baltic Proper received 56% of the total atmospheric deposition of nitrogen and 50% of total atmospheric deposition of phosphorus to the Baltic Sea (**Figure 4.6**). Baltic Proper makes up 50% of the marine surface area of the Baltic Sea (**Table 4.3**). In general, for the sub-basins of Bothnian Bay and Bothnian Sea, which are located in the northern part of the Baltic Sea and far from the main emission areas, the relative share of the actual atmospheric deposition of nitrogen is clearly lower than their proportion of the marine area. Correspondingly, the western sub-basins received relatively higher atmospheric inputs of nitrogen. Because the atmospheric phosphorus inputs were estimated with a constant deposition rate per km^2, the sub-basins are assumed to receive airborne phosphorus according to their marine areas.

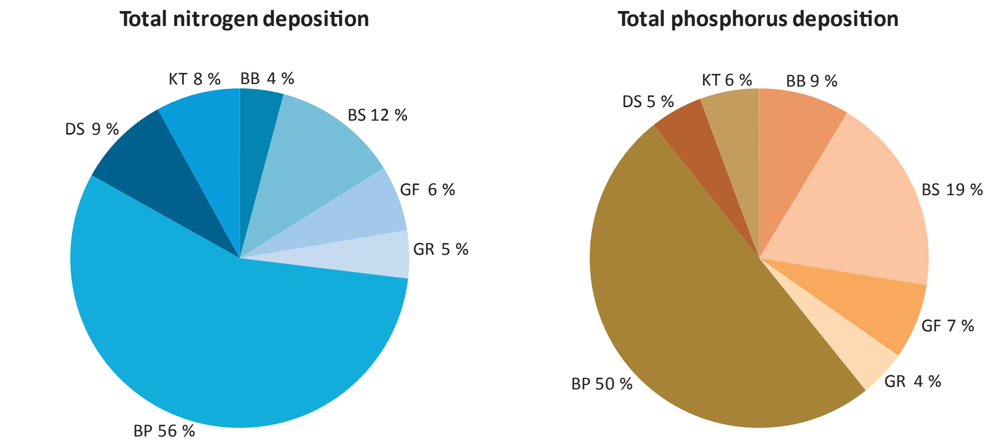
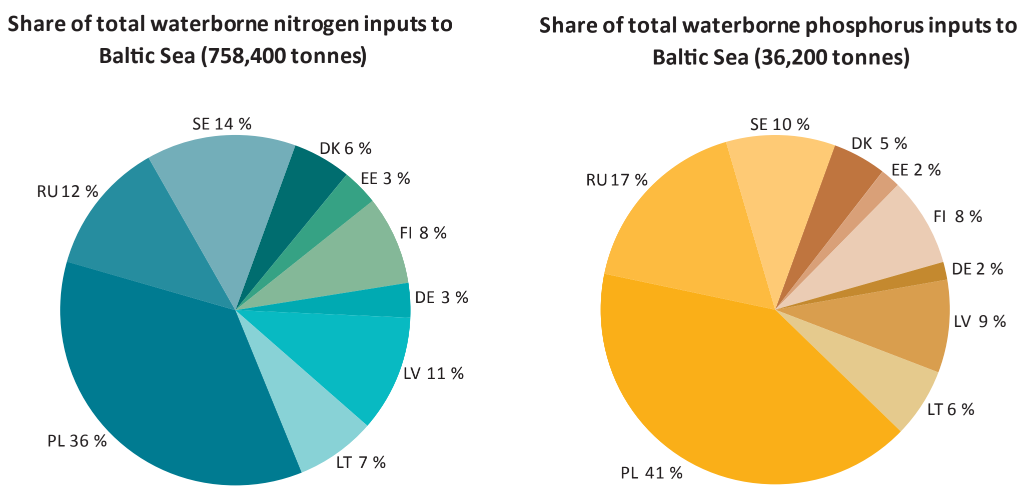


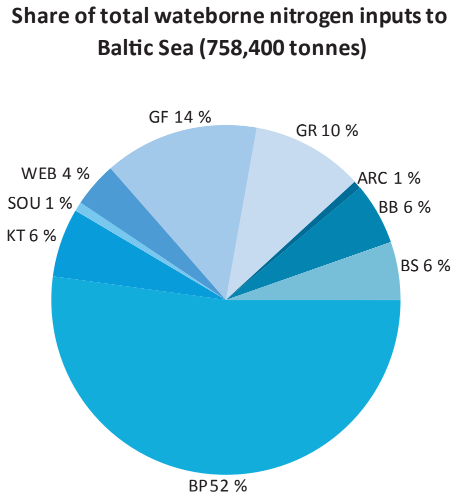
Figure 4.6a and **4.6b.** The relative share of actual atmospheric a) nitrogen and b) phosphorus deposition to the main Baltic Sea sub-basins in 2010.

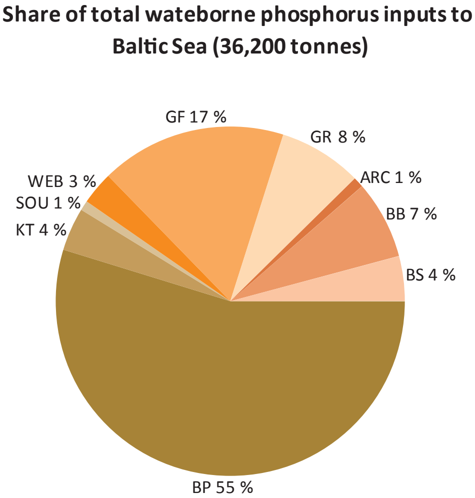
4.3. Total waterborne input to the Baltic Sea

The total waterborne inputs amounted to 758,400 tonnes nitrogen and 36,200 tonnes phosphorus in 2010. The greatest contributors of waterborne nitrogen and phosphorus inputs in 2010 were Poland and Sweden, and the smallest contributors were Estonia and Germany (**Figures 4.7a** and **4.7b**). The Baltic Proper sub-basin received the largest amount of waterborne inputs (more than 50% of total waterborne nutrient inputs) even though the catchment only constitutes 33% of the total catchment area draining to the Baltic Sea (**Figures 4.8a** and **4.8b**). This is partly explained by exceptionally high river flow and high nutrient inputs, for example from Poland, caused by severe floods in 2010 (for normalized 2010 data, the share of nitrogen and phosphorus inputs to the Baltic Proper was 47%).



Figures 4.7a and 4.7b. Total actual waterborne inputs of a) nitrogen and b) phosphorus by country to the Baltic Sea in 2010. Note that the waterborne inputs include transboundary inputs. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

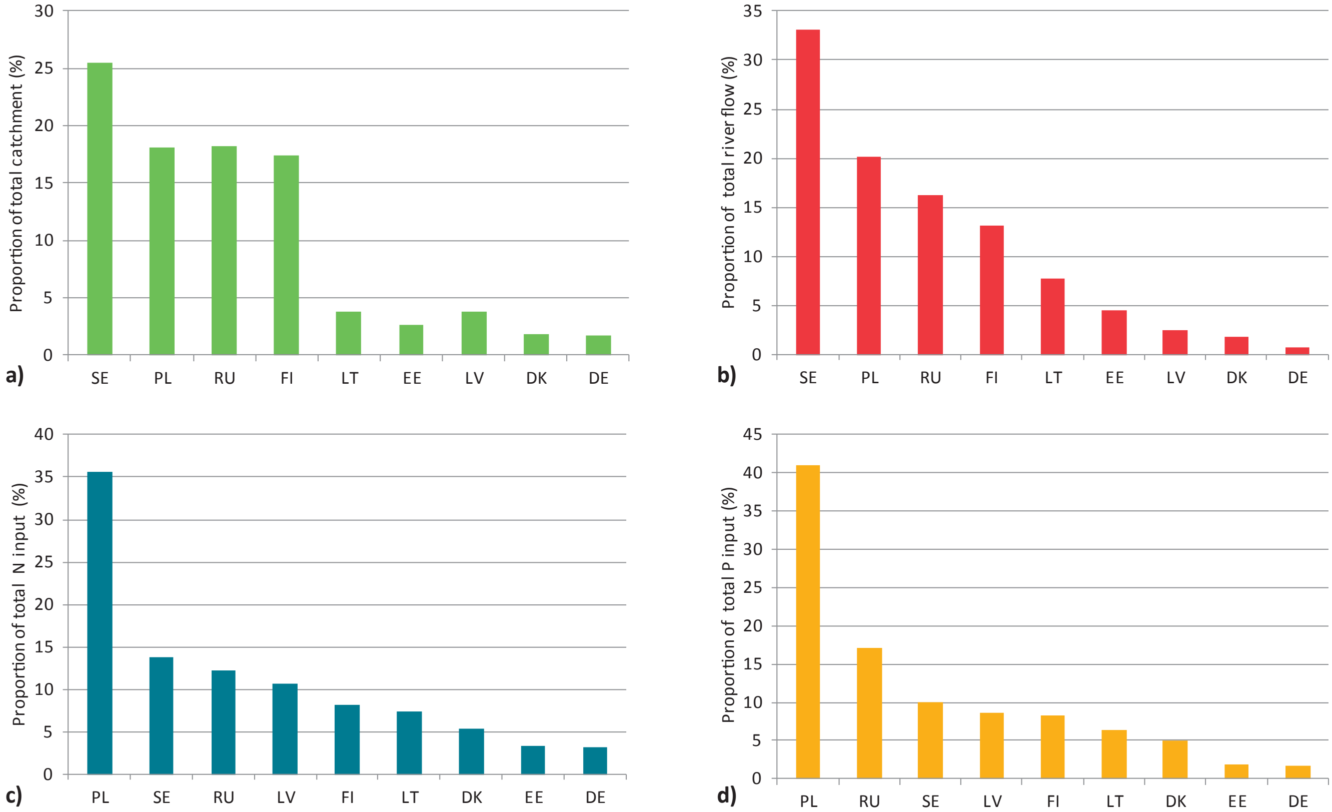




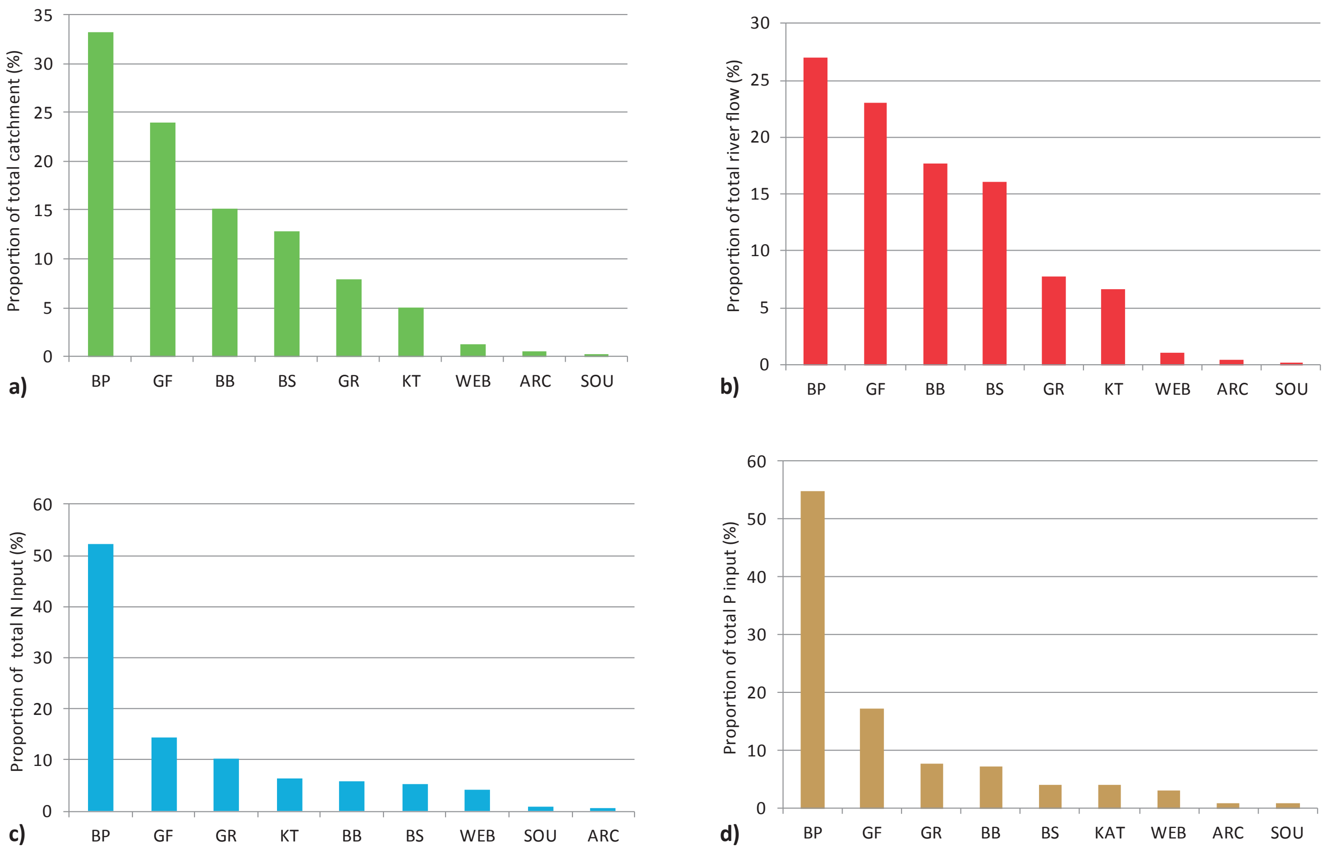
Figures 4.8a and 4.8b. Total actual waterborne inputs of a) nitrogen and b) phosphorus to the Baltic Sea by sub-basin in 2010. Note that the waterborne inputs include transboundary inputs. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

In **Figures 4.9a-d** and **Figures 4.10a-d** the proportion of total waterborne nitrogen and phosphorus inputs and river flow are compared with the corresponding proportion of total catchment by country (**Figure 4.9**) and per sub-basin (**Figure 4.10**). Sweden has 25% of the total catchment, but in 2010 had 33% of total river flow, and only 14% of total waterborne nitrogen input and 10% of total waterborne phosphorus inputs. Poland, on the other hand, with “only” 18% of the total catchment area to the Baltic Sea contributed in 2010 with 20% of the total river flow and more than 35% of the total waterborne nitrogen and 41% of the total waterborne phosphorus inputs. This is related both to high precipitation in Poland during 2010, rather intensive farming, high population density and a lower degree of purification of wastewaters (compared with e.g. Sweden). The relative high share of total flow from Sweden is related to rather high winther precipitation for the whole country and heavy summer rain in southern Sweden. See also **Table 4.3**.

Photo by Lars M. Svendsen



Figures 4.9a-d. a) the proportion of the total Baltic Sea catchment within each country, b) percent contribution to total river flow, and the percent contribution to the total waterborne inputs to the Baltic Sea of c) nitrogen and d) phosphorus by HELCOM country in 2010. Note: the waterborne inputs and river flows of Latvia, Lithuania, Poland and Sweden include transboundary inputs. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*



Figures 4.10a-d. The same as for figure 4.9a-d, but for the Baltic Sea sub-catchments. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

To provide further details on the actual waterborne inputs in 2010, the specific runoff (in l s^{-1} km^{-2}) and area-specific input of waterborne nitrogen and phosphorus in kg km^{-2} per catchment area have been calculated by BNI Sweden and are shown by country and sub-catchment in **Figures 4.11a-c.**

Specific runoff is highest from the mountainous part of Sweden, northern Sweden and south western Sweden (up to 15 l s^{-1} km^{-2}), and lowest in the south eastern part of the Baltic Sea catchment (4-6 l s^{-1} km^{-2}).

Information on area-specific nutrient inputs, expressed as kg km^{-2}, makes it possible to directly compare nutrient inputs from different sub-regions and countries around the Baltic Sea, irrespective of the catchment size (total catchment area is used and not only cultivated land area). The area-specific losses of nitrogen and phosphorus show a different pattern compared to the specific runoff. There is a rather clear southwest to northeast gradient with the highest area-specific waterborne input from catchments in Denmark, Germany and Poland, and with the lowest area-specific nitrogen loss in northern Sweden. The range is from 100 to more than 1,500 kg nitrogen km^{-2}. There are also areas in southern Finland and parts of the Baltic States with rather high area-specific nitrogen losses. High losses often reflect intensive agriculture and land-use, especially in catchments with a relatively low proportion of wetlands and lakes.

The overall pattern for area-specific phosphorus losses is similar to that of nitrogen, with the highest losses in Denmark, Germany and Poland, but also rather high losses from southern Finland and parts of the Baltic States. As with nitrogen, this is related to intensive farming, but it is also linked to high population densities with higher inputs of wastewater and the efficiency level in treatment of wastewater; it also reflects soil types and natural phosphorus contents in soils. Area-specific phosphorus inputs range from about five to more than 60 kg phosphorus per km^2.

Photo by Seppo Knuuttila

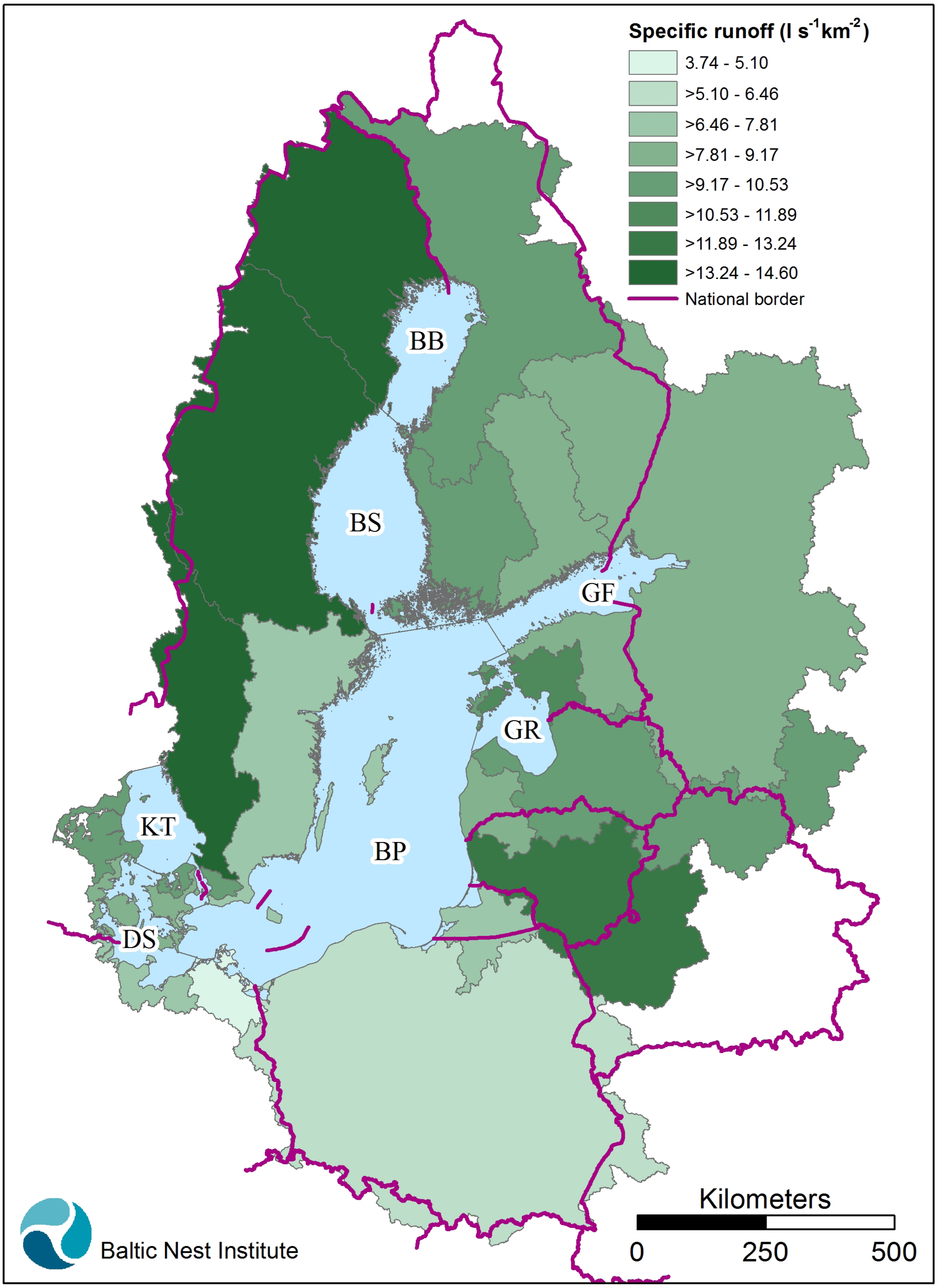


Figure 4.11a. Area-specific runoff (l s^{-1} km^{-2}) in 2010 calculated per country and sub-catchment. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

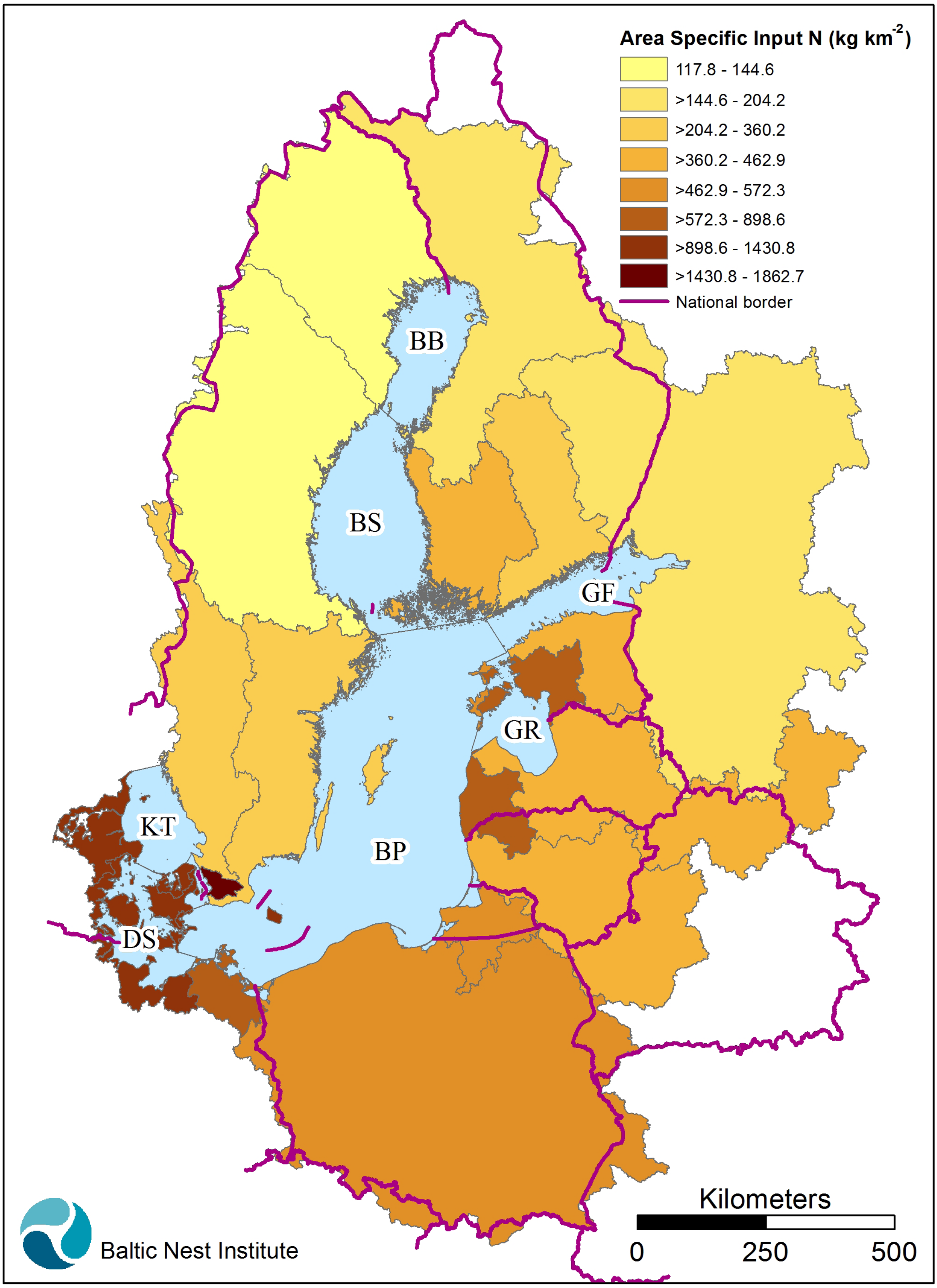


Figure 4.11b. Area-specific riverine nitrogen inputs (kg km^{-2}) in 2010 calculated per country and sub-catchment. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

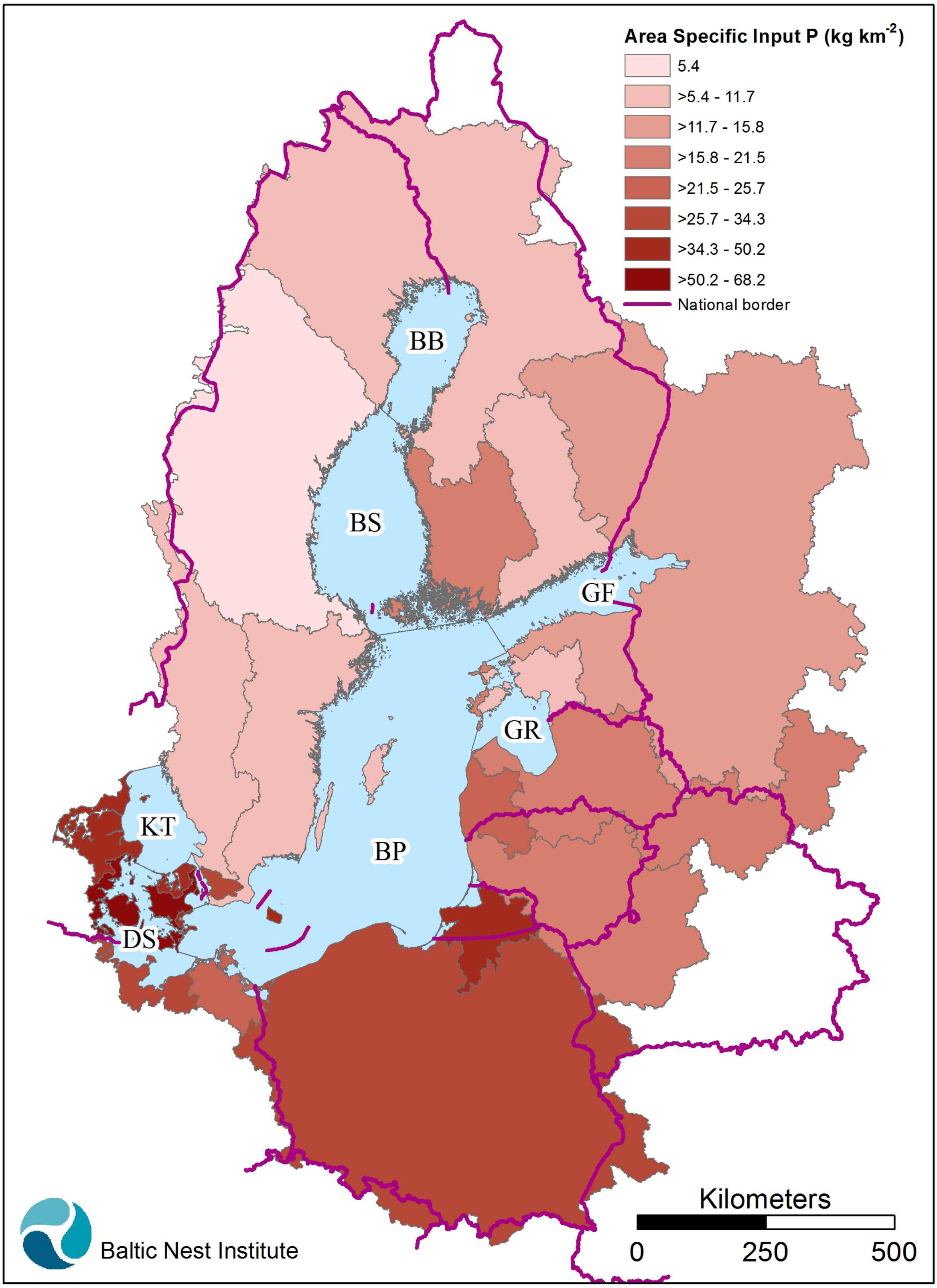


Figure 4.11c. Area-specific riverine phosphorus inputs (kg km^{-2}) in 2010 calculated per country and sub-catchment. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

4.4. Inputs from the seven largest rivers

The seven largest rivers entering the Baltic Sea (the "big 7") are the Neva, the Vistula, the Daugava, the Nemunas, the Kemijoki, the Odra and the Göta älv. Together their catchment areas constitute 50% of the total Baltic Sea catchment area (**Table 4.4**). In 2010, the total river flow in these rivers comprised 46% of the total flow to the Baltic Sea, and they accounted for 53-55% of total waterborne nutrient inputs to the Baltic Sea. Although it has a smaller catchment area than River Neva and only 2/3 of its flow, the Polish River Vistula contributes most followed by the River Odra. Göta älv has the highest specific runoff, more than twice of Nemunas. The area-specific inputs (in kg N and kg P per hectare river catchment) is highest for Vistula and Odra Rivers (about 800 kg N km^{-2} and 42 kg P km^{-2}) and lowest for Kemijoki River with about 1/6 of these specific inputs. The highest area-specific values are found in catchment with rather high population density and extensive agricultural activities compared with the other big rivers catchments.

Table 4.4. Catchment area, waterborne total nitrogen and phosphorus inputs and river flow for the seven largest rivers (the "big 7") discharging into the Baltic Sea, as well as their share of the corresponding totals for the Baltic Sea in 2010. In addition, area coefficient of total nitrogen and total phosphorus and specific river flow for these seven rivers are given. Nemunas, Odra and Vistula enter Baltic Proper, Kemijoki enters Bothnian Bay, Neva enters Gulf of Finland, Daugava enters Gulf of Riga and Göta älv enters Kattegat. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

River	Area (km^{-2})	TN (tonnes)	TP (tonnes)	Flow ($m^3 s^{-1}$)	Area spec. inputs (kg N km^{-1})	Area spec. inputs (kg P km^{-1})	Area spec. runoff (l s^{-1} km^{-2})
Neva	271,800	50,911	1,998	2,860	187	7.4	10.5
Vistula	194,420	145,867	9,233	1,727	750	47	8.9
Odra	118,840	103,865	4,469	895	874	38	7.5
Daugava	86,530	38,965	1,545	791	450	18	9.1
Göta älv	50,230	14,387	410	698	286	8.2	13.9
Nemunas	97,920	44,057	1,774	624	450	18	6.4
Kemijoki	51,130	6,470	338	549	127	3.6	10.7
Sum	**870,870**	**404,522**	**19,768**	**8,144**			
Weighted average					**465**	**23**	**9.4**
Percentage of total waterborne input to BAS (%)	50.4	53.3	54.7	46.0			
Percentage of BAS average (%)					106	101	84.7

The results of the trend analysis of 1994 to 2010 data for these seven largest rivers entering the Baltic Sea are given in Chapter 5.3.

4.5. Sources of atmospheric deposition to the Baltic Sea

The HELCOM Contracting Parties reported their annual nitrogen emission inventory data for 2010 to the EMEP Centre on Emission Inventories and Projections (CEIP) (**Table 4.5**). For Russia, data from the extended domain was included. To fill in the missing gaps in emissions, expert estimates were applied by CEIP. The EMEP MSC-W computed the ship emission data on the bottom line of Table 4.5 by linear interpolation with recent calculations from IIASA for the years 2005 and 2010 (Bartnicki et al. 2012). The ship emission inventory is used in the EMEP calculations of the atmospheric nitrogen inputs. In addition, a more detailed ship emission inventory has been made by the Finnish Meteorological Institute (FMI) based on the automatic identifying system (AIS) security signals. It covers an emission estimate for each individual ship over 300 tonnes gross tonnage as a function of the ship's type, its engine load, fuel type, speed and emission control technology, using current weather and wave height information (Jalkanen et al. 2013). The ship emissions of NO_x based on the AIS data for 2010 are presented in **Figure 4.12**.

Table 4.5. Annual total 2010 nitrogen oxides and ammonia emissions from HELCOM Contracting Parties and Baltic Sea ship traffic. Sum of HELCOM emissions is also included. (Source: Bartnicki et al. 2012)

Emission source	Pollutant (kilo tonnes per year)	
	NOx	NH_3
Denmark	39	61
Estonia	11	8
Finland	51	31
Germany	403	451
Latvia	10	14
Lithuania	18	25
Poland	264	223
Russia	996	975
Sweden	49	43
HELCOM Countries	**1,840**	**1,832**
Baltic Sea shipping	101	

On average the magnitudes of emissions of oxidized and reduced nitrogen in 2010 are at a similar level to each other for all countries (**Table 4.5**). Russia, Germany and Poland have the largest nitrogen emissions, while ship traffic in the Baltic Sea is the fourth largest emitter of NO_x. The most densely trafficked shipping lines in the Baltic Sea are clearly visible in the AIS inventory data (**Figure 4.12**).

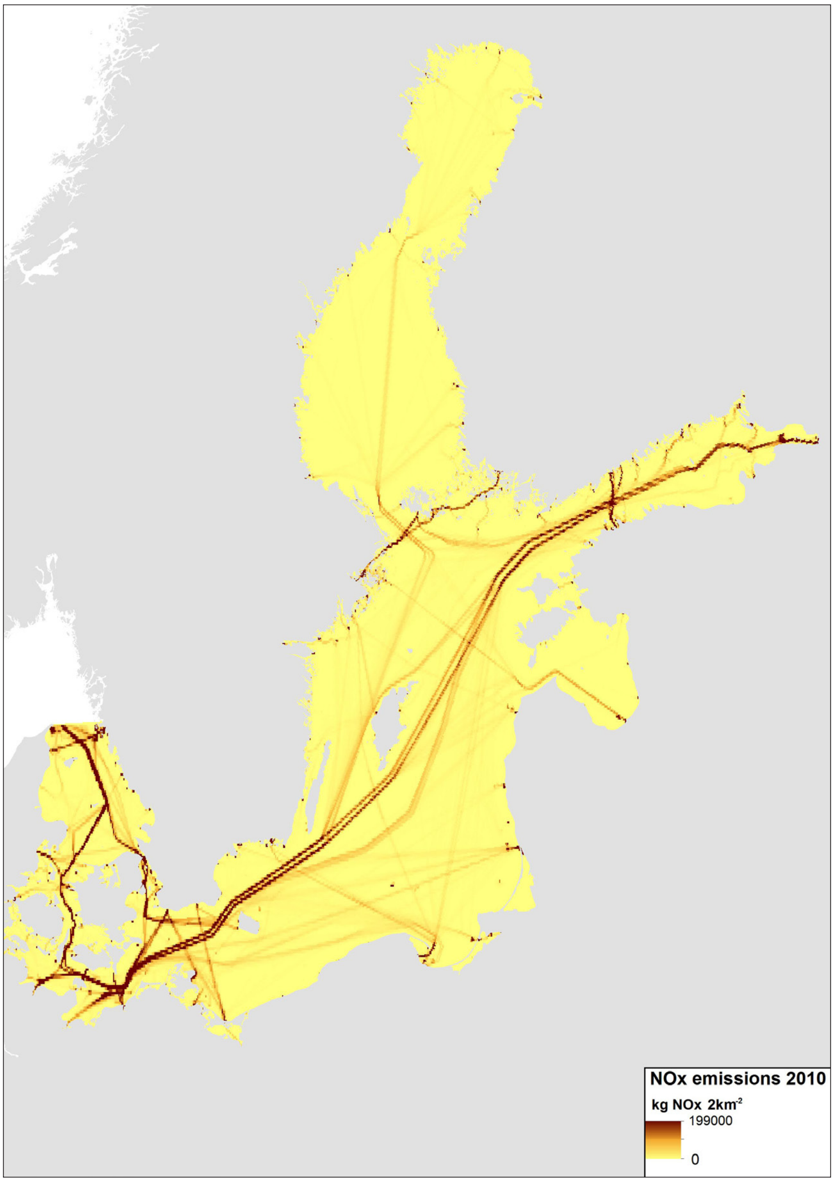


Figure 4.12. NO_x emission map for the Baltic Sea based on the AIS signals of shipping in 2010 (in kg N per2 km^{-2} per year). (Based on: Johansson et al. 2011.)

The emissions of the airborne phosphorus are not well known and the atmospheric deposition of phosphorus is not modelled by any Contracting Party nor by EMEP. Based on deposition measurement data reported by a few HELCOM Contracting Parties (HELCOM 2014b) it has been agreed to use a constant deposition rate of 5 kg P km^{-2} for the Baltic Sea. In the future, this estimate will hopefully be further verified with results from new monitoring projects. The main sources of atmospheric phosphorus input to the sea are estimated to derive from land as airborne dust, pollen, fragments of leaves and other biological material including airborne microalgae.

The proportion of the nitrogen emission that is deposited to the Baltic Sea differs between the different HELCOM countries (**Figure 4.13**). In 2010, about 15% of Danish, Swedish and Estonian nitrogen emissions were deposited onto the Baltic Sea, whereas less than 1% and 4% of the total emissions from Russia and Germany, respectively, entered the Baltic Sea as atmospheric nitrogen deposition. However, it should be noted that the emission inventory used for the calculation covers the whole area of Germany and large parts of Russia, i.e. including areas outside the Baltic Sea catchment area, as the catchment area is defined for the waterborne inputs entering the Baltic Sea.

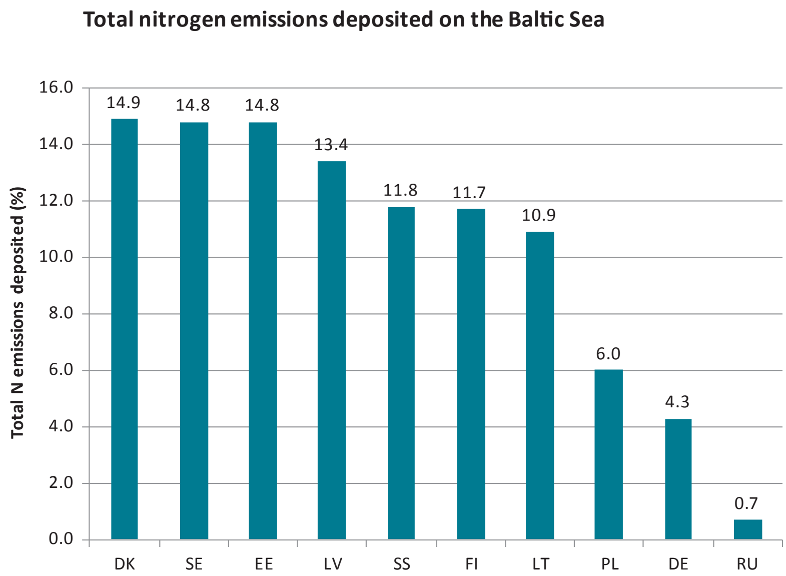


Figure 4.13. The proportion (%) of the nitrogen emission by the HELCOM countries and shipping that is deposited on the Baltic Sea. (SS = Baltic Sea shipping). (Source: Bartnicki et al. 2012)

The EMEP countries report their nitrogen emissions split into 11 emission categories (**Table 4.6** and **Figures 4.14** and **4.15**). The main sectors are combustion in energy production and industry as well as transportation for the oxidized nitrogen and agriculture for the reduced nitrogen (Bartnicki et al. 2012).

Table 4.6. The 11 SNAP emission sectors as specified in the EMEP-CORINAIR Emission Inventory Guidebook. (Source: Bartnicki et al. 2012)

Sector 1	Combustion in energy and transformation industry
Sector 2	Non-industrial combustion plants
Sector 3	Combustion in manufacturing industry
Sector 4	Production processes
Sector 5	Extraction and distribution of fossil fuels and geothermal energy
Sector 6	Solvent and other product use
Sector 7	Road transport
Sector 8	Other mobile sources and machinery (including ship traffic)
Sector 9	Waste treatment and disposal
Sector 10	Agriculture
Sector 11	Other sources and sinks

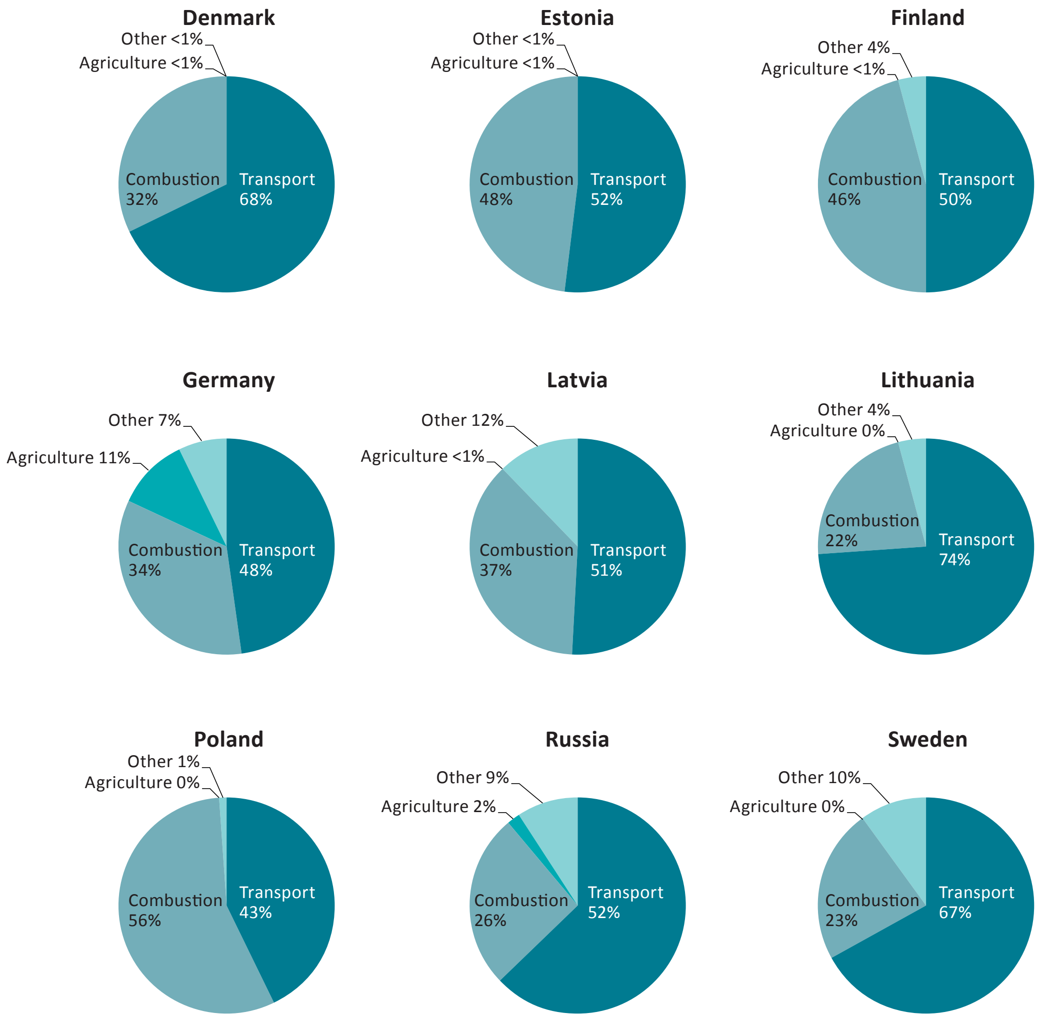


Figure 4.14. Proportion of emissions of oxidized nitrogen from the main sectors (transportation, combustion in energy and transformation industry, agriculture and other sources) from HELCOM countries (Bartnicki et al. 2012).

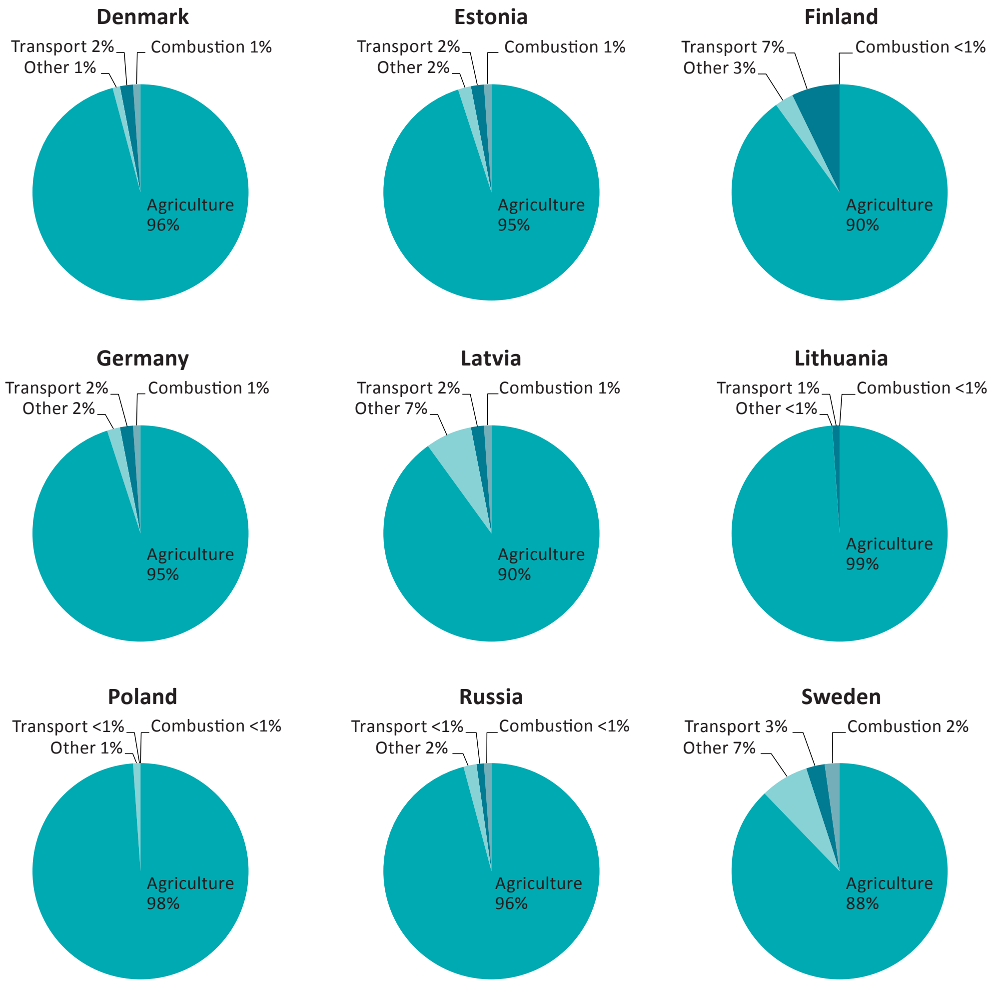
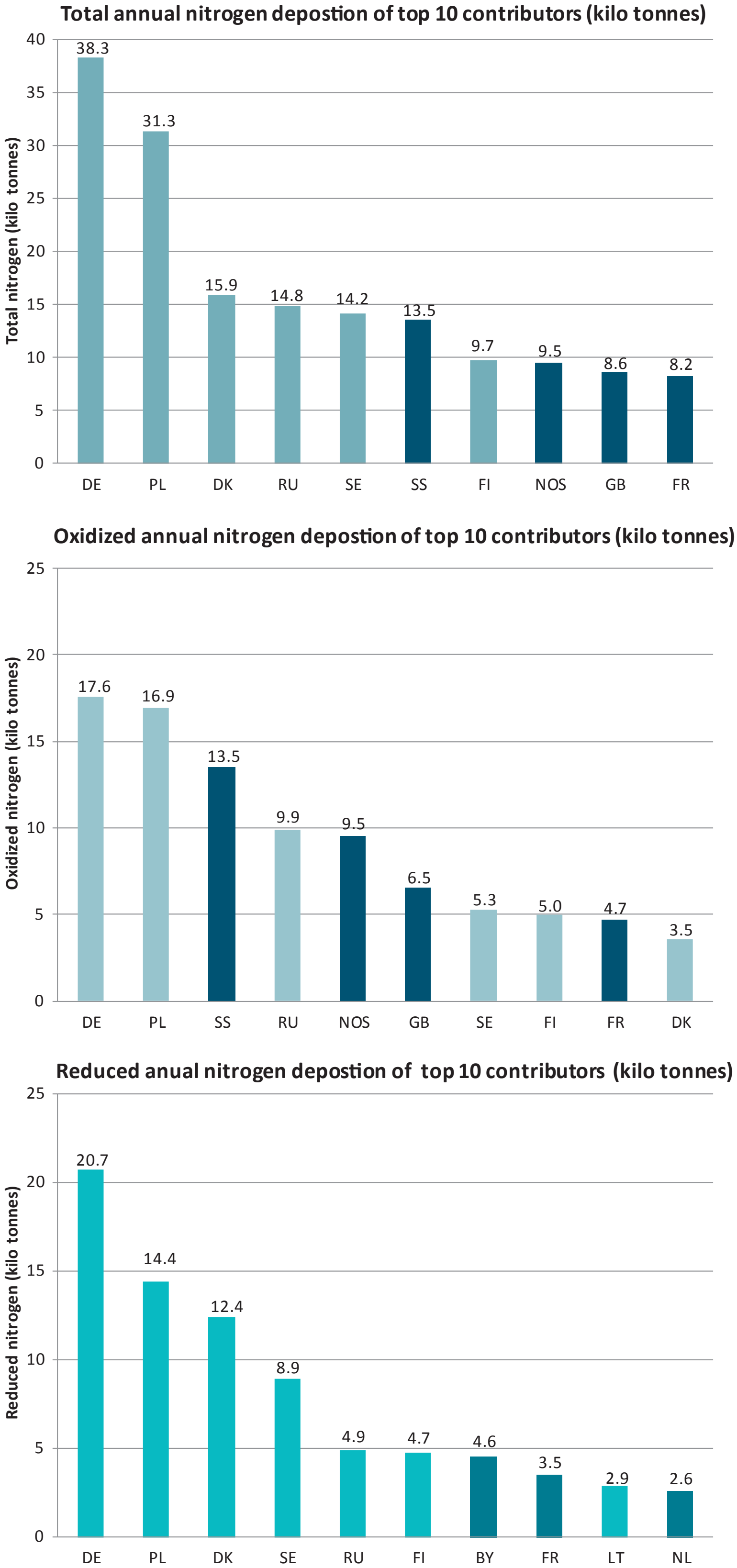


Figure 4.15. Proportion of emissions of reduced nitrogen from the main sectors (transportation, combustion in energy and transformation industry, agriculture and other sources) from HELCOM countries (Bartnicki et al. 2012).

An assessment of the top ten main contributors to the atmospheric deposition of total nitrogen to the Baltic Sea in 2010 shows that Germany and Poland are the greatest contributors, followed by Denmark, Russia and Sweden (**Figure 4.16**). The United Kingdom and France, countries well outside the HELCOM area, were the ninth and tenth largest contributors of total atmospheric nitrogen deposited onto the Baltic Sea, while Baltic Sea shipping was sixth and North Sea shipping eighth. The contribution from the Baltic countries was low, with Lithuania ranking 13^{th}, Latvia 15^{th} and Estonia 17^{th}.

For the oxidized nitrogen deposition, Germany and Poland were also the main contributors. Baltic Sea and North Sea shipping were significant contributors, ranking third and fifth, while Russia was the fourth. The United Kingdom was the sixth largest contributor to the deposition of oxidized nitrogen. Sweden was the seventh followed by Finland, France and Denmark. The Baltic countries contributed with smaller amounts to the deposition, Lithuania ranking 15^{th}, Estonia 19^{th} and Latvia 20^{th}. The large contribution of the ship traffic is remarkable, contributing altogether 23,000 tonnes of oxidized nitrogen deposition as calculated using the EMEP emission inventory. The contribution of shipping is even slightly higher if calculated using the AIS emission inventory, with Baltic Sea shipping alone contributing and estimated 16,000 tonnes (Hongisto 2014).

The sources of reduced nitrogen deposition are mainly HELCOM Contracting Parties. Germany gave also in this case the largest contribution, followed by Poland, Denmark, Sweden, Russia and Finland. Countries outside the HELCOM area, with intensive agriculture, contributed also greatly - Belarus was the seventh, France the eighth and the Netherland the tenth largest contributors. The Baltic countries ranked ninth (Lithuania), 11th (Latvia) and 13th (Estonia).



Figures 4.16a-c. Top ten largest contributors to the annual atmospheric total nitrogen deposition (upper), oxidized nitrogen deposition (middle) and reduced nitrogen deposition (bottom) in kilo tonnes (e.g., DE total nitrogen deposition = 38,300 tonnes) to the Baltic Sea in 2010. Non-HELCOM countries and sources outside HELCOM area are indicated in red. SS = Baltic Sea shipping; BY = Belarus; GB = Great Britain; FR = France; NL = Netherlands; NOS = North Sea shipping.

Detailed tables about the contribution of the different HELCOM countries to nitrogen deposition in each sub-basin are available in the PLC-5.5 data set, which can be accessed as an Excel file via the PLC-5.5 project page on the HELCOM website.

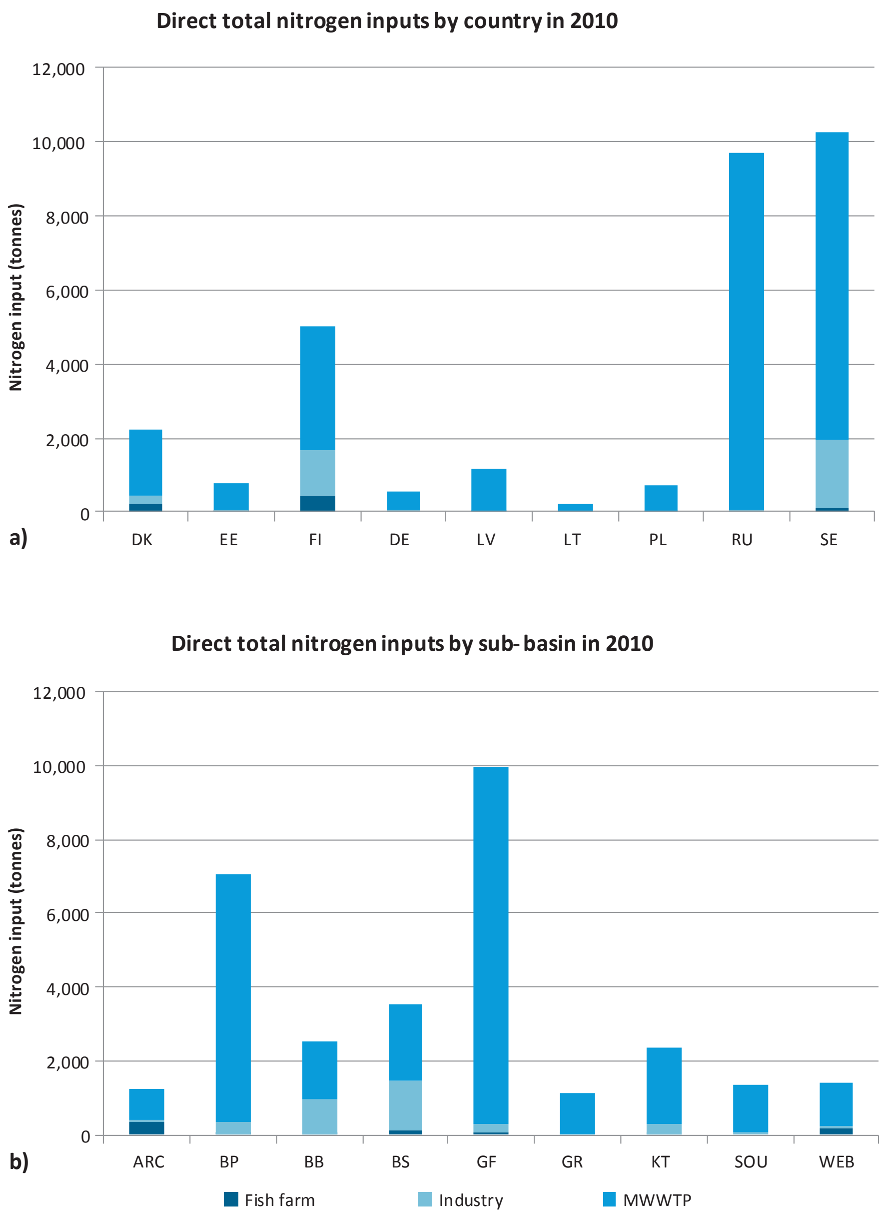
4.6. The importance of direct point source discharges of total waterborne input

The latest source apportionment on all sources of waterborne nutrient inputs was performed on 2006 data in the PLC-5 report (HELCOM 2011 and HELCOM 2012). The next source inventory is a part of the Sixth Pollution Load Compilation (PLC-6) project and will be carried out using 2014 data and reported in the PLC-6 report. Based on annual data reporting, however, it is possible to evaluate the importance of point sources discharging directly to the Baltic Sea.

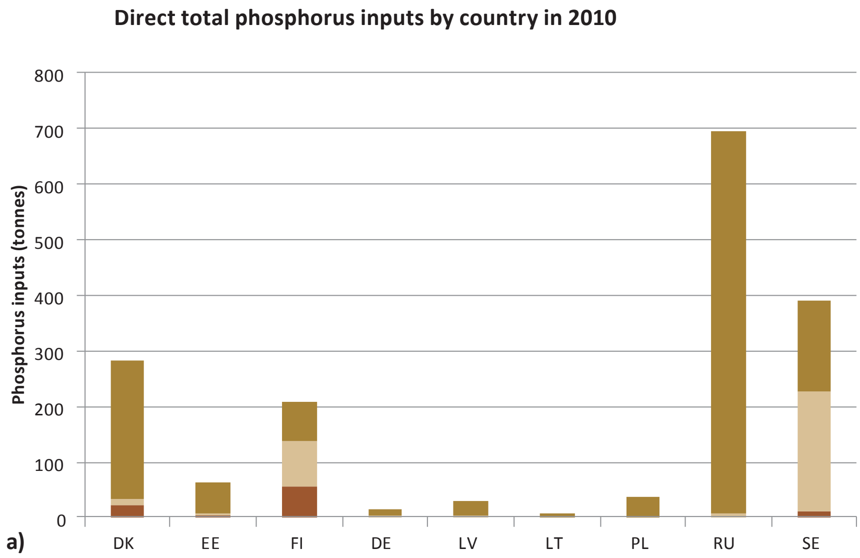
In 2010, the total waterborne inputs of nitrogen and phosphorus were 758,000 tonnes, and 36,200 tonnes, respectively. Out of this, the nitrogen input from point sources discharging directly to the Baltic Sea was 30,500 tonnes, or 4% of the total waterborne nitrogen input. The waterborne phosphorus discharge from direct point sources was 1,700 tonnes, or approximately 5% of the total waterborne phosphorus input.

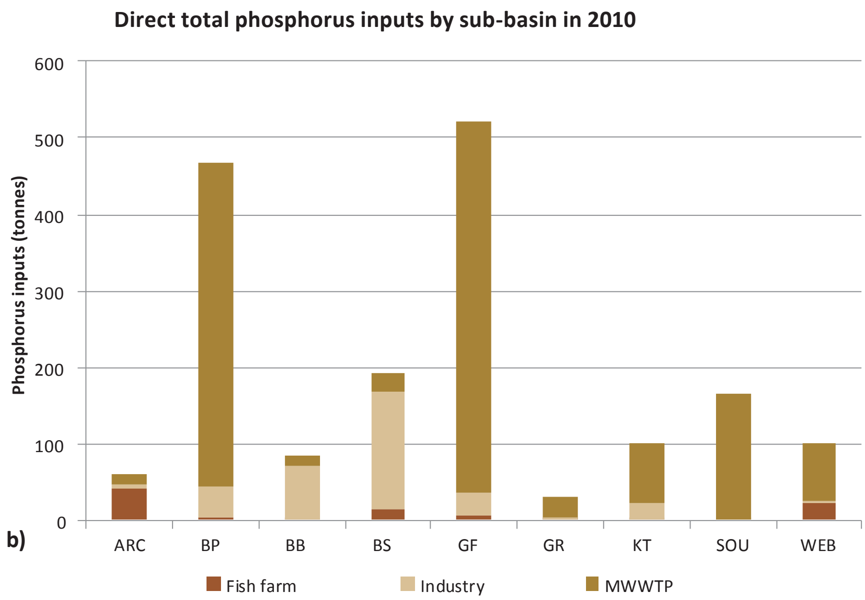
The proportion of direct nitrogen and phosphorus inputs originating from municipal wastewater treatment plants (MWWTP), industry, and fish farms, by country and by sub-basin are presented in **Figures 4.17** and **4.18.** The figures show that the biggest share of the direct point source inputs of nitrogen and phosphorus originated from MWWTP, and were discharged to the Baltic Proper and to the Gulf of Finland. Russia and Sweden are the main sources of nutrient inputs from point sources discharging directly to the Baltic Sea.

Nutrient inputs from direct point sources seem to be most important (constitute the largest share of total waterborne inputs) for the small sub-basins of the Archipelago Sea and the Sound (**Figure 4.19**). The highest share of inputs from point sources was observed in the Sound area, where the direct phosphorus inputs were approximately 50% of total waterborne phosphorus inputs.

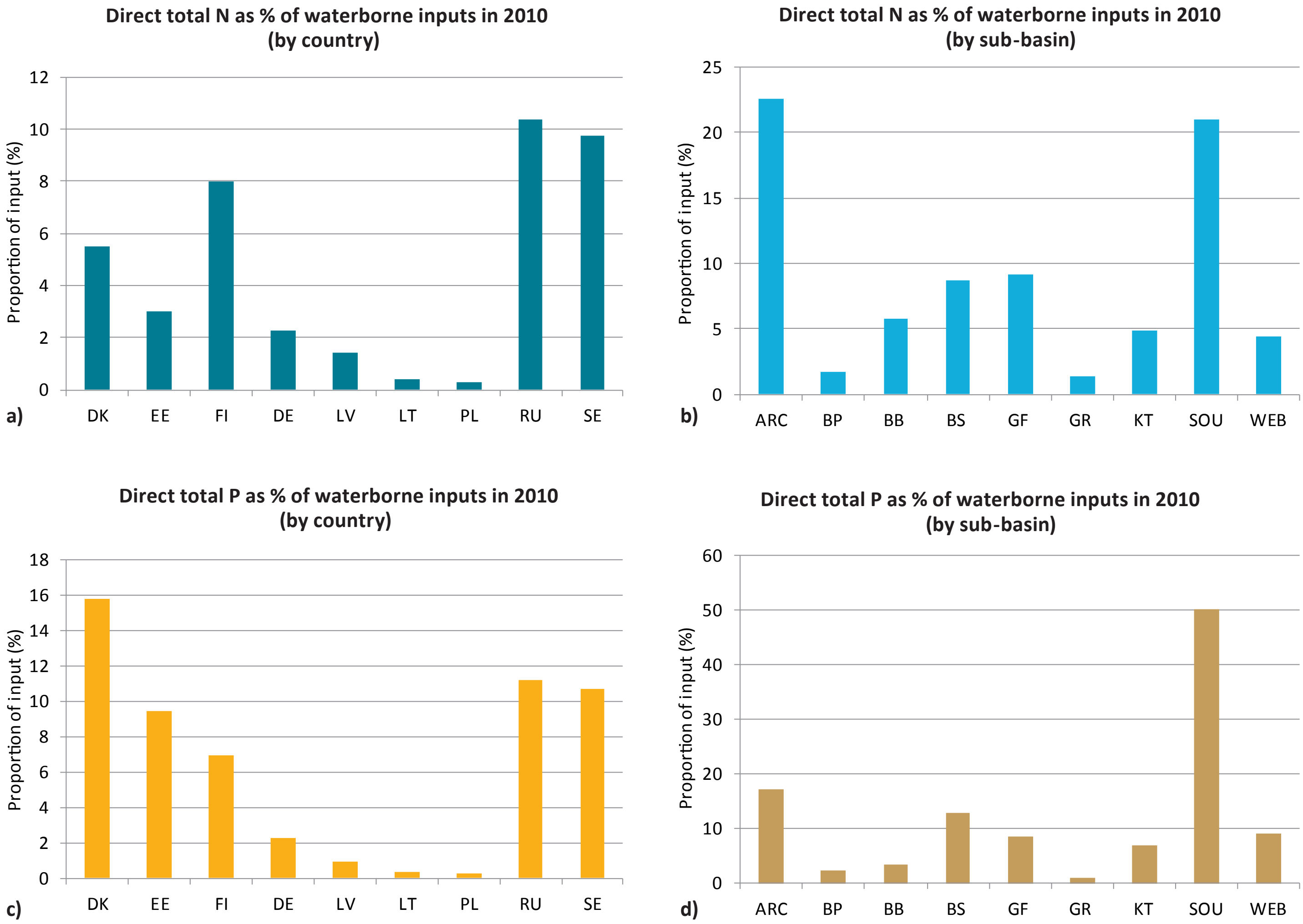


Figures 4.17a and **4.17b.** Direct point source inputs of total nitrogen (in tonnes) into the Baltic Sea by a) country and b) sub-basin in 2010. The proportions between countries may be variable because coastal sources have been defined according to somewhat different principles in different countries. (Missing data: No direct industrial discharges were reported by Poland for 2010). *See also note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*





Figures 4.18a and **4.18b.** Direct point source inputs of total phosphorus (in tonnes) into the Baltic Sea by a) country and b) sub-basin in 2010. The proportions between countries may be variable because coastal sources have been defined according to somewhat different principles in different countries. (Missing data: No direct industrial discharges were reported by Poland for 2010). *See also note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*



Figures 4.19a-d. Proportion (in %) of inputs from direct point sources of total waterborne nitrogen (a and b) and phosphorus (c and d) inputs into the Baltic Sea by country (a and c) and by sub-region (b and d) in 2010. The proportions between countries and regions may be variable because coastal sources have been defined according to somewhat different principles in different countries. (Missing data: No direct industrial discharges were reported by Poland for 2010). *See also note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

4.7. Transboundary pollution

The Baltic Sea also receives transboundary waterborne nitrogen and phosphorus inputs originating from five non-HELCOM countries: Belarus, Czech Republic, Norway, Slovakia and Ukraine. In 2010, these inputs constituted 2% of total nitrogen and 5% of total phosphorus inputs to the Baltic Sea. For some basins, waterborne transboundary inputs play a greater role such as for phosphorus inputs to the Gulf of Riga.

In most tables and figures in this report, the waterborne transboundary input entering the Baltic Sea is included in the waterborne inputs from the receiving HELCOM Contracting Parties. Transboundary inputs from other HELCOM Contracting Parties entering the Baltic Sea - as from Lithuania to Latvia and Russia, Poland to Russia, Germany to Poland, and Finland to Russia - are also included in the riverine inputs of the downstream Contracting Parties unless otherwise indicated. Two rivers, the rivers Torne/Tornio and Narva, are border rivers where the inputs to the Baltic Sea have been divided according to agreed proportions between the bordering countries. For the Odra, which at its outlet is a border river between Poland and Germany, and upstream also receives riverine inputs from the Czech Republic, the total inputs are included as the waterborne input from Poland.

The net waterborne transboundary nitrogen and phosphorus inputs from non-Contracting Parties (**Table 4.7a**) and from Contracting Parties (**Table 4.7b**) have been compiled by BNI Sweden (Gustafsson & Mörth, in prep). The largest amounts of transboundary waterborne nutrient inputs to the Baltic Sea originate from Belarus and drain via Latvia and Lithuania. Except for the German contribution via Odra (Poland), the transboundary waterborne inputs are estimated from observed nutrient fluxes at the border to the upstream country reduced by retention in the downstream country or countries. The retention factors reflecting the surface water retention are available from the BONUS+ project RECOCA (Wulff et al., 2014). For nitrogen these were estimated using a statistical approach (MESAW, Grimvall & Stålnacke 1996) and for phosphorus a hydraulic load and specific runoff approach was used (Behrendt & Opitz 2000). The spatial distributions of retention coefficients are shown in **Figures 4.20a** and **4.20b**. The German contribution via Odra was estimated separately by Germany using the MONERIS model.

Table 4.7a. Transboundary riverine inputs from non-HELCOM countries in the Baltic Sea catchment area (in tonnes per year) used in the revised CART calculations. All data are average for 1997-2003 except for the Belarusian data that are average for 2004-2011. Input at the border is reduced by the retention coefficient to estimated net waterborne input to the Baltic Sea. 'Share of inputs to the sub-basin' expresses how large a proportion of the total waterborne input to a sub-basin originates from the non-Contracting Party during the reference period. *See also note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

From	Via	To	Border		Retention		To Baltic		Share of input to the sub-basin	
			TN (t)	TP (t)	TN	TP	TN (t)	TP (t)	TN (%)	TP (%)
Czech	Poland	BAP	5,700	410	0.40	0.28	3,420	295	1.1	1.7
Belarus	Lithuania	BAP	13,600	914	0.54	0.53	6,256	430	2.1	2.5
Ukraine	Poland	BAP	4,124	127	0.40	0.28	2,474	91	0.8	0.5
Belarus	Poland	BAP	5,071	331	0.40	0.28	3,043	238	1.0	1.4
Total		**BAP**					**15,193**	**1,055**	**5.1**	**6.1**
Belarus	Latvia	GUR	8,532	1,360	0.27	0.32	**6,228**	**925**	**7.9**	**41.4**

Table 4.7b. Transboundary riverine inputs between HELCOM Contracting Parties (in tonnes per year) during the reference period. The input at the border is reduced by the given retention coefficient to estimate net waterborne transboundary inputs to the Baltic Sea. *See also note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

From	Via	To	Border		Retention		To Baltic	
			TN (t)	TP (t)	TN	TP	TN (t)	TP (t)
Lithuania	Latvia	BAP	5,516	158	0.39	0.58	3,365	66
Poland	Russia	BAP	4,400	320	0.30	0.37	3,080	202
Germany	Poland	BAP					2,337	101
Total		**BAP**					**8,782**	**369**
Lithuania	Latvia	GUR	7,185	282	0.27	0.32	5,245	192
Russia	Latvia	GUR	4,256	734	0.54	0.71	1,957	215
Total		**GUR**					**7,202**	**407**
Finland	Russia	GUF			0.48	0.82	5,353	49

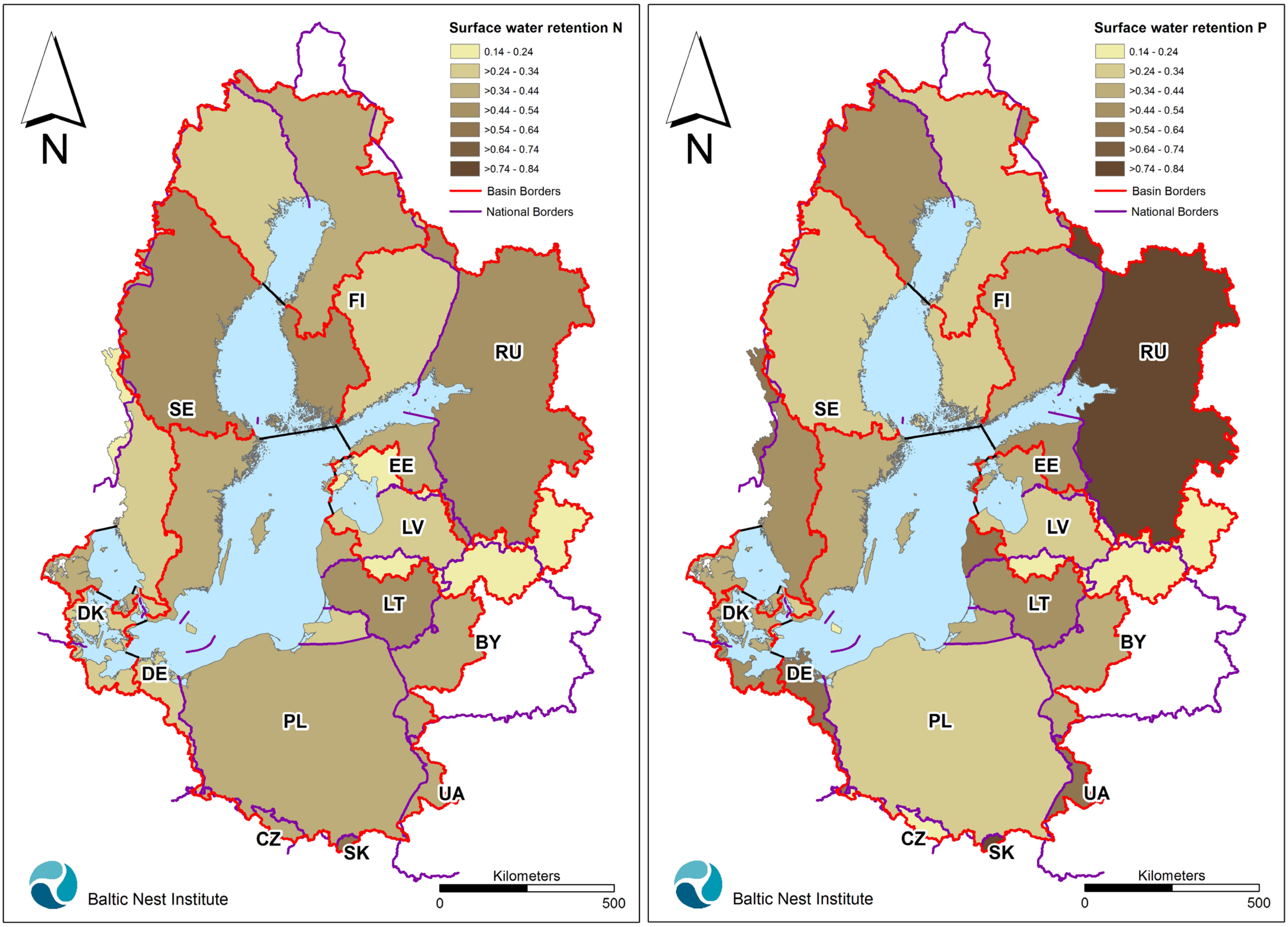


Figure 4.20. The nitrogen (left) and phosphorus (right) surface water retention coefficients used to estimate water-borne transboundary inputs.

5. Air- and waterborne nutrient inputs to the Baltic Sea during 1994-2010

5.1. Atmospheric deposition to the Baltic Sea during 1995-2010

Data on atmospheric emissions and deposition of nitrogen on the Baltic Sea from HELCOM countries and other sources (non-HELCOM countries and shipping) is available from 1995. Emissions are compiled from the whole territory of the countries, but for Russia only a part of the territory is included. The area of the Russian territory was considerably extended in 2006, leading to higher emissions figures from Russia from 2006 onwards.

Emissions from non-Contracting Parties also contribute significantly to nitrogen deposition on the Baltic Sea. Annual emissions of total nitrogen from seven HELCOM countries have decreased from 1995 to 2010 (**Figure 5.1**). According to EMEP (Bartnicki 2012a), emissions have decreased significantly since 1995. The largest reductions have been achieved by Denmark and Sweden, with 41% and 32% lower total nitrogen emissions to air in 2010 compared to 1995, respectively. Emissions from Estonia, Finland, Germany, Lithuania and Poland were 10-28% lower and the emissions from Latvia unchanged compared to 1995. Emissions from Russia increased with 28%, which is partly explained by the extension of the EMEP domain within the Russian territory that resulted in increased emissions after 2006, especially in 2007-2009. It should also be pointed out that the methodology of how emissions are calculated has changed between 1995 and 2010. Overall, the reduction of NO_x emissions was higher than the corresponding reduction in NH_x emissions from most HELCOM Contracting Parties.

Annual atmospheric emissions of total nitrogen by country, 1995-2010

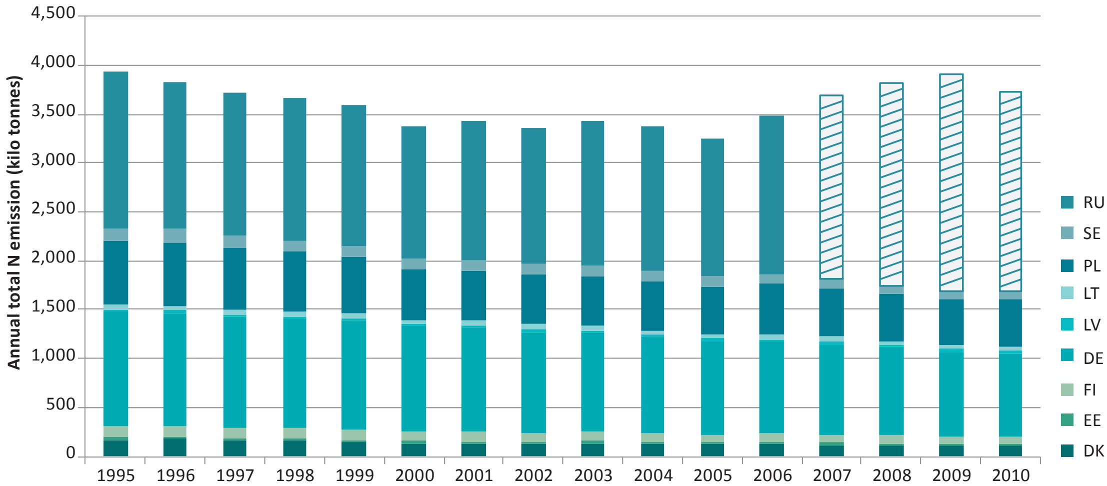


Figure 5.1. Annual atmospheric emissions of total nitrogen from HELCOM countries during 1995-2010. *Note:* the data cover emissions from the entire territories of the countries, except for Russia, where only emissions from the area covered by the EMEP domain are included. The EMEP domain area in Russia was significantly extended after 2006 resulting in a large increase of nitrogen emissions from Russia from 2007 onwards (indicated with stripes). (Data Source: Bartnicki 2012a).

In 2010, approximately 50% of the total nitrogen emissions were in oxidized form (NO_x), mainly resulting from combustion processes; the other 50% were in reduced form (NH_x), mainly ammonia originating from the agricultural sector. In the different HELCOM Contracting Parties, the share of the NO_x of total nitrogen emissions ranged between 40-62% in 2010. In 1995, the share of the NO_x of the total nitrogen emissions was slightly larger. NO_x emissions from shipping have been increasing since 2000 with growing shipping traffic - current estimates indicate a systematic annual increase of these emissions to be in the range of 2-3% (Bartnicki 2012a). An even larger increase has been estimated with a more detailed analysis of the Baltic Sea shipping emissions based on the messages of the automatic identification system (AIS), which enable the positioning of ships with a high spatial resolution (Jalkanen et al. 2013).

Deposition of total nitrogen is affected by climatic conditions and interannual variation of meteorological conditions, such as dominating wind direction, precipitation (intensity, frequency, distribution and type) and temperature. To evaluate to which extent decreased emissions have resulted in lower atmospheric deposition, EMEP has, for HELCOM PLC work in particular, introduced a procedure for the normalization of the annual deposition to the Baltic Sea during 1995-2010 to smoothen the effect of interannual meteorological variation[4] (see Annex 3 Chapter 9.3). **Figures 5.2** and **5.3** show the actual atmospheric nitrogen deposition during 1995-2010 for the seven Baltic Sea sub-basins (**Figure 5.2**) and actual deposition on the Baltic Sea from the Contracting Parties and other sources (**Figure 5.3**) in the same period. A line has been included in both figures to show the normalized total nitrogen deposition to the Baltic Sea during 1995-2010.

Chapter 5.5 includes the results of the statistical analysis on the development in atmospheric nitrogen deposition, showing a statistically significant decline in normalized depositions of total nitrogen for most Contracting Parties and to the whole Baltic Sea. The normalized nitrogen deposition to the Baltic Sea has decreased from approximately 250,000 tonnes in 1995 to some 193,000 tonnes of nitrogen in 2010. However, the actual atmospheric nitrogen deposition was rather high in 2010 (approximately 218,000 tonnes, or 12% higher than in 2009) mainly related to rather high precipitation in that year over some parts of the Baltic Sea catchment area. Further a trend line for the total nitrogen atmospheric deposition to the Baltic Sea has been added to **Figures 5.2** and **5.3**, showing a significant decreasing trend in deposition from 1995 to 2010.

As mentioned earlier in this chapter, the nitrogen emissions figures from Russia have increased since 2006 (as compared with 1995-2005). These sources, however, are situated in distant areas east from the Baltic Sea and hence their contribution to the nitrogen deposition on the Baltic Sea is small.

It should be noted that about 40% of the total nitrogen deposition to the Baltic Sea originates from emissions outside the HELCOM countries, ranging annually between 38-47% with the lowest shares in 2009 and 2010. EMEP has estimated that Baltic Sea shipping contributed from 4-5% of the total nitrogen deposition at the beginning of the period to 5-7% in later years. According to calculations based on the AIS ship emissions inventory, the share of the shipping to the nitrogen deposition was slightly higher in 2008-2010: about 14,000 tonnes nitrogen of the total of about 208,000 tonnes nitrogen deposition (Hongisto 2014).

4 For each year in this period, annual deposition is modeled 16 times by using the meteorological conditions for each year in the period and then taking an average of the 16 model runs (e.g. deposition for 1995 is calculated using meteorological conditions from 1995, 1996, 1997..., 2010, respectively, but using the same emission figures for each model run and then averaging the 16 estimates of the 1995 deposition to a normalized figure).

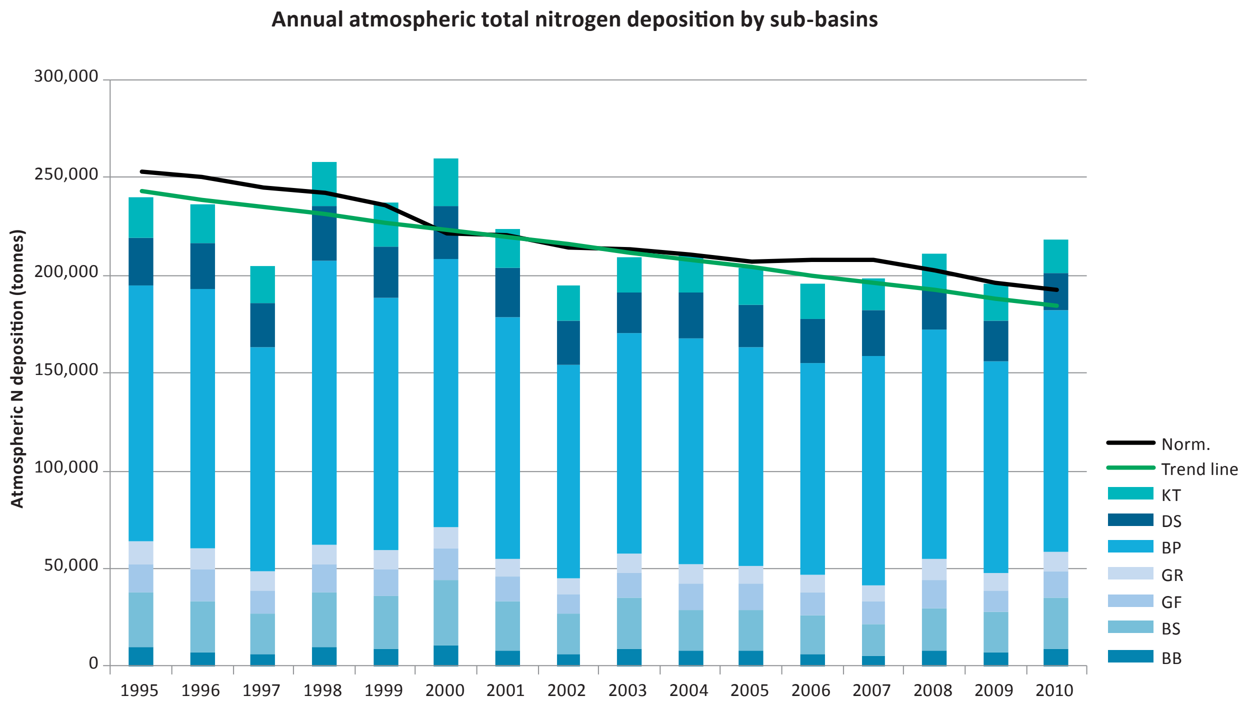


Figure 5.2. Annual actual atmospheric total nitrogen deposition on the sub-basins of the Baltic Sea and annual normalized total nitrogen deposition to the Baltic Sea (black line) and trend line (green bold line, significant trend) during 1995-2010 (tonnes). (Data source: Bartnicki 2012b)

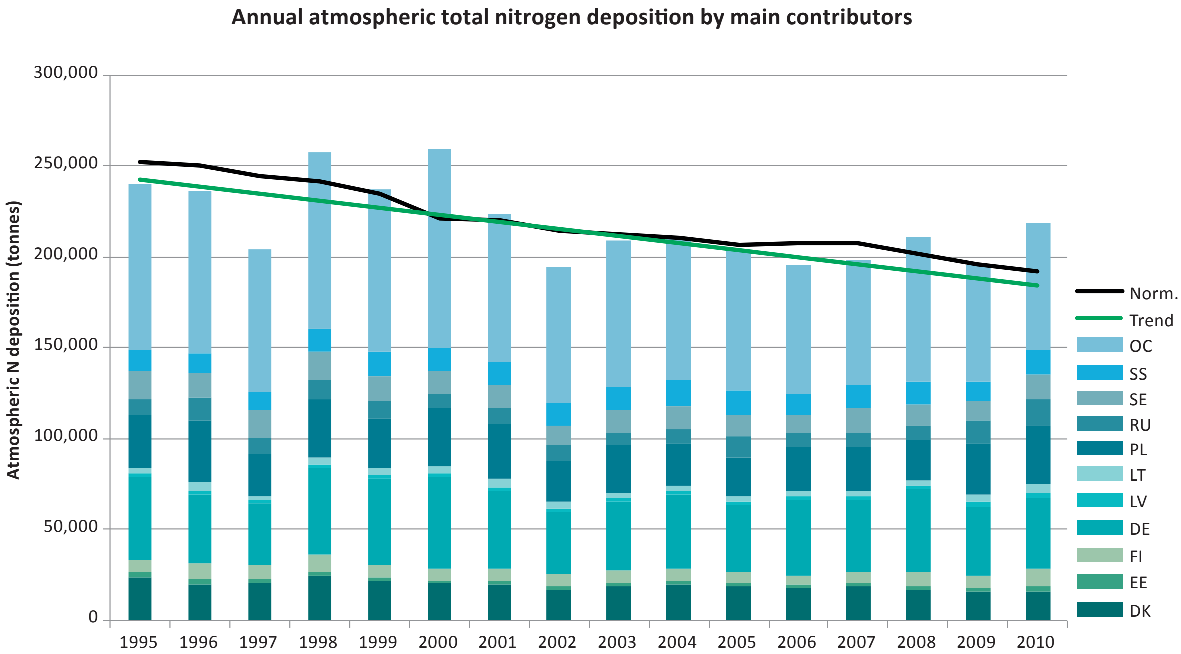


Figure 5.3. Annual actual atmospheric total nitrogen deposition from the main contributors (HELCOM Contracting Parties, Baltic Sea shipping (SS) and other countries and sources (OC) on the Baltic Sea and annual normalized total nitrogen to the Baltic Sea (black line) and trend line (green bold line, significant trend) during 1995-2010 (tonnes). (Data source: Bartnicki 2012b).

NO_x constitutes about 52-58% of total annual atmospheric nitrogen deposition onto the whole Baltic Sea. The percent input varies by sub-basins (from about 40-50% in Western Baltic to 60-65% in Archipelago Sea). However, the ratio NO_x/NH_x within each sub-basin was rather stable during the time period 1995-2010.

5.2. Waterborne nutrient loads to the Baltic Sea from 1994 to 2010

Annual water flow to the Baltic Sea has ranged between approximately 11,000 $m^3 s^{-1}$ (in 2003) to nearly 19,000 $m^3 s^{-1}$ (1998) during 1994-2010 (**Figure 5.4**) and there is no trend in these flows. As a consequence, the actual annual waterborne inputs (riverine and direct inputs) to the Baltic Sea of total nitrogen and total phosphorus by country (**Figures 5.5a** and **5.5b**) and by Baltic Sea sub-basin (**Figures 5.6a** and **5.6b**) show overall rather high interannual variation, making it difficult to compare inputs between years. When assessing trends in riverine and waterborne inputs into the Baltic Sea, the controlling influence of weather conditions, mainly water flow, should be taken into account since there is a close correlation between water flow and nutrient inputs. This overall relation is also seen in **Figures 5.5** and **5.6**. During years with heavy precipitation and associated high water flow, 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. Flow normalization of riverine input[5] data allows for a more correct evaluation of trends in the total waterborne inputs to the Baltic Sea as it, to some extent, can reduce the annual variation caused by the weather conditions (see Annex 9.4). The BNI Sweden 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), Aarhus University carried out trend analysis to evaluate whether there are any statistically significant changes in waterborne nitrogen and phosphorus inputs. Flow normalization of riverine inputs and trend analysis on normalized inputs is carried out according to the methodology agreed upon by HELCOM LOAD (Larsen & Svendsen, 2013).

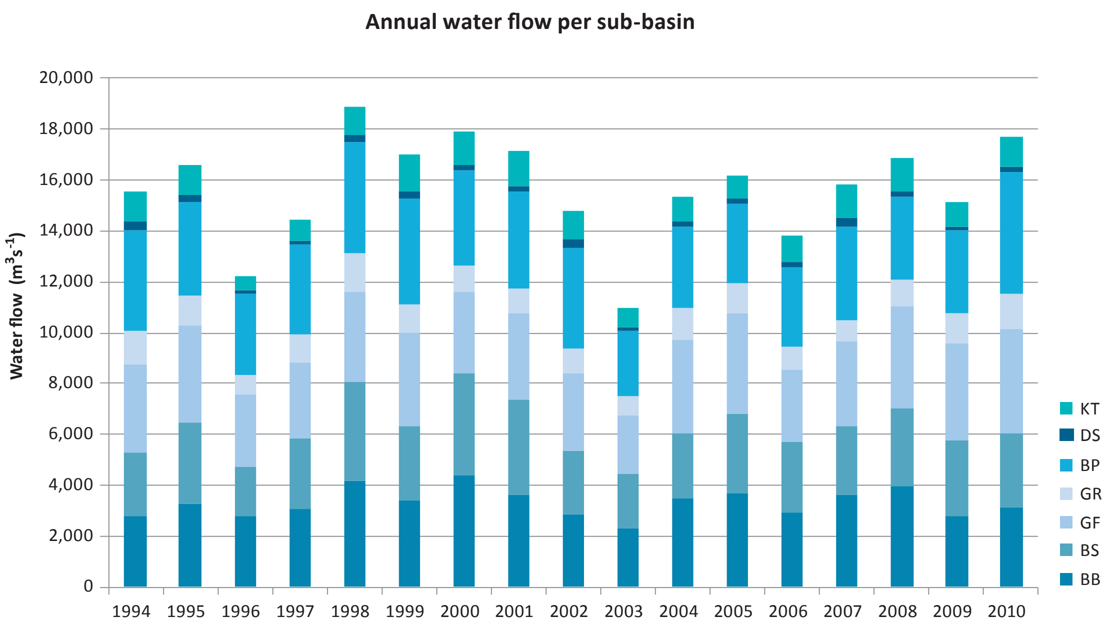


Figure 5.4. Annual water flow to the sub-basin in the Baltic Sea during 1994-2010 (in $m^3 s^{-1}$). *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

In **Figures 5.5a-b** and **5.6a-b**, a linear trend line on annual total flow normalized waterborne inputs of nitrogen and phosphorus, respectively, has been added to allow for visual inspection of trend in the time series of the actual waterborne inputs. The statistical trend analyses are summarized in Chapter 5.5. It is quite clear that there have been significant decreases in waterborne inputs of nitrogen

5 Flow normalization is performed on riverine inputs only, and not on the direct inputs from point sources as their discharges in general are independent on weather conditions. When mentioning flow normalized waterborne inputs, it is the sum of flow normalized riverine inputs + actual non-normalized direct inputs.

and phosphorus from e.g. Denmark, Poland (**Figures 5.5a-b**) and to the Kattegat and Baltic Sea as a whole (**Figures 5.6a-b**), as also confirmed by results of the statistical trend analysis in Chapter 5.5. The importance of weather conditions is rather clear when e.g. comparing the nitrogen and phosphorus waterborne inputs for most Contracting Parties in 2003 with the corresponding inputs in 1998. The high inputs from Poland in 2010 were due to two huge Central European flood events within one year (cf. **Figures 5.5a-b**).

It is quite obvious that flow normalization usually markedly reduces the interannual variation and therefore makes its easier to visually and statistically evaluate any trends in nutrient inputs to the Baltic Sea (**Figures 5.5a-b** and **5.6a-b**). It should be stressed that data on waterborne inputs from Latvia during 2008 to 2010, Russian data from the Kaliningrad Region and from unmonitored areas to Gulf of Finland were not been reported in time and had to be estimated within the project, which may affect the normalized values and trends.

The proportion of direct inputs to the Baltic Sea constitutes only a small share of the total inputs to the Baltic Sea sub-basins (7% of total nitrogen and 11% of total phosphorus at the beginning of the period and 5% and 7%, respectively at the end of the period). Comparisons between the Contracting Parties and between years for some of the given time series must be made with caution (**Figures 5.5** and **5.6**). Some Contracting Parties have not compiled direct inputs in the same way, and changes in methodology during the period 1994-2010 cannot be ruled out, e.g. including some point sources as a part of the riverine inputs some years and in the direct inputs in other years. Poland, Latvia and Lithuania are examples of countries that have a very low proportion of direct inputs of nitrogen and phosphorus (0-1% only). Chapter 4.6 (2010 data) and Chapter 5.2 (2004 to 2010 data) provide further details on direct inputs, and Chapter 5.4 elaborates on the trends in direct inputs. The most robust estimates of the direct sources are the aggregated inputs at the Baltic Sea level.

Figure 5.5a. Actual annual total riverine + direct (waterborne) nitrogen inputs and water flow by Contracting Party to the Baltic Sea and the total inputs to the Baltic Sea (BAS). The total annual normalized waterborne nitrogen inputs are shown by a bold black line. The trend for the flow normalized waterborne total nitrogen input is inserted as a green line to indicate a possible trend (solid line = a statistically significant trend; dotted line = no statistically significant trend; see further explanations in Chapter 5.5). *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

Figure 5.5b. Actual annual total riverine + direct phosphorus (waterborne) inputs and water flow by Contracting Party to the Baltic Sea and the total input to the Baltic Sea (BAS). The total annual normalized waterborne phosphorus inputs are shown by a bold black line. The trend line for the flow normalized waterborne total phosphorus input is inserted as a green line to indicate possible trend (solid line = a statistically significant trend; dotted line = no statistically significant trend; see further explanations in Chapter 5.5. *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

Figure 5.6a. Actual annual total riverine + direct (waterborne) nitrogen inputs and water flow per sub-basin and the total inputs to the Baltic Sea (BAS). The total annual normalized waterborne nitrogen inputs are shown by a bold black line. The trend for the flow normalized waterborne total nitrogen input is inserted as a green line to indicate a possible trend (solid line = a statistically significant trend; dotted line = no statistically significant trend; see further explanations in Chapter 5.5). *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

Figure 5.6b. Actual annual total riverine + direct phosphorus (waterborne) inputs and water flow per sub-basin and the total input to the Baltic Sea (BAS). The total annual normalized waterborne phosphorus inputs are shown by a bold black line. The trend line for the flow normalized waterborne total phosphorus input is inserted as a green line to indicate possible trend (solid line = a statistically significant trend; dotted line = no statistically significant trend; see further explanations in Chapter 5.5). *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

The sources of waterborne nutrient inputs were last assessed using 2006 data in the PLC-5 report (HELCOM 2011 and HELCOM 2012). However, information on inputs from point sources discharging directly into the Baltic Sea is available for 1994-2010 and presented below. The Contracting Parties report three categories of direct sources: municipal wastewater treatment plants (MWWTPs), industries and fish farms. The fish farms are either marine farms or fish farms located along the coast with discharges directly to the Baltic Sea.

Direct discharges of nitrogen and phosphorus from coastal municipal wastewater treatment plants (MWWTP), industries and fish farms into the Baltic Sea (**Figure 5.7**) are generally independent of variations in precipitation, although some municipal wastewater treatment plants may allow untreated overflows during heavy storm-water events. Consequently, no flow normalization is made on discharges from direct point sources. For all these sources, there is an overall statistically significant decrease for both nitrogen and phosphorus inputs to the Baltic Sea from 1994 to 2010 (**Table 5.1**). There is generally a marked decrease from 1994 to about year 2000. Further, there is a decrease for MWWTPs (phosphorus) and for industries from 2005 to 2010. For fish farms, reductions are seen until 2000 and then no major changes in the total input to the Baltic Sea can be noted. For fish farms, this might be a combined result of improved feed usage and better cleaning at fish farms despite current higher production and higher feed consumption in some of the Contracting Parties.

Photo by PURE project

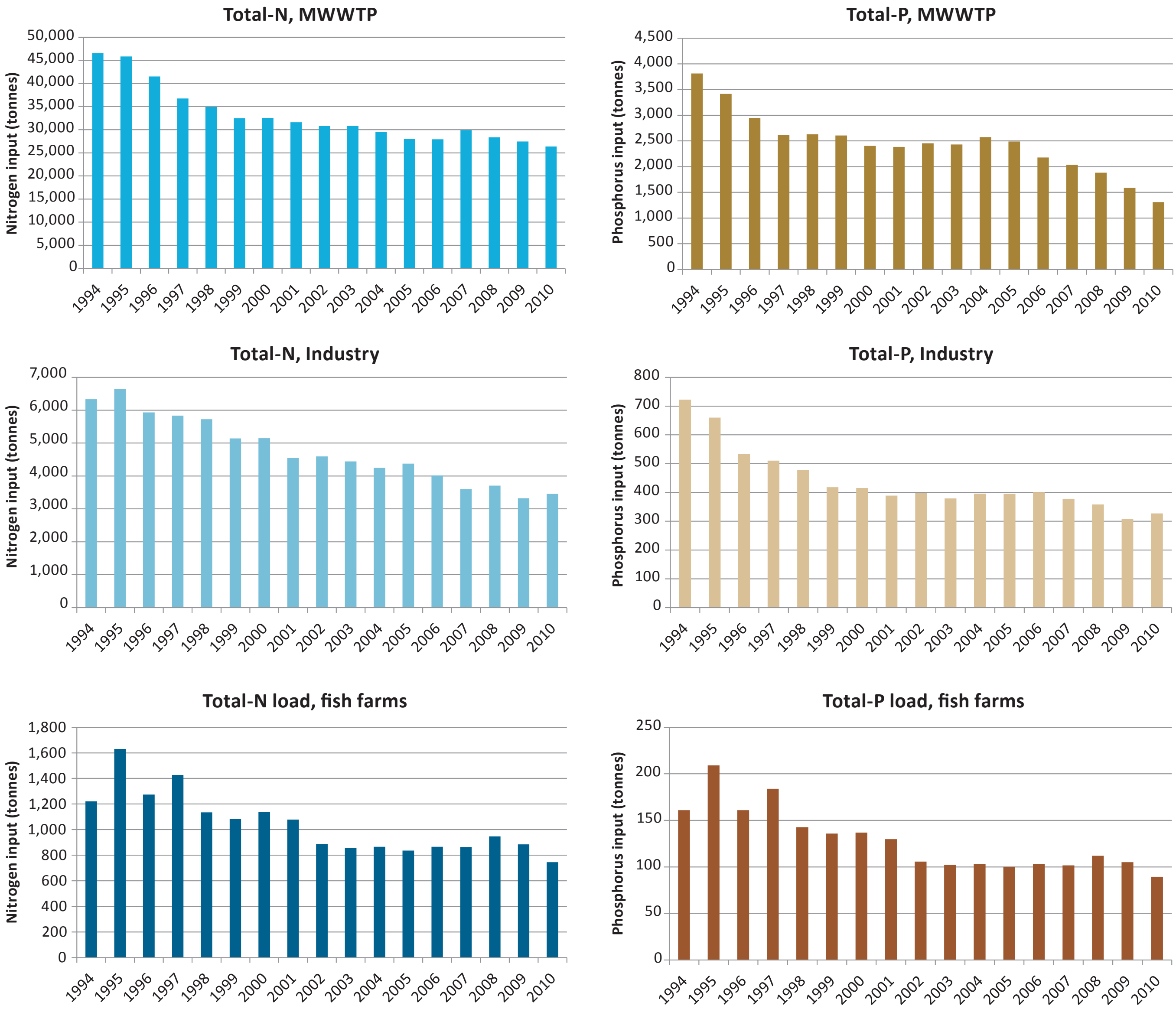


Figure 5.7. Annual direct inputs of total nitrogen and total phosphorus to the Baltic Sea from municipal wastewater treatment plants, MWWTP (top), industrial plants (middle) and fish farms (bottom) discharging directly to the sea during 1994-2010. *See note to Table 4.1a regarding premises on PLC-5.5 data set.*

The direct point source inputs of nitrogen and phosphorus to the Baltic Sea have decreased markedly by 43% and 63%, respectively, from 1994 to 2010 (Table 5.1a-b). Some Contracting Parties have reduced much more, such as Denmark and Germany as well as Lithuania for phosphorus. The real decrease might be higher for some countries, mainly due to some methodology changes quantifying direct inputs at the beginning of the period and because direct point sources have on some occasions been included in the riverine inputs by some Contracting Parties. It should also be noted that municipal nitrogen and phosphorus inputs from the Nordic Contracting Parties decreased significantly already before the 1988 HELCOM Ministerial Declaration (HELCOM 1988) was agreed upon due to measures taken already during the 1970s and 1980s, and also because reductions in some countries took place from 1990-1993. Trend estimates are based on an assumption of a linear trend, which is not always fulfilled and thus might affect the estimated changes in direct inputs from 1994 to 2010.

All Contracting Parties, except Estonia and Latvia, have a statistically significant decrease in total direct point source inputs for nitrogen, and all countries, except Estonia and Poland, have a statistically significant decrease in total direct point source inputs for phosphorus (**Table 5.1a**). In contrast to most other trends for the direct point sources, Latvia shows a significant increase in direct nitrogen inputs. As mentioned before, data from some Contracting Parties are rather uncertain due to changes in methodologies, as well as gaps in the data reporting, and the fact that estimates have been applied to make a complete data set (**Table 5.1a**). Chapter 5.5 describes statistical trend analysis in more detail.

The generally reduced discharges from direct point sources by most countries also have an impact when the trends on the sub-basins are assessed (**Table 5.1b**). The direct discharges to most basins show decreasing trends in both nitrogen and phosphorus inputs, except the nitrogen inputs to the Gulf of Riga, which are increasing markedly.

Tables 5.1a and 5.1b. Results of the Mann-Kendall test for significant trends on direct nitrogen and phosphorus inputs to the Baltic Sea (sum of inputs from municipal wastewater treatment plants, industries and fish farms discharging directly to the sea) by country (**Table 5.1a**) and by sub-basin (**Table 5.1b**). Estimated annual change (with a Theil-Sen slope estimator) in tonnes per year and estimated percentage of change in inputs from 1994 to 2010 where the trend is significant (confidence < 5%). The results where the confidence level is between 5-10% are given in parentheses. Further explanation on statistical methodology is given in Chapter 5.5 and footnotes 6-7). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Table 5.1a

	Direct point sources			
	Estimated Slope (t N y^{-1})	Change since 1994 (%)	Estimated Slope (t P y^{-1})	Change since 1994 (%)
DE	-173	-85	-1.68	-83
DK	-140	-72	-22.1	-79
EE	-	-	-	-
FI	-337	-48	-11.7	-51
LV	30.4	38	-13.1	-90
LT	-44.6	-77	-6.51	-91
PL	(-30)	(-44)	-	
RU	-177	-23	(-35)	(-56)
SE	-345	-37	-13.5	-39
BAS	**-1,163**	**-43**	**-125**	**-63**

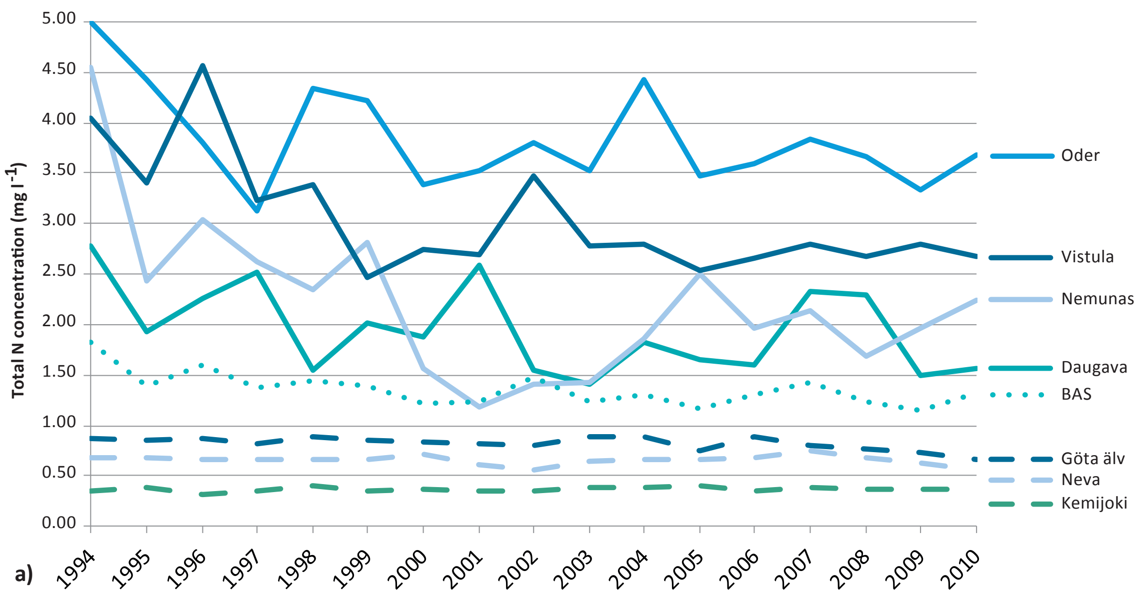
Table 5.1b

	Direct point sources			
	Estimated Slope (t N y^{-1})	Change since 1994 (%)	Estimated Slope (t P y^{-1})	Change since 1994 (%)
BB	-49.4	-24	-3.51	-42
BS	-87.2	-16	-10.1	-41
BP	-253	-47	-19.6	-41
GF	-369	-36	-36.0	-63
GR	40.6	63	-12.5	-90
DS	-335	-75	-18.3	-77
KT	-112	-49	-9.69	-68
BAS	**-1,163**	**-43**	**-125**	**-63**

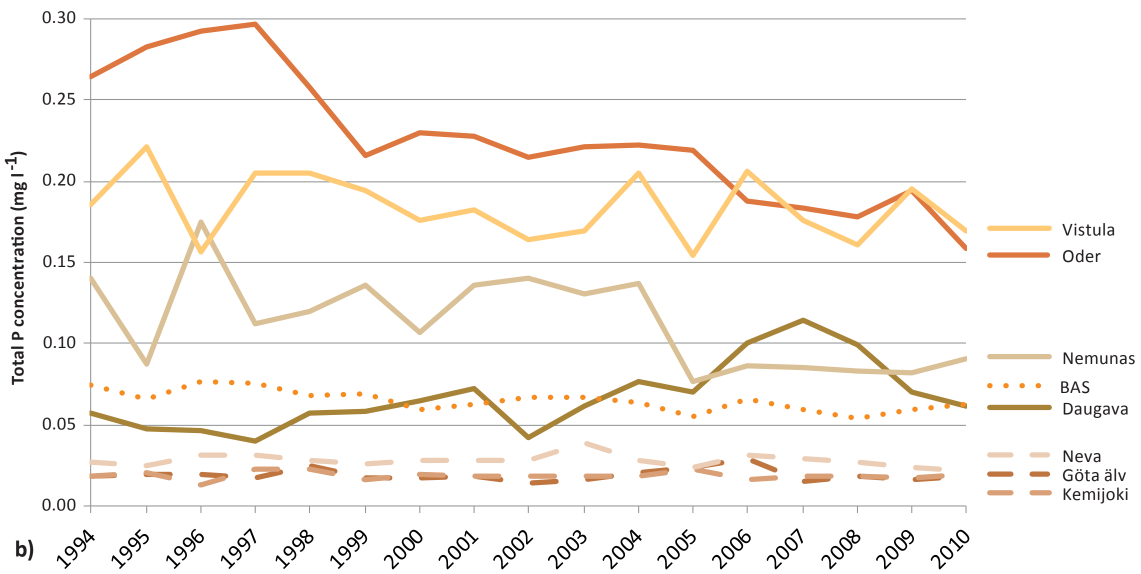
5.3. Inputs from the seven largest rivers during 1994-2010

As stated in Chapter 4.4, the seven largest rivers discharging to the Baltic Sea constituted about 50% of water flow and waterborne inputs in 2010. This sub-chapter provides more information on the waterborne inputs from the seven largest rivers during 1994-2010. Annual flow-weighted concentrations of nutrients have been calculated to allow for comparing concentration levels in the rivers (**Figures 5.8a** and **5.8b**). Odra and Vistula have the highest nitrogen and phosphorus concentrations, and Göta älv, Kemijoki and Neva the lowest. Extent of agricultural land and agricultural intensity together with population density are higher in the catchments of Odra and Vistula compared with the catchments of Göta älv, Kemijoki and Neva.

Annual flow-weighted concentrations of nitrogen

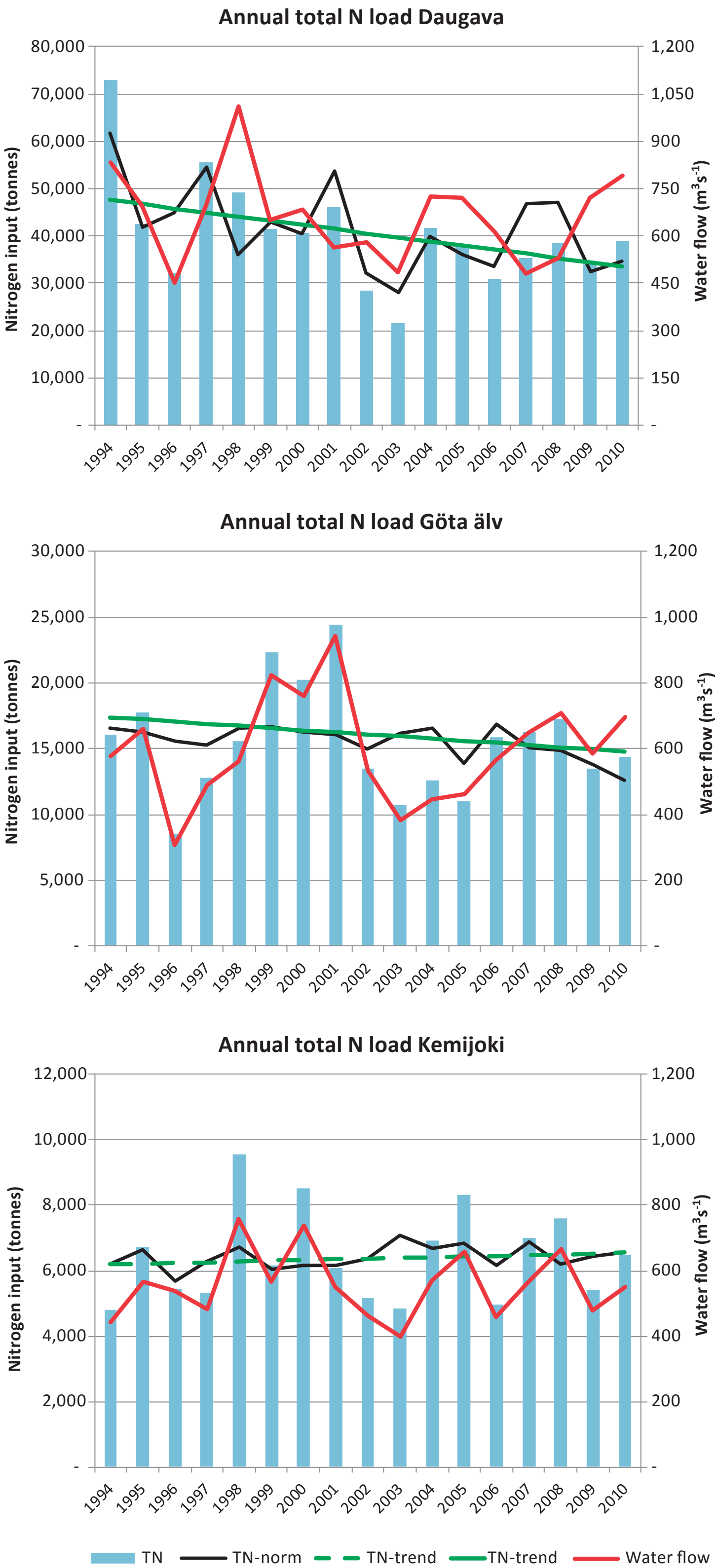


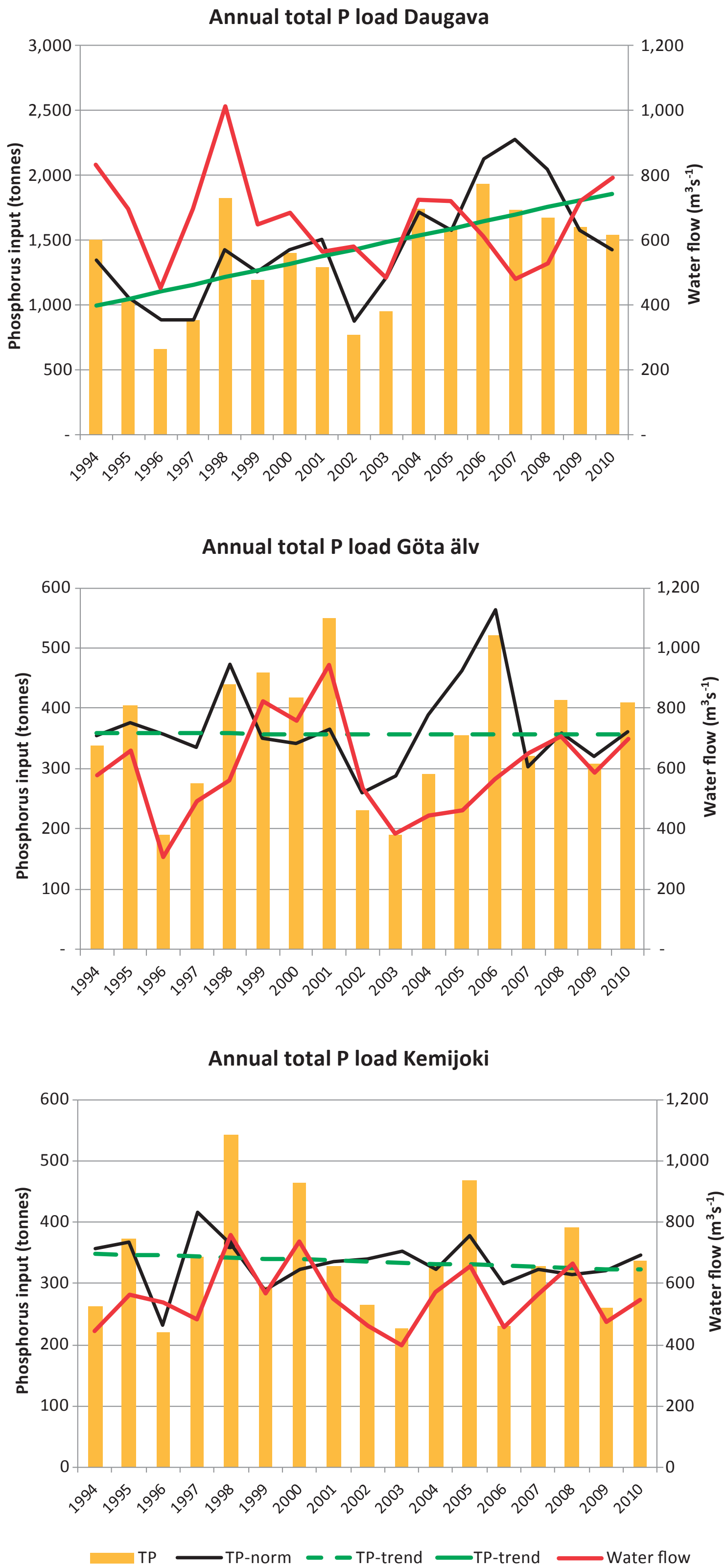
Annual flow-weighted concentrations of phosphorus



Figures 5.8a and b. Annual flow-weighted concentrations of nitrogen (top) and phosphorus (bottom) in mg l^{-1}. Flow normalized concentration is calculated as the annual load of nitrogen or phosphorus at the lowest monitoring point in the river and divided by the corresponding annual water flow. Also the flow-weighted normalized concentration for total riverine inputs to the Baltic Sea (BAS) is shown. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Figures 5.8a and **5.8b** indicate that flow-weighted nitrogen and phosphorus concentrations during 1994-2010 have been decreasing in many of the large rivers mostly from 1994 until the beginning of the 2000s, while for Daugava, flow-weighted concentrations seem to have increased. Trend analysis has been carried on the normalized riverine inputs of nutrients from the seven largest rivers during 1994-2010 (**Figure 5.9**) using the statistical methodology described in Chapter 5.5.





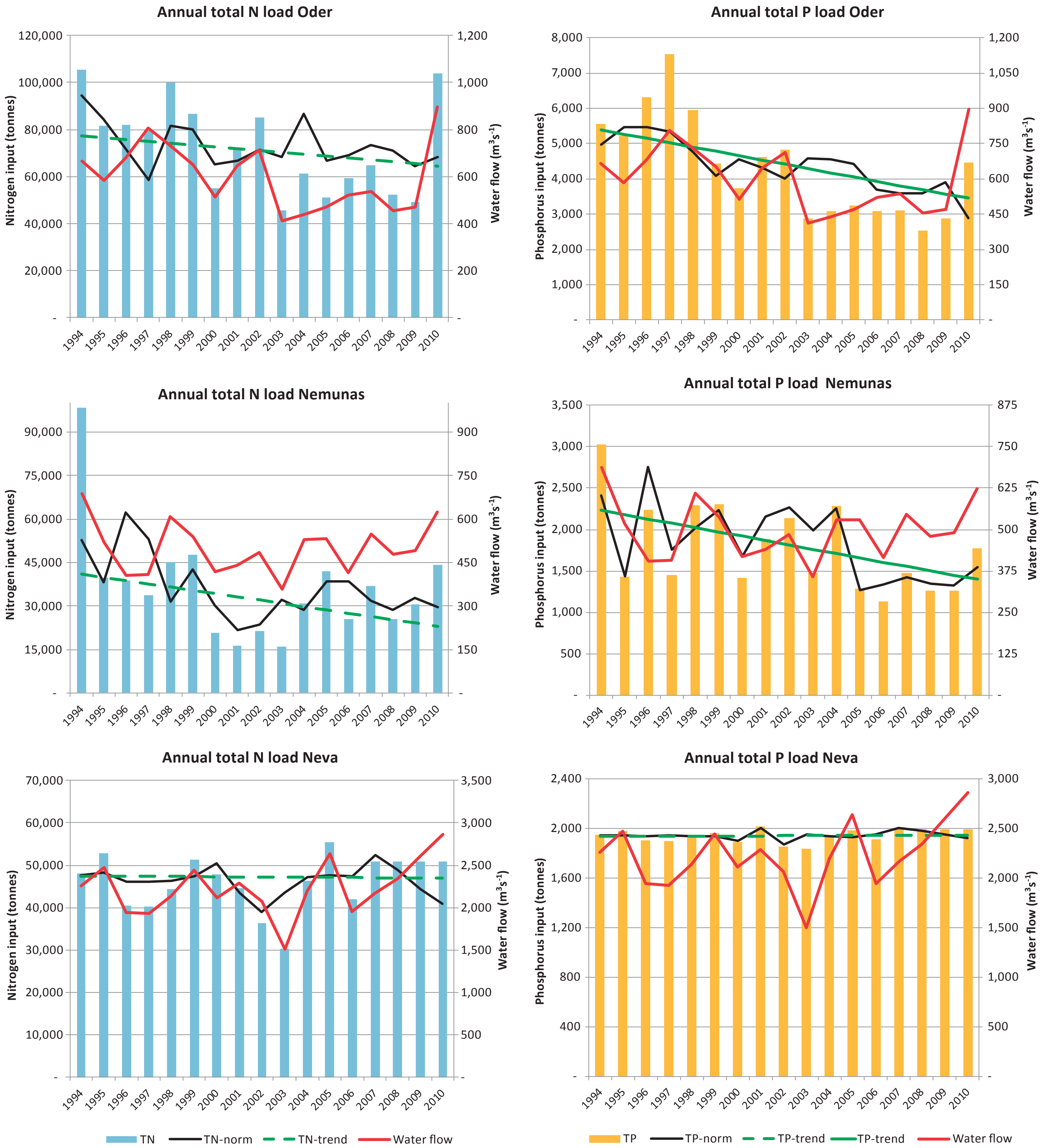

Annual total N load Oder
Nitrogen input (tonnes)
Water flow (m³s⁻¹)
Annual total P load Oder
Phosphorus input (tonnes)
Water flow (m³s⁻¹)
Annual total N load Nemunas
Nitrogen input (tonnes)
Water flow (m³s⁻¹)
Annual total P load Nemunas
Phosphorus input (tonnes)
Water flow (m³s⁻¹)
Annual total N load Neva
Nitrogen input (tonnes)
Water flow (m³s⁻¹)
Annual total P load Neva
Phosphorus input (tonnes)
Water flow (m³s⁻¹)
TN
TN-norm
TN-trend
Water flow
TP
TP-norm
TP-trend
TP-trend
Water flow

Figure 5.9. Annual total riverine total nitrogen (left column) and phosphorus (right column) loads in the seven largest river and total riverine nutrient inputs entering Baltic Sea during 1994-2010 (tonnes). Annual water flow (red line) and the flow normalized nitrogen and phosphorus loads (black line) are also shown. The trend line for the flow normalized riverine nitrogen and phosphorus inputs is inserted as a bold green line to indicate possible trend (solid line = a statistically significant trend; dotted line = no statistically significant trend. See further explanations in Chapter 5.5). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

There is a significant decrease in total nitrogen inputs from Daugava (6%), Göta älv (24%) and Vistula (36%) from 1994 to 2010. For total riverine phosphorus inputs from 1994 to 2010, a significant decrease was observed for Odra (42%) and Vistula (36%) while Daugava had a significant increase (6%) (**Table 5.2**). DCE, Aarhus University (Denmark) tested with a statistical method whether there is any change point in the normalized time series shown in Figure 5.9 to evaluate if the time series should be split in two or more series with different trends (Larsen & Svendsen, 2013). There are no significant change points in any of the time series for the seven largest rivers.

Tables 5.2. Results of the Mann-Kendall test for significant trends on riverine total nitrogen and phosphorus inputs from the seven largest rivers discharging into Baltic Sea and for the corresponding total riverine inputs to the Baltic Sea. Estimated annual change (with a Theil-Sen slope estimator) in tonnes per year and estimated percentage of change in inputs from 1994 to 2010 where the trend is significant (confidence < 5%). The results where the confidence level is between 5-10% are given in parentheses. Nemunas, Odra and Vistula enters Baltic Proper, Kemijoki enters Bothnian Bay, Neva enters Gulf of Finland, Daugava enters Gulf of Riga and Göta älv enter Kattegat Further explanation on statistical methodology is in Chapter 5.5 and footnotes 6-7). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

River	Estimated slope (tonnes N y^{-1})	Change since 1994 (%)	Estimated slope (tonnes P y^{-1})	Change since 1994 (%)
Daugava	(-874)	-6	54	6
Götaelv	-161	-24	-	-
Kemijoki	-	-	-	-
Odra	-	-	-121	-42
Nemunas	-	-	-52	-36
Neva	-	-	-	-
Vistula	-2,025	-36	-	-
Total water BAS	**-8,139**	**-17**	**-499**	**-21**

5.4. Total input to the Baltic Sea during 1995-2010

Total annual inputs (riverine, direct point source waterborne discharges and atmospheric deposition to the sea) of nitrogen and phosphorus to the main Baltic Sea sub-basin during 1995 to 2010 are shown together with the normalized annual total water- and airborne inputs to the these sub-basins (**Figure 5.10**). Further, trend lines for the normalized total nitrogen and phosphorus inputs are included in the figures to indicate possible trends. There is a statistically significant decrease in total water and airborne nitrogen inputs from 1995 to 2010 to the whole Baltic Sea and to all sub-basins except the Bothnian Bay and Gulf of Riga. A statistically significant decrease of total phosphorus inputs during the same period can be seen for inputs to the whole Baltic Sea and to the sub-basins of Bothnian Sea, Baltic Proper, Danish Straits and Kattegat, while there is a significant increase to the Gulf of Riga. It should be remembered that there are rather high uncertainties in the waterborne input data to the Gulf of Riga and in a significant part of the inputs to Gulf of Finland. The change in inputs (in per cent) has been estimated where trends were determined to be statistically significant (cf. Chapter 5.5).

Although this report does not present the information illustrated in Figure 5.10 "per country/source", data per HELCOM country are available in the PLC-5.5 data set, which can be downloaded via the PLC-5.5 project page on the HELCOM website. Such a presentation would require quantification of the inputs from the following sources to the total nitrogen and phosphorus inputs to the Baltic Sea: transboundary airborne inputs from Baltic Sea shipping, North Sea shipping, and other countries that are not members of HELCOM; transboundary waterborne inputs from Belarus, Czech Republic, Slovakia and Ukraine. Such quantification is presently not possible due to lack of information on the contribution of trans-boundary waterborne pollution from upstream countries and the amount which actually ends up in the sea after surface water retention in the catchment area.

Figure 5.10. The actual annual total (air- and waterborne) nitrogen and phosphorus inputs (riverine inputs + direct discharges + atmospheric deposition) to the Baltic Sea sub-basins during 1995-2010 (tonnes). Also, the normalized annual inputs of nitrogen and phosphorus are shown with a black line. The trend line for normalized total nitrogen and phosphorus input is inserted as a bold green line to indicate possible trend (solid line = a statistically significant trend; dotted line = no statistically significant trend. Maximum allowable inputs are indicated with a dotted red line. See further explanations in Chapter 5.5). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

5.5. Trend analysis of input data

In order to evaluate the progress of countries in reaching their nutrient reduction targets and to assess the effectiveness of measures to reduce nutrient inputs, it is important to evaluate the long-term trends in emissions and inputs of nutrients. Thus, the normalized airborne and flow normalized waterborne nitrogen and phosphorus inputs and the development of these inputs from 1994 to 2010 have been calculated and are summarized in this chapter.

> **Note:** Input data has been normalized before trend analysis has been carried out. For more information about normalization of airborne and flow normalization of waterborne input data, see Annexes 9.3 and 9.4

5.5.1. Short introduction on trend analysis methodology

A trend analysis has been carried out by DCE, Aarhus University (Denmark), with Mann-Kendall methodology (Hirsch et al. 1982) on annual flow normalized riverine inputs (A); direct inputs (B); flow normalized waterborne inputs (C = A+B); normalized airborne inputs (D); and the total normalized inputs (E=C+D) of nitrogen and phosphorus for all relevant combinations of Contracting Parties and sub-basins of the Baltic Sea. Where there is a significant trend, the annual changes were deducted with a Theil-Sen slope estimator (Hirsch et al., 1982) and the change from 1994 to 2010 was calculated (1995-2010 for airborne inputs as no information is available for atmospheric deposition from 1994). The methodology has been agreed on by the HELCOM LOAD (more information on trend analysis and determining the changes in input can be found in Larsen & Svendsen 2013).

The Mann-Kendall method is a well-established method for testing for a monotone trend in a time series. It is a non-parametric method based on Kendall's tau, which is a measure of the correlation between two different variables. The method is robust towards outliers and a few missing data. If the trend is linear, Mann-Kendall's method has slightly less power than an ordinary regression analysis.

The results of these statistical analyses for the Contracting Parties and sub-basins are summarized in **Tables 5.3** to **5.5** and in **Tables 5.1a** and **5.1b** (Chapter 5.3) for inputs from direct sources. The graphs in chapters 5.1, 5.2, 5.3 and 5.4 (**Figures 5.2, 5.3, 5.5, 5.6** and **5.10**) give the estimated slopes and inputs of nitrogen and phosphorus from 1994 to 2010 (for airborne input 1995-2010) for cases with a statistically significant trend with a confidence value less than 5%.[6] The figures in parentheses in the tables indicate results with confidence levels between 5-10%. No trend analyses were carried out on airborne phosphorus inputs as the same deposition rate is used for the whole area and throughout the period 1995-2010.

Before flow normalization was performed on riverine inputs, river flow was tested for any trend during 1994-2010 per country and per main Baltic Sea sub-basin and no trend was detected. If there is a trend in river flow the normalization of riverine inputs would be biased.

6 The null hypothesis tested whether there is no linear trend in a data series. This means that if the test shows a low confidence (< 5%), the hypothesis is rejected and there is a high statistical certainty of a linear trend.

5.5.2. Trends of nutrient inputs to the Baltic Sea

The overall developments in atmospheric deposition to Baltic Sea sub-basins and from the main contributors to deposition are described in Chapter 5.1 (**Figures 5.2** and **5.3**).

The normalized annual atmospheric inputs of total nitrogen have decreased with statistical significance (confidence < 5%, see footnote 6) from six HELCOM Contracting Parties, from the non-HELCOM EU countries (EU20), and other countries and sources (OC) (**Table 5.3a** and **5.3b**). The reduction to the Baltic Sea is 24% from 1995-2010 or more than 50,000 tonnes of nitrogen. Denmark has the highest relative reduction (40%), but also Finland, Germany, Poland, Sweden and the EU20 show marked reductions of between 23-34%. On the contrary, the normalized atmospheric total nitrogen inputs from Russia and Baltic Sea shipping (SS) increased significantly, with 34% and 44% respectively, during the same period.

Denmark, Germany, Poland and Sweden reduced their flow normalized total waterborne nitrogen input considerably (36%, 19%, 26% and 15%, respectively) from 1994 to 2010. These reductions are all statistically significant[7] as was the reduction in total inputs to the Baltic Sea (17%). Latvia and Lithuania also showed significant decreases in waterborne inputs of nitrogen, but only with a confidence of between 5-10% (cf. footnote 6); the Latvian data, however, must be interpreted with caution as the data from later years have been estimated due to the lack of reported data. The results from Lithuania are also influenced by very high flow normalized nitrogen inputs in 1994. Only Denmark (32%), Poland (26%) and Sweden (12%) show significant decreases in flow normalized riverine inputs with less than 5% confidence. Results of the trend analyses on direct inputs are included in Chapter 5.3.

The total normalized nitrogen inputs to the Baltic Sea were significantly reduced with 16% from 1994 to 2010 and Denmark (35%), Germany (23%), Poland (20%) and Sweden (15%) also significantly reduced their combined airborne and waterborne inputs during 1994-2010.

Flow normalized waterborne inputs of total phosphorus reduced significantly from all Contracting Parties and to the Baltic Sea (20%), except for Latvia where it increased significantly with 69% (**Table 5.3b**). As mentioned above, Latvian data are rather uncertain for 2008-2010. Denmark (34%), Lithuania (38%) and Poland (25%) have the highest reductions in total flow normalized waterborne phosphorus inputs from 1994 to 2010. Reductions in direct phosphorus inputs play a rather important role for the reduction of total flow normalized waterborne phosphorus inputs to the Baltic Sea, as these are reduced with 63% compared with the 16% reduction on flow normalized riverine phosphorus inputs (see **Table 5.1** in Chapter 5.2).

7 Changes in percentages have been calculated on normalized inputs as ((value 2010 – value 1994)/value 1994)*100% (for atmospheric input 1995 instead of 1994) when the statistical analysis indicated significant trend. The changes are statistically significant while the change in percentages should be interpreted as an estimated change from the beginning to the end the period 1994 (1995)-2010.

Table 5.3a. Estimates of slope (annual change in tonnes per year) and percentage of change (calculated on normalized values as (value 2010 – value 1994)/value 1994 *100%) of annual normalized airborne inputs, flow normalized riverine inputs, waterborne inputs (direct + riverine inputs) and total normalized inputs of total nitrogen from the Contracting Parties and total inputs to the Baltic Sea from 1994 to 2010 (airborne 1995 to 2010) based on a statistical trend analysis. For normalized airborne nitrogen deposition inputs from Baltic Sea shipping (SS), the EU20 (non-HELCOM EU countries) and other sources such as other countries, North Sea shipping etc. (OC) are also included. Only the results where the trend is statistically significant (confidence < 5%) are shown (see footnotes 6-7) and results are given in parentheses where the confidence is between 5-10%. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Country	Airborne inputs		Riverine inputs		Waterborne inputs		Total nitrogen inputs	
	Estimated slope ($t\ N\ y^{-1}$)	Change since 1995 (%)	Estimated slope ($t\ N\ y^{-1}$)	Change since 1994 (%)	Estimated slope ($t\ N\ y^{-1}$)	Change since 1994 (%)	Estimated Slope ($t\ N\ y^{-1}$)	Change since 1994 (%)
DE	-821	-25	-	-	-271	-19	-1,041	-23
DK	-649	-40	-1,064	-32	-1,291	-36	-1,851	-35
EE	-15	-10	-	-	-	-	-	-
FI	-127	-23	-	-	-	-	-	-
LV	-	-	(-1,142)	(-22)	(-1,105)	(-21)	-	-
LT	-	-	(-1,263)	(-39)	(-1,309)	(-39)	-	-
PL	-599	-29	-3,525	-26	-3,550	-26	-3,128	-20
RU	212	44	-	-	-	-	-	-
SE	-313	-31	-872	-12	-1,163	-15	-1,422	-15
SS	230	34					230	34
EU20	-1,503	-34					-1,503	-34
OC	-296	-15					-296	-15
BAS	**-3,895**	**-24**	**-7,207**	**-16**	**-8,139**	**-17**	**-10,428**	**-16**

Table 5.3b. Estimates of slope (annual change in tonnes per year) and percentage of change (see caption in **Table 5.3a**) of annual flow normalized riverine inputs, waterborne inputs (riverine + direct inputs) and total normalized inputs of total phosphorus from the Contracting Parties and the total to the Baltic Sea from 1994 to 2010 (airborne 1995 to 2010) from statistical trend analysis. As atmospheric phosphorus deposition is assumed constant during 1994-2010, the slope and change is zero and is thus not shown in the table (total deposition of phosphorus is nearly 2,100 tonnes). Only the results where the trend is statistically significant (confidence < 5%) are shown and the results are given in parentheses where the confidence is between 5-10%. *See note to Table 4.1b regarding the pre-conditions on the PLC-5.5 data set.*

Country	Airborne inputs		Riverine inputs		Waterborne inputs		Total phosphorus inputs	
	Estimated slope ($t\ P\ y^{-1}$)	Change since 1995 (%)	Estimated slope ($t\ P\ y^{-1}$)	Change since 1994 (%)	Estimated Slope ($t\ P\ y^{-1}$)	Change since 1994 (%)	Estimated Slope ($t\ P\ y^{-1}$)	Change since 1994 (%)
DE			(-5.5)	(-16)	-8.55	-23	-7.5	-20
DK			-23.2	-21	-49.2	-34	-41.8	-29
EE			-12.9	-26	(-11.5)	(-21)	-	-
FI			(-32)	(-15)	-48.2	-19	-45.1	-17
LV			85.6	100	74.9	69	86	75
LT			-63.4	-36	-71	-38	(-61)	(-33)
PL			-215	-24	-220	-25	-224	-24
RU			-	-	-	-	-	-
SE			-48.6	-22	-57.5	-23	-48.2	-18
BAS			**-354**	**-16**	**-499**	**-20**	**-476**	**-18**

Normalized atmospheric deposition of nitrogen decreased significantly to all seven Baltic Sea sub-basins (18-27%) from 1995 to 2010 (**Table 5.4a**) and with 24% to the Baltic Sea. The Kattegat, the Danish Straits and the Baltic Proper also show a statistically significant decrease for both flow normalized riverine (21-29%) and total waterborne (22-39%) nitrogen inputs from 1994 to 2010, while all sub-basins, except the Bothnian Sea and the Gulf of Riga, show a significant reduction (6-32%) in normalized total nitrogen inputs from 1994 to 2010.

Total normalized waterborne phosphorus inputs decreased significantly for the Bothnian Sea (28%), the Baltic Proper (26%), the Danish Straits (40%), and the Kattegat (22%). A significant decrease was also calculated for the Bothnian Bay (21%), but here the confidence level was between 5-10%. On the other hand, inputs increased with about 50% to the Gulf of Riga (Latvia data are rather uncertain, especially for 2008-2010), whereas no significant trends were detected for the Gulf of Finland (**Table 5.4b**).

The highest percentage reduction in total waterborne nitrogen and phosphorus inputs was calculated for the sub-basins were the proportion of nutrients from waste water of total inputs was high in the mid-1990s.

Table 5.4a. Estimates of slope (annual change in tonnes per year) and percentage of change (calculated on normalized values as (value 2010 – value 1994)/value 1994 *100%) of annual normalized airborne inputs, flow normalized riverine inputs, waterborne inputs (direct + riverine inputs) and total normalized inputs of total nitrogen by sub-basin and total inputs to the Baltic Sea from 1994 to 2010 (airborne 1995 to 2010) based on a statistical trend analysis (see caption of Table 5.3). Only the results where the trend is statistically significant (confidence < 5%) are shown and the results are given in parentheses where the confidence is between 5-10%. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

	Airborne inputs		Riverine inputs		Waterborne inputs		Total nitrogen inputs	
	Estimated slope (t N y^{-1})	Change since 1995 (%)	Estimated slope (t N y^{-1})	Change since 1994 (%)	Estimated slope (t N y^{-1})	Change since 1994 (%)	Estimated slope (t N y^{-1})	Change since 1994 (%)
BB	-114	-20	-	-	-	-	-	-
BS	-391	-22	-	-	-	-	-654	-12
BP	-2,206	-24	-4,256	-21	-4,655	-22	-6,077	-20
GF	-177	-18	-	-	-	-	-516	-6
GR	-160	-22	-	-	-	-	-	-
DS	-461	-26	-750	-29	-1,200	-39	-1,594	-32
KT	-410	-27	-874	-22	-968	-23	-1,358	-23
BAS	**-3,895**	**-24**	**-7,207**	**-16**	**-8,139**	**-17**	**-10,428**	**-16**

Table 5.4b. Estimates of slope (annual change in tonnes per year) and percentage of change (see caption in Table 5.4a) of annual flow normalized riverine inputs, waterborne inputs (= riverine + direct inputs) and total normalized inputs of total phosphorus by sub-basin and the total to the Baltic Sea from 1994 to 2010 (airborne 1995 to 2010) from statistical trend analysis (see caption of Table 5.3). Only the results where the trend is statistically significant (confidence < 5%) are shown and the results are given in parentheses where the confidence is between 5-10%. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

	Airborne inputs		Riverine inputs		Waterborne inputs		Total phosphorus inputs	
	Estimated slope (t P y^{-1})	Change since 1995 (%)	Estimated slope (t P y^{-1})	Change since 1994 (%)	Estimated slope (t P y^{-1})	Change since 1994 (%)	Estimated slope (t P y^{-1})	Change since 1994 (%)
BB			(-33)	(-21)	(-36.3)	(-21)	-	-
BS			-35	-25	-45.8	-28	-47.1	-24
BP			-297	-25	-321	-26	-331	-24
GF			-	-	-	-	-	-
GR			68,8	69	56.2	47	76.2	63
DS			-17.8	-23	-44.9	-40	-35.9	-30
KT			-14.4	-15	-24.2	-22	-21.2	-17
BAS			**-354**	**-16**	**-499**	**-20**	**-476**	**-18**

Table 5.5a shows statistically significant changes in the total inputs of nitrogen and phosphorus from 1994 to 2010 for all relevant countries by sub-basin. Denmark, Germany (with exception of total phosphorus to the Baltic Proper) and Poland are the only Contracting Parties with significant reductions of total air + waterborne nitrogen and total phosphorus input to all the main Baltic Sea sub-basins they have inputs to. Finland and Sweden have significant reductions of total nitrogen and phosphorus inputs to most sub-basins, apart from to the Bothnian Bay and the Bothnian Sea. For Sweden, the reduction in total phosphorus inputs to the Kattegat is not significant and for Finland it is not significant to the Gulf of Finland. Latvia has significant increase of total nitrogen inputs to all sub-basins besides to the Baltic Proper, but no trends for total phosphorus inputs. Latvia has significant increases of total phosphorus inputs (with 88% to the Baltic Proper and 72% to the Gulf of Riga), but no trends in total nitrogen inputs to Baltic Sea sub-basins. Lithuania has no significant trends in nitrogen and phosphorus inputs except for a decrease in total phosphorus inputs to the Baltic Proper. Overall, Denmark has the highest reduction in nitrogen and phosphorus inputs to different Baltic Sea sub-basins. Due to previously mentioned uncertainties in Latvian and Russian data, the trend analysis on their input data should be interpreted with some reservations.

The total nitrogen and phosphorus inputs in **Table 5.5a** are further divided into airborne inputs (**Table 5.5b**), total waterborne inputs (**Table 5.5c**), riverine inputs (**Table 5.5d**) and direct inputs from point sources (**Table 5.5e**).

Six Contracting Parties have significantly reduced their atmospheric nitrogen inputs to all main Baltic Sea basins. Russia had a significant increase in atmospheric nitrogen inputs (41-45%) from 1995 to 2010 although this is partly due to a change in the EMEP methodology where emissions from a larger part of Russia have been included in deposition calculations after 2006 (cf. Chapter 5.1). There was no significant trend in atmospheric nitrogen inputs from Latvia and Lithuania to the Baltic Sea sub-basins, except for to the Gulf of Riga where the atmospheric nitrogen inputs increased significantly from Latvia. Denmark had the highest significant reduction (approximately 40% reduction to all sub-basins) and Estonia the lowest (approximately 10%), whereas Russian deposition increased. The twenty EU members that are not Contracting Parties of HELCOM (EU20) significantly reduced, with approximately 35%, their contribution to atmospheric nitrogen inputs to all Baltic Sea basins. Atmospheric deposition of nitrogen originating from Baltic Sea shipping (SS) significantly increased to all sub-basins with 34%. Atmospheric inputs from other countries and sources (OC), significantly decreased to five sub-basins, but there were significant increases in deposition to the Kattegat and the Danish Straits, which partly might relate to higher deposition caused by North Sea shipping emissions.

The total waterborne and riverine inputs of nitrogen and phosphorus given in **Table 5.5c** and **5.5d** include transboundary inputs from non-Contracting Parties and from Contracting Parties, and are assigned to the country with the river mouth. In future PLC assessments these inputs will be separated and allocated to the individual countries that are the sources of the inputs entering the Baltic Sea based on available information. Based on expert estimates and best available data, about 8% of total waterborne nitrogen and phosphorus inputs to the Baltic Proper are of transboundary origin. For the Gulf of Finland the corresponding figures are 5% (nitrogen) and less that 1% (phosphorus) (Tables 4.7a and 4.7b). For the Gulf of Riga transboundary waterborne inputs are important, consisting of 17% of total waterborne nitrogen and 60% of the total phosphorus inputs. Transboundary inputs should be kept in mind when interpreting results on riverine and total waterborne inputs. Overall, riverine and total waterborne inputs of nitrogen and phosphorus have decreased to Baltic Proper, Danish Straits and Kattegat from all Contracting Parties with waterborne inputs to these sub-basins. For the Baltic Proper no trend is given for Russian data as they are estimated and almost the same values have been used for all years from 1994 to 2010. Further, significant increases in riverine and waterborne phosphorus inputs from Latvia to the Baltic Proper were observed, which may be partly explained by uncertainties on their data.

For the Bothnian Bay, Bothnian Sea, Gulf of Riga and Gulf of Finland there was no overall significant trends in the riverine or total waterborne nitrogen and phosphorus inputs from the countries that are contributing to these inputs. Finland had a significant increase in nitrogen inputs to Bothnian Bay and Bothnian Sea, while at the same time a significant decrease in phosphorus inputs to these basins. Latvia shows significantly high increases in waterborne and riverine phosphorus inputs. Denmark had overall the highest reduction in both riverine and waterborne nitrogen and phosphorus inputs to the sub-basins it discharges to.

Overall, there are more significant reductions in total waterborne inputs to sub-basins by countries than for the corresponding riverine inputs because there is an overall significant reduction in the direct discharges from point sources for both nitrogen and phosphorus (**Table 5.5e**). However, no significant decreases in the direct discharges were observed for Sweden (for nitrogen inputs to Bothnian Bay and Bothnian Sea), Poland (phosphorus inputs to Baltic Proper), Estonia (nitrogen inputs to Gulf of Finland and Gulf of Riga, and phosphorus inputs to Gulf of Finland), and Russia (nitrogen and phosphorus inputs to Baltic Proper). For Estonia, Poland and Russia this might be explained by changes in methodologies (with the direct inputs being include as part of riverine inputs in some years) and the use of estimates for missing data.

Table 5.5a Significant changes in **total (air- + waterborne)** normalized nitrogen and phosphorus inputs to the Baltic Sea by country and by sub-basin from 1994 to 2010. For phosphorus, only the country by sub-basin results are included where there are waterborne inputs from the country. *n.i.* = no waterborne inputs from the Contracting Party to this sub-basin. Only results where the trend is statistically significant (confidence < 5%) are shown; results where the confidence is between 5-10% are given in parentheses. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

	BB		BS		BP		GF		GR		DS		KT	
	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%
DE	-29	*n.i.*	-29	*n.i.*	-19	-	-29	*n.i.*	-29	*n.i.*	-26	-23	-26	*n.i.*
DK	-42	*n.i.*	-42	*n.i.*	-40	-27	-42	*n.i.*	-42	*n.i.*	-38	-32	-29	-23
EE	-11	*n.i.*	-11	*n.i.*	(-18)	-	-	-	-	-	-11	*n.i.*	-7.7	*n.i.*
FI	-	-18	-	(-19)	-32	*n.i.*	-20	-	-33	*n.i.*	-37	*n.i.*	-37	*n.i.*
LV	-	*n.i.*	-	*n.i.*	-	88	-	*n.i.*	-	72	-	*n.i.*	-	*n.i.*
LT	-	*n.i.*	-	*n.i.*	-	(-33)	-	*n.i.*	-	*n.i.*	-	*n.i.*	-	*n.i.*
PL	-28	*n.i.*	-29	*n.i.*	-19	-24	-28	n.i	-29	*n.i.*	-27	*n.i.*	-28	*n.i.*
RU	41	*n.i.*	44	*n.i.*	10	-	-	-	44	*n.i.*	44	*n.i.*	43	*n.i.*
SE	-	-	-	-28	-19	-20	-37	*n.i.*	-39	*n.i.*	-38	-26	-18	-
SS	34		34		34		34		34		34		34	
EU20	-34		-33		-34		-33		-33		-33		-36	
OC	-21		-23		-16		-28		-24		10		8.8	

Table 5.5b. Significant changes in normalized nitrogen and phosphorus **deposition** to the Baltic Sea by country and by sub-basin from 1995 to 2010. As phosphorus deposition is calculated as the same fixed value during 1995-2010 no statistical test was performed. Only results where the trend is statistically significant (confidence < 5%) are shown; results where the confidence is between 5-10% are given in parentheses. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

	BB		BS		BP		GF		GR		DS		KT	
	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%
DE	-29	-	-29	-	-26	-	-29	-	-29	-	-21	-	-26	-
DK	-42	-	-42	-	-41	-	-42	-	-42	-	-37	-	-37	-
EE	-11	-	-11	-	-10	-	-9.1	-	-8.9	-	-11	-	-7.8	-
FI	-14	-	-19	-	-32	-	-27	-	-33	-	-37	-	-37	-
LV	-	-	-	-	-	-	-	-	13	-	-	-	-	-
LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PL	-28	-	-29	-	-29	-	-28	-	-29	-	-27	-	-28	-
RU	41	-	44	-	45	-	41	-	44	-	44	-	43	-
SE	-3le en6	-	-35	-	-29	-	-37	-	-36	-	-32	-	-28	-
SS	34	-	34	-	34	-	34	-	34	-	34	-	34	-
EU20	-34	-	-33	-	-33	-	-33	-	-33	-	-36	-	-36	-
OC	-21	-	-23	-	-16	-	-28	-	-24	-	10	-	8.8	-

Table 5.5c. Significant changes in flow normalized total **waterborne** nitrogen and phosphorus inputs to the Baltic Sea by country and by sub-basin from 1994 to 2010. Only results where the trend is statistically significant (confidence < 5%) are shown; results where the confidence is between 5-10% are given in parentheses. *n.i.* = no waterborne inputs from the Contracting Party to this sub-basin. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

	BB		BS		BP		GF		GR		DS		KT	
	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%
DE	n.i.	n.i.	n.i.	n.i.	-	-16	n.i.	n.i.	n.i.	n.i.	-33	-27	n.i.	n.i.
DK	n.i.	n.i.	n.i.	n.i.	-33	-33	n.i.	n.i.	n.i.	n.i.	-42	-41	-29	-26
EE	n.i.	n.i.	n.i.	n.i.	-	-26	-	-11	-	-38	n.i.	n.i.	n.i.	n.i.
FI	16	-24	-	-16	n.i.	n.i.	-15	-16	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
LV	n.i.	n.i.	n.i.	n.i.	-	105	n.i.	n.i.	-	61	n.i.	n.i.	n.i.	n.i.
LT	n.i.	n.i.	n.i.	n.i.	(-39)	-38	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
PL	n.i.	n.i.	n.i.	n.i.	-26	-25	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
RU	n.i.	n.i.	n.i.	n.i.	-	-	-	-7.7	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
SE	-	-21	-	-33	-20	-24	n.i.	n.i.	n.i.	n.i.	-37	-28	-20	(-16)

Table 5.5d. Significant changes in total flow normalized **riverine** nitrogen and phosphorus inputs to the Baltic Sea by country and by sub-basin from 1994 to 2010. Only results where the trend is statistically significant (confidence < 5%) are shown; results where the confidence is between 5-10% are given in parentheses. *n.i.* = no waterborne inputs from the Contracting Party to this sub-basin. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

	BB		BS		BP		GF		GR		DS		KT	
	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%
DE	n.i.	n.i.	n.i.	n.i.	-	-	n.i.	n.i.	n.i.	n.i.	(-16)	(-16)	n.i.	n.i.
DK	n.i.	n.i.	n.i.	n.i.	-31	-12	n.i.	n.i.	n.i.	n.i.	-36	-26	-28	-18
EE	n.i.	n.i.	n.i.	n.i.	-	-	(22)	-	-	(-37)	n.i.	n.i.	n.i.	n.i.
FI	17	-21	-	-	n.i.	0	-	-	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
LV	n.i.	n.i.	n.i.	n.i.	-	106	n.i.	n.i.	(-24)	91	n.i.	n.i.	n.i.	n.i.
LT	n.i.	n.i.	n.i.	n.i.	(-39)	-36	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
PL	n.i.	n.i.	n.i.	n.i.	-26	-25	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
RU	n.i.	n.i.	n.i.	n.i.	-	-	-	-	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
SE	-	-	-	-34	-19	-20	n.i.	n.i.	n.i.	n.i.	-28	-20	-18	-

Table 5.5e Significant changes in total direct **inputs** (point sources discharging directly to the sea) of nitrogen and phosphorus to the Baltic Sea by country and by sub-basin from 1994 to 2010. Only results where the trend is statistically significant (confidence < 5%) are shown; results where the confidence is between 5-10% are given in parentheses. *n.i.* = no waterborne inputs from the Contracting Party to this sub-basin. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

	BB		BS		BP		GF		GR		DS		KT	
	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%	N%	P%
DE	n.i.	n.i.	n.i.	n.i.	-92	-82	n.i.	n.i.	n.i.	n.i.	-83	-83	n.i.	n.i.
DK	n.i.	n.i.	n.i.	n.i.	-88	-94	n.i.	n.i.	n.i.	n.i.	-75	-78	-60	-79
EE	n.i.	n.i.	n.i.	n.i.	-19	-41	-	-	-	(-31)	n.i.	n.i.	n.i.	n.i.
FI	-36	-48	-38	-53	n.i.	n.i.	-60	-49	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
LV	n.i.	n.i.	n.i.	n.i.	-56	-73	n.i.	n.i.	-2	-92	n.i.	n.i.	n.i.	n.i.
LT	n.i.	n.i.	n.i.	n.i.	-77	-91	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
PL	n.i.	n.i.	n.i.	n.i.	(-44)	-	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
RU	n.i.	n.i.	n.i.	n.i.	-	-	-27	(-69)	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
SE	-	-29	-	-32	-51	-42	n.i.	n.i.	n.i.	n.i.	-57	-57	-43	-48

5.6. Development of waterborne loads and total nitrogen inputs compared to the BSAP targets

As mentioned in the Preface, the HELCOM Contracting Parties agreed - when adopting the HELCOM Baltic Sea Action Plan (BSAP) - to reduce their nutrient inputs so that good environmental status of the Baltic Sea can be achieved by 2021 (HELCOM 2007). The provisional reduction requirements were calculated by deducting maximum allowable nutrient inputs (MAI) to the Baltic Sea sub-basins from waterborne reference inputs and dividing the reduction requirement between the Contracting Parties according to specified allocation principles. In the 2013 Copenhagen Ministerial Declaration a new set of MAI and country-wise allocation of reduction targets (CART) were agreed on, using the present PLC-5.5 data set as the basis (see e.g. HELCOM 2013a).

5.6.1. Reference period

For the calculations of revised MAI and CART, it was decided to use the average inputs in the period 1997-2003 as the reference period. Waterborne input averages are based on a sum of flow normalized riverine inputs, not normalized inputs from direct point sources, and normalized nitrogen airborne inputs. For the airborne phosphorus inputs the estimate presented in Chapter 4.2 was used.

The reference inputs per sub-basin are shown in **Table 5.6**. Total reference inputs to the Baltic Sea were 910,343 and 36,893 tonnes per year for nitrogen and phosphorus, respectively. Some 25% of the nitrogen inputs were airborne while atmospheric phosphorus deposition constituted less than 6% of total phosphorus inputs. About half of the nutrient inputs to the Baltic Sea are to the Baltic Proper.

Table 5.6. Waterborne, airborne and total inputs in the reference period (average 1997-2003) calculated using normalized data for riverine inputs of both nitrogen and phosphorus, and for nitrogen airborne inputs. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Sub-basins	Reference waterborne inputs (tonnes)		Reference airborne inputs (tonnes)		Reference total inputs (tonnes)	
	Total N	Total P	Total N	Total P	Total N	Total P
BB	49,437	2,494	8,185	181	57,622	2,675
BS	54,605	2,379	24,767	394	79,372	2,773
BP	297,679	17,274	126,243	1,046	423,921	18,320
GF	102,919	7,359	13,333	150	116,252	7,509
GR	78,373	2,235	10,045	93	88,417	2,328
DS	41,605	1,496	24,393	105	65,998	1,601
KT	58,484	1,569	20,277	118	78,761	1,687
BAS	**683,109**	**34,807**	**227,242**	**2,087**	**910,343**	**36,893**

Reference inputs were divided according to source, e.g. HELCOM countries and in the case of airborne nitrogen inputs also by Baltic Sea shipping (SS), non-HELCOM EU countries (EU20) and other sources/countries (OC). There is no source attribution available for the airborne phosphorus inputs. Country (source) by sub-basin inputs are presented in **Tables 5.7a** to **5.7c** for total inputs of nitrogen, airborne inputs of nitrogen and total inputs of phosphorus, respectively. Tables 4.7a and 4.7b indicate how the waterborne transboundary nitrogen and phosphorus inputs were divided for the 2013 Copenhagen Ministerial Declaration decision on new specific CARTs (HELCOM 2013a). In future PLC assessments the transboundary waterborne inputs will be taken into account separately.

Table 5.7a. Reference totals of nitrogen air- and waterborne inputs (average normalized data 1997-2003) by country (source) and by sub-basin (tonnes nitrogen). SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ sub-basin	Nitrogen inputs (tonnes)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE	801	2,994	32,555	1,477	1,437	20,708	3,364	**63,336**
DK	226	854	10,046	376	374	28,587	30,027	**70,490**
EE	93	299	1,795	12,683	12,777	17	20	**27,685**
FI	34,389	27,978	1,993	17,903	250	60	79	**82,651**
LV	62	258	11,100	206	66,284	23	26	**77,959**
LT	108	464	44,920	294	437	51	61	**46,335**
PL	631	2,647	212,487	1,313	1,335	1,061	1,133	**220,607**
RU	696	1,465	14,831	75,754	510	164	178	**93,599**
SE	17,571	31,502	39,299	565	440	5,870	35,032	**130,278**
OC	1,090	3,793	15,278	2,166	1,572	1,958	2,152	**28,009**
SS	361	1,461	7,169	739	561	826	751	**11,868**
EU20	1,595	5,658	32,449	2,775	2,441	6,673	5,938	**57,528**
ALL	**57,622**	**79,372**	**423,921**	**116,252**	**88,417**	**65,998**	**78,761**	**910,344**

Table 5.7b. Reference airborne nitrogen inputs (average normalize data 1997-2003) by country (source) and by sub-basin (tonnes nitrogen). SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping).

Source/ Sub-basin	Nitrogen inputs (tonnes)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE	801	2,994	25,708	1,477	1,437	7,865	3,364	**43,646**
DK	226	854	8,182	376	374	5,311	5,635	**20,956**
EE	93	299	661	680	247	17	20	**2,018**
FI	1,764	2,337	1,993	994	250	60	79	**7,476**
LV	62	258	967	206	441	23	26	**1,982**
LT	108	464	2,384	294	437	51	61	**3,799**
PL	631	2,647	19,655	1,313	1,335	1,061	1,133	**27,774**
RU	696	1,465	3,881	1,748	510	164	178	**8,643**
SE	758	2,537	7,916	565	440	384	941	**13,542**
OC	1,090	3,793	15,278	2,166	1,572	1,958	2,152	**28,009**
SS	361	1,461	7,169	739	561	826	751	**11,868**
EU20	1,595	5,658	32,449	2,775	2,441	6,673	5,938	**57,528**
ALL	**8,185**	**24,767**	**126,243**	**13,333**	**10,045**	**24,393**	**20,277**	**227,242**

Table 5.7c. Reference totals of phosphorus air- and waterborne inputs (average normalize data 1997-2003) by country (source) and by sub-basin (tonnes phosphorus). OS: Atmospheric deposition of phosphorus (not possible to allocate the airborne phosphorus to any country or source). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Phosphorus inputs (tonnes)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE	0	0	175	0	0	351	0	**525**
DK	0	0	59	0	0	1,040	829	**1,928**
EE	0	0	23	504	277	0	0	**804**
FI	1,668	1,255	0	637	0	0	0	**3,560**
LV	0	0	269	0	1,959	0	0	**2,228**
LT	0	0	2,635	0	0	0	0	**2,635**
PL	0	0	12,310	0	0	0	0	**12,310**
RU	0	0	960	6,218	0	0	0	**7,178**
SE	826	1,125	843	0	0	105	740	**3,639**
OS	181	394	1,046	150	93	105	118	**2,087**
ALL	**2,675**	**2,773**	**18,320**	**7,509**	**2,328**	**1,601**	**1,687**	**36,894**

5.6.2. Total nutrient inputs 1994-2010 compared to the Maximum Allowable Inputs (MAI)

A new set of MAI for total air- and waterborne nitrogen and phosphorus inputs to the seven Baltic Sea sub-basins was agreed in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a) as shown in **Table 5.8**. Compared to the reference inputs (Table 5.6) it will require a reduction with more than 118,100 tonnes of total nitrogen and nearly 15,200 tonnes total phosphorus inputs (normalized) to reduced total air- and waterborne inputs to fulfil MAI.

Table 5.8. Maximum allowable inputs (MAI) of total air- and waterborne nitrogen and phosphorus inputs to the Baltic Sea sub-basins as decided in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a).

Baltic Sea Sub-basin	Maximum Allowable Inputs (MAI)	
	Total N (tonnes)	Total P (tonnes)
BS	79,372	2,773
BB	57,622	2,675
BP	325,000	7,360
GF	101,800	3,600
GR	88,417	2,020
DS	65,998	1,601
KT	74,000	1,687
BAS	**792,209**	**21,716**

Figure 5.11 illustrates how the sum of normalized total airborne and flow normalized waterborne nutrient inputs to the Baltic Sea and the seven sub-basins have developed from 1994 to 2010 compared with the MAI. It is not the scope of this report to evaluate fulfilment of MAI, but rather to indicate progress. Figure 5.11 indicates that in the latest three years with quantified inputs (2008-2010):

- Total inputs of nitrogen were lower than MAI to Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat
- Total inputs of phosphorus were lower than MAI to Bothnian Bay, Danish Straits and Kattegat
- Total inputs of nitrogen were markedly higher than MAI for Gulf of Finland and Baltic Proper, and regarding phosphorus, inputs were considerably above MAI for Gulf of Finland, Gulf of Riga, Baltic Proper and the Baltic Sea as a whole.

In Chapters 5.6.3 and 5.6.4 further details are given on progress in nutrient input reduction during 2008-2010 as compared with the reference period.

Figure 5.11. Total inputs (normalized water flow, non-flow normalized direct point source inputs, and normalized atmospheric nitrogen deposition and non-normalized phosphorus deposition) of nitrogen and phosphorus to the Baltic Sea from 1995 to 2010, including the maximum allowable inputs (MAI) as agreed in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

5.6.3. Comparison of inputs during 2008-2010 to the reference period

In order to evaluate the progress of countries in reaching their nutrient reduction targets and to assess the effectiveness of measures to reduce nutrient inputs, it is important to evaluate the long-term trends in emissions and inputs of nutrients. Thus, a comparison between inputs during 2008-2010 (the most recent three-year average – used for a robust comparison) and the reference period (1997-2003) has been calculated.

The average normalized total (airborne plus waterborne) inputs of nitrogen and phosphorus during 2008-2010 were compared with the corresponding normalized reference inputs (Table 5.7a and 5.7c) and aggregated by country (Table 5.9), and by country and sub-basin for total nitrogen (Table 5.10a) and total phosphorus (Table 5.11a). Further changes in normalized total nitrogen airborne inputs from the reference period to the average of 2008-2010 by country and sub-basin and the corresponding changes in flow-normalized waterborne nitrogen inputs are calculated in **Table 5.10c** and **Table 5.10e**, respectively. The percentage of changes since the reference period has been calculated in **Tables 5.10b, 5.10.d, 5.10f** and **5.11b**, although it has not been tested whether these changes are statistically significant. The results can be used by the Contracting Parties to assess how they are proceeding in reducing inputs of nutrient inputs to the Baltic Sea.

Photo by Seppo Knuuttila

All Contracting Parties, except for Latvia and Russia (nitrogen), have lower normalized total nitrogen and phosphorus inputs during 2008-2010 compared to the reference period. Latvia has a markedly higher total normalized phosphorus input; however, data from 2008-2010 are uncertain due to lack of reported data. For the Baltic Sea, the normalized total nitrogen and phosphorus inputs have decreased with approximately 10%, or with more than 80,000 tonnes of nitrogen and nearly 3,800 tonnes of phosphorus, respectively. More than 30,000 tonnes of the total nitrogen reduction is due to reductions in the atmospheric deposition, of which 15,500 tonnes has been reduced by non-Contracting Parties (some 90% of this reduction originates from the EU20 countries that are not HELCOM Contracting Parties). However, inputs from Baltic Sea shipping have increased by more than 1,700 tonnes of nitrogen since the reference period to 2008-2010. Changes in total phosphorus inputs are a result of decreasing waterborne inputs, as the values for atmospheric phosphorus inputs are the same as for the reference period. It should be underlined that it has not been tested whether these changes are statistically significant and, for example for Finland, the decreases indicated in **Tables 5.9** to **5.11** might partly be due to the fact that normalization seems to not completely remove all variations caused by weather conditions, especially in the catchments to the Bothnian Bay and Bothnian Sea.

Table 5.9. Percentage of change in the total normalized nitrogen and phosphorus inputs from the reference period (average of 1997-2003) to 2008-2010 (average) by country and for Baltic Sea shipping (SS); the EU countries that are not HELCOM Contracting Parties (EU20); and other non-HELCOM Contracting Parties and other sources contributing to atmospheric nitrogen deposition (OC). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Country (source)	Reference total input 1997-2003 (tonnes)		Normalized input 2008-2010 (tonnes)		Change (%)	
	TN	TP	TN	TP	TN	TP
DE	63,335	526	54,949	520	-13	-1
DK	70,490	1,928	56,538	1,745	-20	-10
EE	27,684	804	25,760	648	-7	-19
FI	82,652	3,560	73,038	3,208	-12	-10
LV	77,959	2,227	79,960	2,811	3	26
LT	46,335	2,635	41,546	1,834	-10	-30
PL	220,606	12,310	204,637	10,666	-7	-13
RU	93,598	7,178	95,518	6,310	2	-12
SE	130,279	3,639	113,891	3,315	-13	-9
OC	28,009	2,087	26,360	2,087	-6	0
SS	11,868	0	13,592	0	15	-
EU20	57,528	0	43,618	0	-24	-
ALL	**910,343**	**36,893**	**829,406**	**33,143**	**-9**	**-10**

Table 5.10a. Changes in normalized total nitrogen air- and waterborne input from the reference period to the average of 2008-2010 in tonnes. SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in nitrogen inputs (tonnes)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE	-165	-616	-4,754	-304	-290	-1,673	-587	**-8,388**
DK	-67	-250	-2,493	-111	-109	-6,152	-4,771	**-13,951**
EE	-6	-17	-330	200	-1,768	-2	-1	**-1,925**
FI	-1,500	-4,697	-409	-2,921	-53	-15	-19	**-9,613**
LV	0	4	1,987	8	3	0	0	**2,001**
LT	-16	-71	-4,559	-45	-84	-7	-8	**-4,789**
PL	-75	-313	-15,017	-155	-161	-119	-130	**-15,970**
RU	316	660	1,746	-1,184	229	73	80	**1,919**
SE	-2,071	-1,770	-5,441	-118	-88	-1,083	-5,815	**-16,386**
OC	-107	-417	-941	-284	-164	134	131	**-1,649**
SS	53	212	1,041	107	81	120	109	**1,723**
EU20	-385	-1,337	-7,757	-650	-571	-1,694	-1,515	**-13,910**
ALL	**-4,023**	**-8,611**	**-36,928**	**-5,457**	**-2,974**	**-10,417**	**-12,528**	**-80,937**

Table 5.10b. Changes in **Table 5.10a** as percentage of values in **Table 5.7a**. SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in nitrogen inputs (%)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE	-21	-21	-15	-21	-20	-8	-17	**-13**
DK	-29	-29	-25	-30	-29	-22	-16	**-20**
EE	-7	-6	-18	2	-14	-10	-7	**-7**
FI	-4	-17	-21	-16	-21	-24	-24	**-12**
LV	1	2	18	4	0	-2	-1	**3**
LT	-14	-15	-10	-15	-19	-13	-13	**-10**
PL	-12	-12	-7	-12	-12	-11	-12	**-7**
RU	45	45	12	-2	45	45	45	**2**
SE	-12	-6	-14	-21	-20	-18	-17	**-13**
OC	-10	-11	-6	-13	-10	7	6	**-6**
SS	15	15	15	15	15	14	15	**15**
EU20	-24	-24	-24	-23	-23	-25	-26	**-24**
ALL	**-7**	**-11**	**-9**	**-5**	**-3**	**-16**	**-16**	**-9**

Table 5.10c. Changes in normalized total nitrogen airborne input from the reference period to the average of 2008-2010 in tonnes. SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in nitrogen inputs (tonnes)							
	BB	BS	BP	GF	GR	DS	KT	ALL
DE	-165	-616	-4,587	-304	-290	-1,063	-587	**-7,611**
DK	-67	-250	-2,159	-111	-109	-1,222	-1305	**-5,221**
EE	-6	-17	-38	-9	0	-2	-1	**-74**
FI	-161	-284	-409	-170	-53	-15	-19	**-1,110**
LV	0	4	48	8	57	0	0	**117**
LT	-16	-71	-446	-45	-84	-7	-8	**-677**
PL	-75	-313	-2,567	-155	-161	-119	-130	**-3,520**
RU	316	660	1,746	792	229	73	80	**3,896**
SE	-151	-486	-1,304	-118	-88	-70	-151	**-2,368**
OC	-107	-417	-941	-284	-164	134	131	**-1,649**
SS	53	212	1,041	107	81	120	109	**1,723**
EU20	-385	-1,337	-7,757	-650	-571	-1,694	-1515	**-13,910**
ALL	**-763**	**-2,914**	**-17,374**	**-939**	**-1,152**	**-3,865**	**-3397**	**-30,403**

Table 5.10d. Changes in **Table 5.10c** as percentage (%) of values in **Table 5.7b.** SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in nitrogen inputs (%)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE	-21	-21	-18	-21	-20	-14	-17	**-17**
DK	-29	-29	-26	-30	-29	-23	-23	**-25**
EE	-7	-6	-6	-1	0	-10	-7	**-4**
FI	-9	-12	-21	-17	-21	-24	-24	**-15**
LV	1	2	5	4	13	-2	-1	**6**
LT	-14	-15	-19	-15	-19	-13	-13	**-18**
PL	-12	-12	-13	-12	-12	-11	-12	**-13**
RU	45	45	45	45	45	45	45	**45**
SE	-20	-19	-16	-21	-20	-18	-16	**-17**
OC	-10	-11	-6	-13	-10	7	6	**-6**
SS	15	15	15	15	15	14	15	**15**
EU20	-24	-24	-24	-23	-23	-25	-26	**-24**
ALL	**-9**	**-12**	**-14**	**-7**	**-11**	**-16**	**-17**	**-13**

Table 5.10e. Changes in flow-normalized total nitrogen waterborne input from the reference period to the average of 2008-2010 in tonnes. SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in nitrogen inputs (tonnes)							
	BB	BS	BP	GF	GR	DS	KT	ALL
DE			-167			-610		**-776**
DK			-333			-4,930	-3,467	**-8,730**
EE			-293	210	-17,68			**-1,851**
FI	-1,339	-4,413		-2,751				**-8,503**
LV			1,938		-54			**1,884**
LT			-4,112					**-4,112**
PL			-12,450					**-12,450**
RU				-1,977				**-1,977**
SE	-1,921	-1,284	-4,137			-1,013	-5,664	**-14,019**
OC								
SS								
EU20								
ALL	**-3,260**	**-5,698**	**-19,553**	**-4,518**	**-1,822**	**-6,553**	**-9,131**	**-50,534**

Table 5.10f. Changes in flow-normalized total nitrogen waterborne input from the reference period to the average of 2008-2010 in percentage (%) of reference flow-normlaized waterborne inputs tonnes. SS = Baltic Sea shipping; EU20 = non-HELCOM EU countries; OC = other non-HELCOM countries and other sources (e.g. North Sea shipping). *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in nitrogen inputs (%)							
	BB	BS	BP	GF	GR	DS	KT	ALL
DE			-2			-5		**-4**
DK			-18			-21	-14	**-18**
EE			-26	2	-14			**-7**
FI	-4	-17		-16				**-11**
LV			19		0			**2**
LT			-10					**-10**
PL			-6					**-6**
RU			0	-3				**-2**
SE	-11	-4	-13			-18	-17	**-12**
OC								
SS								
EU20								
ALL	**-7**	**-10**	**-7**	**-4**	**-2**	**-16**	**-16**	**-7**

Table 5.11a. Changes in the normalized total phosphorus air- and waterborne inputs from the reference period (**Table 5.7c**) to the average of 2008-2010 in tonnes. There are only changes in waterborne inputs as atmospheric inputs are the same as in the reference period. OS: Other sources, such as atmospheric deposition, cannot be allocated to any specific country or source. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in phosphorus inputs (tonnes)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE	0	0	8	0	0	-14	0	**-5**
DK	0	0	-8	0	0	-72	-103	**-184**
EE	0	0	0	-99	-57	0	0	**-156**
FI	-184	-135	0	-32	0	0	0	**-352**
LV	0	0	145	0	438	0	0	**583**
LT	0	0	-801	0	0	0	0	**-801**
PL	0	0	-1,644	0	0	0	0	**-1,644**
RU	0	0	0	-868	0	0	0	**-868**
SE	76	-171	-135	0	0	-22	-72	**-324**
OS	0	0	0	0	0	0	0	**0**
ALL	**-108**	**-306**	**-2,435**	**-1,000**	**381**	**-108**	**-175**	**-3,751**

Table 5.11b. Changes in **Table 5.11a** as percentage (%) of values in **Table 5.7c.** OS: Other sources, such as atmospheric deposition, cannot be allocated to any specific country or source. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Source/ Sub-basin	Change in phosphorus inputs (%)							
	BB	BS	BP	GF	GR	DS	KT	BAS
DE			5			-4		**-1**
DK			-14			-7	-12	**-10**
EE			0	-20	-20			**-19**
FI	-11	-11		-5				**-10**
LV			54		22			**26**
LT			-30					**-30**
PL			-13					**-13**
RU			0	-14				**-12**
SE	9	-15	-16			-21	-10	**-9**
OS	0	0	0	0	0	0	0	**0**
ALL	**-4**	**-11**	**-13**	**-13**	**16**	**-7**	**-10**	**-10**

5.6.4. Evaluation of progress towards MAI

There have been reductions in inputs of total nitrogen and phosphorus to all Baltic Sea sub-basins since the reference period (1997-2003) to 2008-2010, besides for phosphorus inputs to the Gulf of Riga (**Table 5.12**). For Kattegat the reduction in nitrogen inputs is about three times higher than the reduction requirement. For nitrogen inputs to the Baltic Proper and Gulf of Finland, more than one third of the needed reduction requirement was obtained in 2008-2010, while for phosphorus the input reduction is about 22-25% of the required reduction. On the other hand, it seems as though phosphorus inputs increased to the Gulf of Riga from the reference period to 2008-2010.

Table 5.12. Evaluation of progress towards reaching MAI showing the required reduction according to the 2013 Ministerial Declaration, the achieved reduction in the 2008-2010 period (see **Tables 5.9** to **5.11**) and the remaining needed reduction. *See note to Table 4.1a regarding the pre-conditions on the PLC-5.5 data set.*

Sub-basins/ inputs in tonnes	Required reduction to obtain MAI		Achieved reduction		Remaining needed reduction	
	Total N	Total P	Total N	Total P	Total N	Total P
Bothnian Bay	0	0	4,023	108	0	0
Bothnian Sea	0	0	8,611	306	0	0
Baltic Proper	98,921	10,960	36,928	2,435	61,993	8,525
Gulf of Finland	14,452	3,909	5,457	1,000	8,995	2,909
Gulf of Riga	0	308	2,974	-381	0	689
Danish Straits	0	0	10,417	108	0	0
Kattegat	4,761	0	12,528	175	0	0
Baltic Sea total	**118,134**	**15,177**	**80,937**	**3,751**	**70,988**	**12,132**

Of the obtained reductions in total nitrogen inputs to Baltic Proper, Gulf of Finland and Kattegat, decreases in atmospheric deposition make up 47%, 17% and 27% of the reductions, respectively.

6. Discussion and conclusion

The "Summary" chapter at the beginning of the report summarizes the main results of this report. This chapter briefly discusses shortcomings, some main findings, presents some conclusions based on the results and summarizes lesson learned.

6.1. Shortcomings of airborne and waterborne PLC-5.5 data, analysis and applied methodologies

6.1.1. Emission assessments

The atmospheric nitrogen deposited onto the Baltic Sea originates from oxidized (NO_x) and reduced (NH_x) nitrogen emissions from the HELCOM countries, non-HELCOM countries and ship traffic. Due to non-linearities in the atmospheric chemistry, also other emissions have an effect on the transport and deposition of nitrogen; especially sulphur dioxide emissions are important.

Countries participating in the EMEP programme annually report their emission inventory data using standard formats in accordance with the EMEP reporting guidelines. Nitrogen emissions have been reported since the 1980s and methods have been developed gradually resulting in a rather good reliability and comparability in the nitrogen emissions from different countries. Also, the EMEP Centre of Emission Inventories and Projections (CEIP, http://www.ceip.at) audits the emission estimates from different countries using independent auditors and centralized, in-depth review of emission inventories are performed annually since 2008.

When EMEP MSC-W are modelling the nitrogen deposition to the Baltic Sea, expert estimates for the emissions are used when data are missing or unrealistic. This reduces the risk for large anomalies in the calculations of the depositions and source-allocation budgets in case of substantial errors in the emissions estimates. The nitrogen emissions from the different HELCOM countries have different weight in the transport and deposition to the Baltic Sea. In 2010, the range was from 15% of annual national emissions deposited on the Baltic Sea for Denmark, Estonia and Sweden to 0.7% for Russia (Bartnicki et al. 2012). Since 2007 the area in Russia included in EMEP emissions inventory has been markedly expanded leading to also higher nitrogen emission and deposition from Russia since 2007 as compared to the level 2004-2006. In addition, emissions outside the HELCOM countries have a great effect on the deposition of the oxidized nitrogen to the Baltic Sea. Hence, in the future, increased attention should be given to the status and development of the most important emissions relative to the nitrogen deposition to the Baltic Sea.

Ship traffic is an important contributor to the nitrogen deposition and the emissions are still increasing in contrast to the emissions from most countries. In 2010, the contribution of Baltic Sea shipping to the oxidized nitrogen deposition to the Baltic Sea was the third largest, while North Sea shipping was the fifth largest contributor (Bartnicki et al. 2012). EMEP MSC-W has modelled ship traffic emissions derived from the IIASA ship emission estimates for the years 2005 and 2010 using a linear interpolation between the years. The results indicate an annual increase of 1.8%. According to a more detailed analysis of Baltic Sea shipping emissions based on the messages of the automatic identification system (AIS) (**Figure 4.12**), which enable the positioning of ships with a high spatial resolution (Jalkanen et al. 2013), the NO_x emissions were 17% higher than the EMEP estimates (Bartnicki et al. 2011) and increased by 14% between 2006 and 2008 alone. Because of the growing importance of the emissions of ship traffic on nitrogen deposition to the Baltic Sea, the modelling of its deposition and source-allocation need to, in the future, make use of more detailed emission estimates.

For the PLC-5.5 assessment, the atmospheric phosphorus deposition to the Baltic Sea was roughly estimated to be over 2,000 tonnes per year based on rather sparse measurements taken mainly at coastal monitoring stations. There is no emission inventory available for phosphorus to enable the confirming of this estimate with modelling. There is great need for a study of the most important phosphorus sources and an evaluation of the emissions in order to enable a more substantiated estimate of atmospheric phosphorus deposition.

6.1.2. Atmospheric deposition

The deposition of the nitrogen compounds to the Baltic Sea is calculated using emission data from several sources, meteorology and land use data, which are combined in the EMEP model for nitrogen deposition computations. Increased quality of these factors has gradually improved the deposition estimates, benefitting also the present PLC assessment. There is a large interannual variation in nitrogen deposition due to meteorological conditions, however, the method for normalization of values presented and used in this report helps to follow the general development of the changes from 1995 to 2010 and to test for possible trends.

HELCOM countries run about 20 stations around the Baltic Sea where measurements of atmospheric concentrations and depositions of various components are taken. The monitoring data are used for verifying the modelling work. The used laboratories participate in intercalibrations for the sampling and analysis and are in general producing data with a satisfactory quality. The valuable data collected at these stations could be used for broader scale assessment work. In addition, the station network would preferably be extended to cover also small islands and other places that better represent open sea areas.

The estimate of phosphorus deposition in this report is based on a constant deposition rate (5 kg P km^{-2}) with no temporal or spatial change. The reason is that only a limited number of measurements from the HELCOM countries were available for evaluation, and there were no measurement from the open sea. The measurements covered in most cases only wet deposition, and only few data of particulate concentration or dry deposition were available. There is an urgent need for wider measurements of airborne phosphorus inputs to the Baltic Sea area and estimates of emissions for the modelling work.

6.1.3. Source-allocation budgets for nitrogen deposition

The source-allocation budgets help to determine the most important emitters contributing to the deposition of nitrogen on to the Baltic Sea. EMEP suggests using the results of source receptor calculations only as an indication of relative contributions (Bartnicki 2012). Even then, the greatest emitters and most important emission sectors can be identified. This helps to focus the efforts for deposition abatements effectively.

Large interannual variation occurs in the source-allocation budgets using actual data. The normalization method used for deposition calculations in this report would also give a good estimate of the overall source-allocation. There were no large differences in the mean source-allocation budgets in 2000-2006 as compared to the mean in 1997-2003 (Bartnicki & Valiyaveetil 2008), which supports the general view that the relative contributions are rather stable.

There are notable differences in the source-allocation budgets for oxidized and reduced nitrogen deposition. HELCOM countries contribute to half of the oxidized nitrogen deposition and about 75% to the reduced nitrogen deposition (Bartnicki & Valiyaveetil 2008). For NO_x deposition, the contribution of ship traffic is as large as is the contribution from areas outside HELCOM countries.

6.1.4. Water flow and riverine inputs

The final PLC-5.5 data set on riverine and direct point source inputs of nitrogen and phosphorus is the most complete, consistent and quality assured PLC data set to date. Even compared with the PLC-5 data set, a lot of updates and changes have been applied, which is summarized in Chapter 3.4 (cf. **Figure 3.2**). The main challenges were related to missing data from unmonitored or former monitored areas, or when reported data clearly were incorrect. Additional challenges include the lack of reporting of Latvian data from 2008 to 2010, rather many missing data on Russian inputs to Baltic Proper and from unmonitored areas to the Gulf of Finland, and incorrectly reported riverine inputs for some rivers. Chapter 3.4.2 summarizes how the missing data, data gaps, removing of outliers, and correcting and updating data were handled.

An inventory of the sampling frequency for water samples for chemical analysis and discharge measurement in rivers, carried out in 2013 under the HELCOM PLC-6 project, has revealed that many Contracting Parties have a sampling frequency of 12 to 26 samples per year, which follows the minimum requirement stated in the PLC guidelines of at least 12 samples per year. Some Contracting Parties have evenly distributed the samples (e.g. 1 per month) while others have distributed samples to cover high and low flow episodes, and some with higher frequency in rivers with high variation in nitrogen and phosphorus concentrations. In Latvia, and for some rivers in Estonia, the frequency has been as low as three, four or seven times per year. In general, all Contracting Parties apply continuous registration of stage (water level) and make 12 annual flow measurements (calibrations) in a river cross section and calculate daily river flow. Apart from Latvia, and some rivers in Estonia, the sampling and monitoring frequency should ensure robust estimates of riverine inputs of nitrogen and phosphorus with acceptable bias and precision. Few samples result in very high uncertainty - which is especially likely for rivers with high and fluctuating concentrations of particulate matter that gives a high risk to get a large bias (underestimation of the river load) and low precision (Kronvang & Bruhn 1996).

It is therefore important to organize sampling to cover the variation in river flow and concentrations by ensuring to sample low and high load events without getting bias in the sampling. With few samples there is a great risk to markedly underestimate the nitrogen and especially phosphorus loads in the rivers e.g. for Latvian rivers. Further, it should be ensured that the optimal calculation method is used to calculate the annual load in the rivers based on the monitoring results.

It has generally not been investigated if the water samples collected are representative on the temporal as well as the spatial scale for the river at the sampling site, and it would be important to investigate where and how samples are taken in order to get as representative samples as possible.

For seven of the Contracting Parties, the catchment area covered by monitoring is between 70% and 92%. Only Denmark (nearly 50%) and Germany (approximately

55%) have large proportions of the catchment area that are not covered by river monitoring stations due to many small river catchments, coastal areas and the influence of tides, etc. Several methodologies are used for estimating actual flow and nutrient inputs from unmonitored areas entering the Baltic Sea, from very simple area-specific coefficients (extrapolation from monitored areas), advanced empirical models to sophisticated hydrophysical-biochemical models (dynamical models). The used methods are often not reported and might give some inconsistencies when comparing the data from different Contracting Parties. There have been some changes in the methods applied during 1994 to 2010, which emphasizes the importance that Contracting Parties resubmit data when a new methodology changes the data on inputs. Methodological changes might also influence the outcomes of trend analyses.

6.1.5. Direct point source inputs

Quantification and reporting on water flow as well as nitrogen and phosphorus inputs from point sources discharging directly to the Baltic Sea has been one of the major challenges. In 2010 the direct inputs of nitrogen and phosphorus made up 4% and 5%, respectively, of total waterborne nitrogen and phosphorus inputs. There were however large annual variations in the proportion of direct point sources inputs within Contracting Parties – even beyond what can be considered to be realistic. Some Contracting Parties have changed methodology where the direct point sources in some years were included in the monitored or unmonitored/coastal inputs and in other years reported as direct inputs or only partly reported or even not reported at all.

Data gaps have in many cases been filled in by using the average of the values reported for the direct input category (waste water treatment plants, industry and fish farms) from years with reported values. This might affect the result of trend analysis on direct inputs, especially when data are missing from several sequential years.

Not all Contracting Parties are reporting inputs from individual plants, but rather as aggregated point source inputs to a Baltic Sea sub-basin, which makes the evaluation of the data difficult, and may also obscure any potential variation in the underlying sources.

6.1.6. Analytical methods and limits of quantification

As many laboratories are involved in the production of the data used for estimating inputs, it is of major concern that the data have an appropriate quality, and that the estimated inputs are comparable. There has been a steady progress in analytical quality assurance as more and more of the involved laboratories are accredited, or at least are using quality assured methods similar to the accreditation demands. As the majority of chemical data used in the PLC-5.5 assessment have been produced by accredited laboratories or at least documented and validated according to EN ISO/EC 17025 or similar standards, it can be concluded that the analyses have been performed within a quality assurance system that ensures the quality of the analyses and in that way the data are reliable. However, when assessing time series of input estimates it is vital to remember that the data quality is comparatively less reliable in historical data.

Additionally, it is also important that the involved laboratories use adequate limits of quantification (LOQ) when producing the data used to estimate the inputs. Generally, the recommendation that only a minor part of the analytical results are supposed to be below the LOQs is followed. The used LOQs are supposed to be adequate for the concentration levels in the various rivers and point sources being assessed. Further, the respective LOQs need to be under constant surveillance, since when the amount of observations below the LOQs increase, the quality and the reliability of the input estimates deteriorate, thus hampering comparisons and assessments.

Moreover, it is important to arrange periodical intercalibrations between the laboratories involved in PLC analyses. For instance, an intercalibration activity conducted in 2013 aimed to ensure a high data quality for the PLC-6 project, and the results will to be used in the PLC-6 assessment.

For future PLC reporting the Contracting Party should report their quality assurance criteria as LOQ, the expanded uncertainty as well as the fraction of samples below LOQ for the involved laboratories.

6.1.7. Estimation of uncertainties on national data sets

Chapter 3.5.2 outlines different sources of uncertainty on the data set on total nitrogen and phosphorus inputs from Contracting Parties to the Baltic Sea. Uncertainty consists of two components, namely precision and bias, but is often given as one common value.

Low sampling frequency in rivers and in outlets from point sources result in higher uncertainty on input data and further a marked risk of high bias (underestimations). How and where the samples are collected (i.e. how representative the sampling is regarding quantifying the "real" load or input) and the methods applied for calculation of annual inputs may also influence the uncertainty. Uncertainty estimates in laboratory analyses are available and should be reported in future PLC assessments. The estimated or modelled inputs from unmonitored areas might include a high uncertainty depending on the applied methodology, which will be especially important in areas where there is a large share of unmonitored areas. Further, also filling in of data gaps or not reported data imposes uncertainty on the total input estimates.

So far, the Contracting Parties have not been requested to report uncertainty estimates on their reported data sets. Chapter 3.5.2 gives an example from Denmark (cf. **Table 3.1**) with estimates on uncertainties on total waterborne inputs to the sea from Denmark. The uncertainty was 2.1% (bias: -2.0%, precision: 0.5%) for nitrogen and 3.4% (bias: -3.0%; precision: 1.6%) for phosphorus (Kronvang et al. 2014). It should also be remembered that when aggregating a large amount of data from monitored and unmonitored areas as well as from direct point source inputs, the uncertainty would be less for the aggregated inputs compared to unaggregated data. Further, Denmark has many monitoring stations and measures outflows from even small point sources with a high annual frequency. On the other hand, Denmark has comparatively large unmonitored areas as about 50% of the catchment areas discharging to the Baltic Sea is unmonitored regarding the riverine nutrient loads, which will influence the total uncertainty of the total nutrient inputs to the sea.

The PLC-5.5 project roughly estimated an uncertainty of 15-25% for total annual waterborne nitrogen and 20-30% for total annual phosphorus inputs to Kattegat, Western Baltic, the main part of Baltic Proper, Bothnian Bay and Bothnian Sea, and for the remaining parts of the Baltic Sea up to 50% uncertainty. The uncertainty for annual water flow to the above mentioned sub-basins was estimated to be less than 5-10% and 10-20%.

For the next PLC assessment (PLC-6), Contracting Parties are requested to report information on the uncertainty for the main sources of uncertainty and to provide estimates on the total uncertainty of national data sets on total water flow and nutrient inputs to the sub-basins of the Baltic Sea. The uncertainty estimates will be very important to take into account e.g. when evaluating progress in fulfilment of the MAI and CART adopted by the 2013 Copenhagen Ministerial Declaration as well as when evaluating the effectiveness of measures taken to reduce nitrogen and phosphorus inputs to the Baltic Sea.

6.2. Changes in nutrient inputs

This chapter concludes on the main findings on air- and waterborne nitrogen and phosphorus inputs in 2010, the trend in these inputs from 1994 to 2010, the reduction in nutrient inputs in 2008-2010 as compared to the corresponding inputs during the reference period (1997-2003), and finally evaluates progress towards fulfilment of MAI.

6.2.1. Inputs in 2010

The actual (not normalized) total nutrient input to the Baltic Sea in 2010 was 977,000 tonnes of nitrogen and 38,300 tonnes of phosphorus, respectively (cf. **Tables 4.1a** and **4.1b**). Of this, nearly 219,000 tonnes of nitrogen (22%) entered the Baltic Sea as atmospheric deposition, the remaining 758,000 tonnes entered as waterborne (i.e. riverine + direct inputs) nitrogen inputs. Direct inputs of nitrogen (30,500 tonnes) constituted 4% of waterborne nitrogen inputs and 3% of total nitrogen inputs.

Atmospheric deposition of phosphorus was calculated using a fixed deposition rate and amounted to nearly 2,100 tonnes of phosphorus or more than 5% of total phosphorus input. Waterborne inputs of phosphorus entered the sea as 34,500 tonnes of riverine inputs and 1,700 tonnes direct discharges from point sources. Direct phosphorus inputs therefore comprise less than 5% of total phosphorus inputs.

The Baltic Proper, which has one third of the Baltic Sea catchment area and covers 50% of the Baltic Sea surface area, received 53% of total nitrogen and 55% of total phosphorus input, followed by the Gulf of Finland (13% of total nitrogen and 17% of total phosphorus inputs, but with 24% of the catchment area) (cf. **Table 4.3**).

The main countries contributing to total nitrogen inputs were Poland (30%), Sweden (12%), and Russia (11%) (cf. **Figure 4.2a**). The largest inputs of phosphorus originated from Poland (37%), Russia (16%) and Sweden (9%) (cf. **Figure 4.2b**). In 2010, high precipitation occurred over southern and some eastern parts of the Baltic Sea catchment area, leading to very high runoff and nutrient inputs from Poland.

There is a large interannual variation in inputs of nutrients due to meteorology. Therefore, methods for normalizing airborne and flow normalizing riverine inputs have been applied (Annexes 2 and 3 in Chapter 9) to compensate for these variations, which also makes it easier to compare inputs between Contracting Parties and sub-basins and to compare inputs between individual years and to make trend analyses.

The normalized total inputs in 2010 were considerably lower than the actual total inputs, amounting to 802,000 tonnes (18% less) of nitrogen and 32,200 tonnes (16% less) of phosphorous (cf. **Tables 4.2a** and **4.2b**).

The area-specific input of nitrogen to the Baltic Sea was typically highest in sub-regions with intensive agricultural activity and high population densities such as the Danish Straits, the Kattegat and the western part of Baltic Proper with 900-1,900 kg N km^{-2} (cf. **Figure 4.11b**). Overall, area-specific inputs are highest in the south western and southern catchments of the Baltic Sea and lowest in the northern part, where for example inputs to the Bothnian Bay and the Bothnian Sea were 120-150 kg N km^{-2}. Parts of southern Finland and the Baltic States, however, also have net inputs over 600 kg N km^{-2}. For phosphorus, the highest area-specific losses were found in catchment areas with high population densities, many industries and high agricultural activity, which are more or less the same catchments as for nitrogen (**Figure 4.11c**). The highest area-specific losses amounted to 50-70 kg P km^{-2} and were found in the southern and western parts of the catchment. The lowest area-specific losses were from the Swedish sub-catchment to the Bothnian Sea with <5 kg P km^{-2}. Furthermore, geology, climate, wastewater treatment efficiency, the frequency of surface runoff and snow/ice cover have an impact on area-specific inputs of nutrients.

The seven largest rivers entering to the Baltic Sea (Daugava, Göta älv, Kemijoki, Nemunas, Neva, Odra, and Vistula) cover 50% of the catchment area. Fifty-three percent of total waterborne nitrogen and 54% of total phosphorus inputs entered the Baltic Sea via these rivers in 2010, with only 46% of the total river flow (cf. **Table 4.4**). Therefore, it is rather important to ensure high precision and low bias when quantifying inputs from these rivers for the overall estimate of nutrient inputs to the Baltic Sea.

The main sectors emitting oxidized nitrogen (NO_x) are combustion in energy production and industry as well as transportation while agriculture is the main source for emissions of reduced nitrogen (NH_x). For the atmospheric deposition of nitrogen to the Baltic Sea, it is notable that the emissions from the different HELCOM countries have different weights in the transport and deposition to the Baltic Sea ranging from 15% of annual national emissions being depositing on the Baltic Sea for Denmark, Estonia and Sweden to 0.7% of Russian emissions (cf. **Figure 4.13**). HELCOM countries contribute half of the oxidized nitrogen deposition and about 75% to the reduced nitrogen deposition to the Baltic Sea. The top three contributors to atmospheric nitrogen deposition in 2010 were Germany (18%), Poland (14%) and Denmark (7%).

Shipping traffic is an important contributor to NO_x deposition and its emissions are still increasing contrary to emissions from most countries. Areas outside HELCOM countries are substantial contributors to NO_x deposition, whereas ammonium deposited on the Baltic Sea mainly originates from HELCOM countries.

There are notable differences in the source-allocation budgets for oxidized and reduced nitrogen deposition (cf. **Figure 4.16**). Of the top ten contributors to the total nitrogen deposition on the Baltic Sea, four are non-Contracting Parties (Baltic Sea shipping, North Sea shipping, the United Kingdom and France). In 2010, Baltic Sea shipping contributed with 13,500 tonnes deposited nitrogen, the twenty EU countries which are not HELCOM members (EU20) contributed with 40,000 tonnes nitrogen and other sources (other countries (OC), including North Sea shipping) contributed with 29,300 tonnes nitrogen. Baltic Sea shipping supplied 6% of total atmospheric nitrogen deposition in 2010, and EU20 + OC contributed 32%. In total, Baltic Sea shipping, EU20 and OC accounted for more than 8% of total nitrogen inputs to the Baltic Sea in 2010.

The estimate of the atmospheric phosphorus inputs is based on a constant deposition rate of 5 kg P km^{-2}, due to a lack of sufficient data. It is not possible to quantify the sources of phosphorus inputs.

Net transboundary waterborne nitrogen and phosphorus inputs to the Baltic Sea from non-Contracting Parties (Czech, Belarus, Ukraine and Slovakia), taking into account surface water retention within the catchments, are only important for some rivers entering the Baltic Proper and the Gulf of Riga (cf. **Table 4.7a**). In total, 5% of waterborne nitrogen and 6% of total phosphorus that entered the Baltic Proper in 2010 were estimated to have originated from non-Contracting Parties. The corresponding figures for waterborne inputs to the Gulf of Riga are 8% for nitrogen and for 41% for phosphorus. Of the total waterborne inputs to the entire Baltic Sea, these transboundary inputs from non-HELCOM Contracting Parties comprise 3% of waterborne nitrogen and 5% for waterborne phosphorus inputs.

The waterborne inputs to the Baltic Proper, the Gulf of Riga and the Gulf of Finland also include net transboundary inputs from other HELCOM Contracting Parties. These have been quantified as a basis for discussions on burden-sharing of BSAP nutrient reduction requirements to the different sub-basins (cf. **Table 4.7b**). The net transboundary inputs from HELCOM countries amounted to approximately 8,800 tonnes nitrogen and 370 tonnes phosphorus to Baltic Proper, 7,200 tonnes nitrogen and 410 tonnes phosphorus to the Gulf of Riga and 5,400 tonnes nitrogen and 50 tonnes phosphorus to the Gulf of Finland in 2010. Only for the Gulf of Riga did these inputs constitute 10% or more of the total inputs to the sub-basin. Compared with total waterborne inputs to the Baltic Sea, these transboundary inputs comprise 3% for nitrogen and 2% for phosphorus.

It should be underlined that some of the estimates of waterborne transboundary inputs are based on averages for some years, and that the retention estimates in surface waters in the Contracting Parties receiving inputs are rather rough estimates. In the future, it is necessary to ensure good monitoring data and/ or estimates on transboundary inputs at the border where Contracting Parties receive transboundary inputs and to make further model developments to quantify retention estimates in surface waters. Good estimates of the net transboundary input to the Baltic Sea sub-basins is necessary for proper follow-up of the new CART decided on in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a).

In 2010, the total transboundary air- and waterborne inputs constituted 12% of total nitrogen and, and transboundary waterborne phosphorus inputs nearly 8% of total waterborne phosphorus inputs to the Baltic Sea (at present it is not possible to determine sources for airborne phosphorus inputs). To the Gulf of Riga the corresponding figures was 24% for nitrogen and 58% for phosphorus.

The PLC-5.5 assessment does not include further source quantification and evaluation. The next more comprehensive source inventory, which quantifies also sources of riverine inputs, will be based on 2014 data and assessed in the PLC-6 report, which is expected to be published in 2017.

6.2.2. Trends in water- and airborne inputs during 1995-2010

Based on normalized data (normalized airborne, flow normalized riverine and not normalized direct inputs) – which was used to remove, as far as possible, variations in inputs due to meteorological conditions – the total inputs via rivers, direct inputs from point sources, and atmospheric deposition in the mid-1990s were approximately 1,050,000 tonnes of nitrogen and 40,000 tonnes of phosphorus. Atmospheric deposition constituted approximately 250,000 tonnes of nitrogen (24%) and 2,100 tonnes of phosphorus (5%). Since the mid-1990s the inputs to the Baltic Sea have been reduced significantly, amounting to a reduction of more than 200,000 tonnes of nitrogen and about 7,000 tonnes of phosphorus inputs per year. The atmospheric deposition of phosphorus remains at 2,100 tonnes, as it is calculated using the same deposition rate (5 kg P km^{-2}) for all years, due to lack of data. The decrease in inputs is primarily the consequence of measures taken to improve wastewater treatment, reduce emissions to air from combustion processes and losses from diffuse sources (agriculture and forestry) to air and surface waters. Some of these measure where implemented before the mid 1990s.

To assess the validity of the calculated changes in nitrogen and phosphorus inputs, statistical analyses were carried out on the normalized input time series from 1995 to 2010 in order to test for trends (decrease or increase). These analyses show that the total (air- and waterborne) inputs of nitrogen and phosphorus to the Baltic Sea have significantly decreased (confidence < 5%, see footnotes 6 and 7 in Chapter 5) with 16% and 18%, respectively from 1995 to 2010 (cf. **Tables 5.3a** and **5.3b**). Denmark (35% for nitrogen and 29% for phosphorus), Germany (23% for nitrogen, 20% for phosphorus), Poland (20% for nitrogen, 24% for phosphorus) and Sweden (15% for nitrogen, 18% for phosphorus) have significantly reduced both their total nitrogen and phosphorus inputs to the Baltic Sea. Further, both Finland (17%) and Lithuania (33%) reduced their total phosphorus inputs, although the statistical confidence for Lithuania is less than 10% (c.f. footnote 6 and 7). Total phosphorus inputs from Latvia increased significantly (75%), but the data are rather uncertain, especially at the beginning and in the end of the period. The EU20 (the EU countries that are not HELCOM Contracting Parties) and other non-HELCOM countries and sources, besides Baltic Sea shipping, have also significantly reduced their nitrogen inputs (atmospheric deposition) to the Baltic Sea, with 34% and 15% respectively, while deposition from Baltic Sea shipping significantly increased with 34%.

There were significant reductions in total inputs of nitrogen and phosphorus to the Bothnian Sea (12% for nitrogen, 24% for phosphorus), the Baltic Proper (20% for nitrogen, 24% for phosphorus), the Danish Straits (32% for nitrogen, 30% for phosphorus) and the Kattegat (23% for nitrogen, 17% for phosphorus). Further, total nitrogen inputs decreased significantly to the Gulf of Finland (6%), but increased significantly for total phosphorus inputs to the Gulf of Riga (63%) (cf. **Tables 5.4a** and **5.4b**). However, the latter increase is a bit questionable due to the rather uncertain Latvian data mentioned above.

The total atmospheric deposition of nitrogen to the Baltic Sea decreased significantly (24%). For individual countries, significant reductions in contribution to atmospheric deposition were noted for Denmark (40%), Estonia (10%), Finland (23%), Germany (25%), Poland (29%) and Sweden (31%) (cf. **Table 5.3a**). A significant increase in atmospheric deposition of nitrogen from Russia (44%) was noted; however this may be partly due to the inclusion of emissions from a larger area of the country after 2006.

With regard to waterborne nitrogen inputs to the Baltic Sea (riverine + direct discharges from point sources), only Denmark (36%), Poland (26%), Germany (19%) and Sweden (15%) had significant reductions with a high statistical confidence (< 5%). Latvia and Lithuania also had decreased waterborne nitrogen inputs, but with a confidence between 5 and 10% (cf. **Table 5.3a**). The total waterborne inputs of phosphorus from all countries except Russia and Latvia were reduced by 19-38%. Waterborne phosphorus inputs from Latvia increased significantly with nearly 70% (cf. **Table 5.3b**).

Inputs of nitrogen and phosphorus from direct sources (point sources discharging directly to the Baltic Sea) decreased significantly from 1995 to 2010 with 43% and 63%, respectively (cf. **Table 5.1a**). Denmark, Germany, Finland, Lituania and Sweden significantly (confidence < 5%) reduced both their direct nitrogen and phosphorus inputs. Russia had a significant reduction in direct nitrogen inputs, and Latvia had a significant decrease for phosphorus. On the contrary, direct inputs of nitrogen from Latvia increased by 38%. The overall reductions in nitrogen and phosphorus inputs are certain, even though the results of the trend analysis for some countries are uncertain due to changed methodology for defining direct point sources. The methodology for estimating changes from 1995 to 2010 assumes a linear development in direct inputs, which is not always the case. Hence, in the future, the development in inputs should be tested for change points in the development, and the time series divided into two or more subsamples according to the change point and making a separate analysis for each of these sub-samples.

Nitrogen and phosphorus inputs for all combinations where HELCOM countries have inputs to the Baltic Sea sub-basins have been tested for trends and significant changes from 1994 to 2010, and the results follow the trends given above for individual countries (cf. **Table 5.5a-e**). As an example, Denmark has significantly reduced total nitrogen and phosphorus inputs to all sub-basins to which Denmark supplies nitrogen and phosphorus. Sweden, which has inputs to five sub-basins, has significantly reduced total inputs of nitrogen and phosphorus to the Baltic Proper and the Danish Straits while, whereas there are no significant reductions to the Bothnian Bay or of total phosphorus to the Kattegat or of total nitrogen to Bothnian Sea.

It is noteworthy that other non-HELCOM countries (OC, cf. **Table 5.5b**) reduced atmospheric nitrogen deposition with 16-28% to five of the Baltic Sea sub-basins form 1995 to 2010, but for Danish Straits and Kattegat there was a contemporary increase of 9-10%, which partly can be explained by higher emissions from shipping on the North Sea. It is also worth noting that the atmospheric deposition from Latvia to the Gulf of Riga has increased significantly with 13% during the same period.

There have been some very high and statistically significant reductions in inputs from point sources discharging directly to the Baltic Sea (cf. **Table 5.5e)**, e.g. from Denmark to Baltic Proper (with 88% nitrogen, 92% phosphorus) and to Danish Straits (75% nitrogen, 78% phosphorus), from Germany to Baltic Proper (92% nitrogen, 82% phosphorus) and to Danish Straits (83% nitrogen, 83% phosphorus), from Latvia to Gulf of Riga (92% phosphorus), and from Lithuania to Baltic Proper (77% nitrogen, 91% phosphorus). Some Contracting Parties (such as Denmark, Finland and Sweden) took many measures in the 1970s, 1980s and early 1990s, which reduced especially nitrogen and phosphorus inputs to inland surface waters from municipal wastewater treatment plants (and also measures that to some extent also reduced diffuse losses) before 1995 when the PLC assessment period begins. These countries have also implemented further measures since 1995 to reduce inputs. Poland, the Baltic States and Russia implemented advanced wastewater treatment later, the effects of which are mainly reflected in reduced inputs from these countries after the reference period 1997-2003. It should also be noted that many measures taken to reduce diffuse losses to inland surface waters, will take several years before they result in reduced nutrient inputs to both coastal and open waters of the Baltic Sea due to retention in inland waters. Moreover, in some catchments, retention in soils, groundwater and inland surface waters are so high that it can require a factor of 5-10 times higher factual reductions in order to obtain a given absolute reduction in inputs to the sea.

For the seven largest rivers, Daugava (6%), Göta älv (24%) and Vistula (36%) had significant decreases in riverine nitrogen inputs from 1994 to 2010 (cf. **Table 5.2**). For corresponding riverine phosphorus input, only Odra (42%) and Nemunas (36%) showed a significant decrease, while Daugava had a significant increase (6%).

6.2.3. Inputs during 2008-2010 compared to the reference period (1997-2003)

The average total normalized nitrogen and phosphorus inputs during 2008-2010 (cf. **Table 5.9**) – the latest three years for which the total nitrogen and phosphorus inputs have been assessed - is used to evaluate changes in nutrient inputs compared to inputs during a reference period (cf. **Table 5.6**). The period 1997-2003 was used as a reference in the Baltic Sea Action Plan (HELCOM 2007), and also when revised MAI were adopted in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a). The needed total nitrogen and phosphorus input reductions are determined as the average normalized inputs during 1997-2003 minus MAI for nitrogen and phosphorus.

The average total inputs during 2008-2010 were approximately 829,000 tonnes of nitrogen and 33,100 tonnes of phosphorus, with 197,000 tonnes of the nitrogen inputs entering the sea via atmospheric deposition (24%). The annual atmospheric deposition of phosphorus remains at 2,100 tonnes, calculated using the same deposition rate (5 kg P km^{-2}) for all years (cf. Chapter 6.1.2). The average normalized total nitrogen and phosphorus inputs to the Baltic Sea during 2008-2010 decreased with approximately 9%, or about 81,000 tonnes of nitrogen and 10%, or nearly 3,800 tonnes of phosphorus, compared to the reference period. It should be underlined that it has not been tested whether these changes in inputs are statistically significant. More than 30,000 tonnes of the total nitrogen reduction was due to reduction in the atmospheric deposition, of which 15,500 tonnes was reduced by non-Contracting Parties (mainly the EU20 countries, with 13,900 tonnes nitrogen). Nitrogen deposition from Baltic Sea shipping increased with 15%, or more than 1,700 tonnes, to all Baltic Sea sub-basins compared to the reference period (cf. **Table 5.10b** and **5.10c**). Waterborne phosphorus inputs decreased by 11% during the same period.

The input reductions were higher for some Contracting Parties, such as Denmark (20% nitrogen), Estonia (19% phosphorus), Finland (12% nitrogen), Germany (13% nitrogen), Lithuania (30% phosphorus), Poland (13% phosphorus), Russia (12% phosphorus) and Sweden (13% nitrogen). Latvia had an increase in their inputs (3% nitrogen, 26% phosphorus), but this might be partly explained by that data from 2008-2010 have been estimated (no data reported). It should be underlined that, for example for Finland, a part of the estimated decrease might be due to the fact that normalization of inputs has not been fully compensated for all variations imposed by weather (high precipitation), especially for Finnish inputs entering to the Bothnian Bay.

Regarding inputs from countries to the different sub-basins, changes in total inputs of nitrogen from the reference period to 2008-2010 indicate reductions to all sub-basins from all countries except for, Latvia (no decrease to any sub-basin), Russia (only decrease to Gulf of Finland) and Estonia (no decrease to Gulf of Finland) (cf. **Table 5.10a** and **5.10b**). One reason for this is that atmospheric deposition from all HELCOM Contracting Parties to all sub-basins decreased, except from Latvia and Russia (cf. **Table 5.10c**). For phosphorus, it is not possible to assign amounts of the atmospheric deposition, as the sources have not been quantified. Hence, the inputs of phosphorus from countries to different sub-basins were only calculated if a country has waterborne inputs to a sub-basin. Phosphorus inputs have reduced since the reference period (not tested if it is significant) from Denmark, Finland, Germany, Lithuania and Poland to all sub-basins that they have waterborne inputs to (cf. **Table 5.11a** and **5.11b**). Sweden reduced waterborne phosphorus inputs to all sub-basins, except to the Bothnian Bay, and Estonia to the Gulf of Finland and Gulf of Riga. Russia reduced waterborne phosphorus inputs to Gulf of Finland, while waterborne phosphorus inputs from Latvia increased to both Baltic Proper (54%) and Gulf of Riga (22%). It should be recalled that data from Latvia and for unmonitored areas in Russia are rather uncertain.

Denmark had the highest reduction in total nitrogen reduction to Baltic Sea sub-basins followed by Germany and Sweden in 2008-2010 compared to the reference period (cf. **Table 5.10a** and **5.10b)**. For total phosphorus Lithuania, followed by Estonia and Poland, had the highest reductions to the sub-basins (cf. **Table 5.11a** and **5.11b**).

6.2.4. Evaluation of progress toward fulfilling MAI

In the Baltic Sea Action Plan (HELCOM 2007) the HELCOM Contracting Parties decided to reduce inputs of nitrogen and phosphorus to agreed maximum allowable inputs (MAI) in order to achieve good environmental status in the Baltic Sea by 2021. The follow-up system for assessing progress in fulfilling MAI and the subsequent nutrient reductions requirements for Contracting Parties (CART) is under development and not ready for use in this report. In order to facilitate future evaluation of progress in fulfilling the HELCOM nutrient reduction requirements and to support Contracting Parties in evaluating their national progress towards CART, the reductions in normalized total nitrogen and phosphorus inputs from the reference period (1997-2003) to 2008-2010 are compared with the revised MAI (cf. **Table 5.8**), which were decided on in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a).

The revised maximum allowable annual nutrient inputs are 792,209 tonnes of nitrogen and 21,716 tonnes of phosphorus, which when compared to the average annual input during the reference period (1997-2003) requires a total (air- and waterborne) nitrogen input reduction of 118,134 tonnes and a reduction of 15,178 tonnes of waterborne phosphorus inputs.

For Kattegat the average annual inputs of total air- and waterborne nitrogen in 2008-2010 have been reduced by a factor three times more than the reduction requirements (> 12,500 tonnes nitrogen, compared to the requirement of 4,761 tonnes nitrogen) (cf. **Table 5.12**). For nitrogen inputs to the Baltic Sea and Gulf of Finland, more than one third of the needed reduction requirement was obtained in the period 2008-2010, and for phosphorus the corresponding figures are 22-25%. For the Gulf of Riga, total phosphorus inputs during 2008-2010 had increased with approximately 380 tonnes phosphorus since the references period, resulting in a remaining reduction requirement that is more than double as compared to the requirement in the 2013 Copenhagen Ministerial Declaration (HELCOM 2013a). A decrease in nitrogen deposition from EU20 accounts for 12% of the obtained reduction in the total nitrogen inputs to Kattegat since the reference period.

There are no nitrogen and phosphorus reduction requirements to the Bothnian Bay, Bothnian Sea and Danish Straits, and the inputs have not increased since the reference period (cf. **Table 5.12**). Further, there are no nitrogen reduction requirements to the Gulf of Riga nor phosphorus reduction requirements to Kattegat, and the corresponding inputs have not increased since 1997-2003.

6.3. Lessons learned and future prospects

Although the data set used for this assessment is the most complete, consistent and quality assured PLC data set ever, there is still room for improving the quality of pollution input data. This Chapter presents shortcomings and suggestions for further enhancing PLC data.

The quantification of nitrogen deposition is based on standard methodology using emission from several sources, meteorology and land use data, which are combined in the EMEP model for nitrogen deposition computations. There is international cooperation under the umbrella of EMEP and standard methodologies are used by Contracting Parties. However, nitrogen emission inventories for some components could be further developed e.g. for ship emissions. It might also be valuable to obtain deposition data on a finer scale than the one currently available for PLC assessment purposes; this is of course dependent on quality and resolution of reported emission data. There is about 20% deviation between depositions monitored at measurement sites compared with modelling results, implying that there is room for further refinement of the model and the monitoring system. It would be valuable to have more monitoring stations located in the Baltic Sea on small (remote) islands in order to get a better idea of deposition rates in open sea areas.

Currently, there exist no emission inventories for phosphorus and there is a need for a study of the most important emission sources. Further, phosphorus deposition is only monitored at very few sites, and there is a need for more monitoring stations (also in the Baltic Sea on small islands) with measurements of both wet and dry phosphorus deposition (especially the latter is very rarely monitored).

In general, the monitoring of riverine nutrient inputs to the Baltic Sea is quite satisfactorily, although there are still considerable problems to obtain complete high quality data from some countries, especially due to missing or incorrect data from unmonitored areas and directs point sources. The PLC-5.5 data is considered to be the most complete and consistent data set on nitrogen and phosphorus inputs to the Baltic Sea to date. The compilation has required an extensive amount of human resources to ensure a data quality that is as good as possible and to fill in data-gaps and correct obvious erroneous data. It is essential that all Contracting Parties report as complete, high quality, data as feasible, including waterborne inputs from monitored as well as unmonitored areas, and direct point sources. Without complete data sets, there is no opportunity to assess the current trends in nutrient inputs, or to follow progress in whether Contracting Parties are reaching the MAIs and CARTs agreed on in the BSAP and 2013 Copenhagen Ministerial Declaration (HELCOM 2007 and HELCOM 2013a). In addition, to ensure comparability between the various data reported, it is vital that the methodology used by the Contracting Parties is consistent and transparent, and that if changes occur that clear and concise documentation is provided in order to enable assessment of the changes and their consequences. For future assessments, it is vital that the data flows both within countries, as well as to the PLC database/Data Manager function well, and that agreed deadlines are followed. Compliance is essential in order to allow for timely and quality assured data and assessment products for politicians and decision-makers, e.g. for HELCOM and EU reporting requirements.

Contracting Parties should, in the future, quantify and report uncertainty for different components (expanded analysis uncertainty, sampling uncertainty and total uncertainty of reported data).

Standardizing and developing methods for quantification of transboundary waterborne inputs and retention in inland surface waters are crucial to provide consistent and comparable data for estimating net transboundary inputs reaching the Baltic Sea and to make it possible to follow-up the progress in fulfilling CART.

Further, in the future, before trend analysis tests are carried out, a test for break points in time series should be included as described in Larsen & Svendsen (2013), taking into account that development in inputs to the sea might change over time reflecting application of measures and when their full effects are obtained.

In addition, it is also important to increase HELCOM cooperation with OSPAR, EEA, and other organizations in order to streamline the reporting of nutrient inputs to the sea and to ensure the comparability of the various data products and assessments to be used also within the Marine Strategy Framework Directive (MSFD). The increased use of input data within both the MSFD and Water Framework Directive (WFD) will increase the demands on data quality and comparability. This will certainly increase the usability of the HELCOM PLC data, which in turn will hopefully increase the incentive for the HELCOM Contracting Parties to invest the resources needed for providing high quality data for the assessments. In order to obtain such high quality data however, full control of the whole process is necessary - from sampling to data reporting – which in turn requires adequate resources and willingness at all levels - from the personnel taking water samples to politicians and decision-makers.

Photo by Tuija Ruoho-Airola

7. Acknowledgements

The PLC-5.5 has been carried out as a project with Mr. Lars M. Svendsen, Danish Centre for Environment and Energy, Aarhus University, Denmark as Project Manager supported by a project group that has assisted the project manager in writing the report and scrutinizing the underlying data: Susanne Boutrup and Søren E. Larsen (Denmark), Peeter Ennent (Estonia), Seppo Knuuttila and Tuija Ruoho-Airola (Finland), Dietmar Koch and Antje Ulrich (Germany), Svajunas Plunge (Lithuania), Waldemar Jarosinski (Poland), Natalia Oblomkova (Russia), and Lars Sonesten and Håkan Staaf (Sweden), Bo Gustafsson (Baltic Nest Institute, Sweden), Jerzy Bartnicki (EMEP MSC-West), Mikhail Durkin and Minna Pyhälä, HELCOM Secretariat.

Data used in this updated PLC-5 report include new data provided by the HELCOM Contracting Parties from 2008-2010, updates and corrections to old PLC data; new data provide by the Cooperative Programme for the Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP); and the Baltic Nest Institute Stockholm (BNI Sweden). This report has been elaborated to provide a complete list of tables and figures of nutrient inputs to the Baltic Sea from 1994-2010. This is an extended version of the *Review of the Fifth Baltic Sea Pollution Load Compilation for the HELCOM Ministerial Meeting in October 2013* (HELCOM 2013c), which only provided an overview and the main results.

The PLC-5.5 work was only possible with the close cooperation of the HELCOM Contracting Parties - Denmark, Estonia, Finland, Germany, Lithuania, Poland, Russia and Sweden - who carried out the measurements both in the rivers, at diffuse and point sources as well as at air quality measuring stations, performed source apportionments and reported the information to the data consultants. Sincere thanks are due to representatives of all the Contracting Parties who have contributed to the work of the PLC-5.5 project, not only during the expert meetings, but also in the collection, compilation, presentation and submission of national data as well as in the checking of the results and commenting on the drafts of the PLC-5.5 report.

Special thanks go to Pekka Kotilainen (PLC Data Consultant, Finnish Environment Institute), Jerzy Barnicki (EMEP Data Consultant), Bo Gustafsson and Magnus Mörth (Baltic Nest Institute, Sweden) for making the several flow normalization calculations, data aggregations and some maps and tables; and Søren E. Larsen (Danish Centre for Environment and Energy, Aarhus University) who carried out several of the statistical trend analyses.

8. References

Bartnicki, J., Gusev, A., Aas W. & Valiyaveeti, S., 2013. Atmospheric Supply of Nitrogen, Lead, Cadmium, Mercury and Dioxins/Furans to the Baltic Sea in 2011. EMEP/MSC-W Technical Report 2/2013.

Bartnicki, J., Gusev, A., Aas W. & Valiyaveeti, S., 2012. Atmospheric Supply of Nitrogen, Lead, Cadmium, Mercury and Dioxins/Furans to the Baltic Sea in 2010. EMEP/MSC-W Technical Report 2/2012.

Bartnicki J. 2012a. Nitrogen emissions to the air in the Baltic Sea area. HELCOM Baltic Sea Environment Fact Sheets 2012.

Bartnicki J. 2012b. Atmospheric nitrogen deposition to the Baltic Sea. HELCOM Baltic Sea Environment Fact Sheets 2012.

Bartnicki, J. & Valiyaveetil, S. 2013. Atmospheric nitrogen deposition to the Baltic Sea. HELCOM Baltic Sea Environment Fact Sheets 2013.

Bartnicki, J., Valiyaveetil, S. & Fagerli, H., 2011. Atmospheric deposition of nitrogen to the Baltic Sea in the period 1995–2006. Atmos. Chem. Phys. 11: 10057–10069.

Bartnicki, J., & Valiyaveetil, S., 2008. Estimation of atmospheric nitrogen deposition to the Baltic Sea in the periods 1997-2003 and 2000-2006. Summary report for HELCOM. Meteorological Synthesizing Centre-W of EMEP. Oslo. December 2008.

Behrendt, H. & Opitz, D. (2000). Retention of nutrients in river systems: dependence on specific runoff and hydraulic load. Hydrobiologia, 410:111–122.

EMEP 2006. *Transboundary acidification, eutrophication and ground level ozone in Europe since 1990 to 2004", EMEP Status Report 2006 to support the Review of Gothenburg Protocol. EMEP Status Report 1/2006. Joint MSC-W & CCC & ICP-FORESTs & ICP-M&M & ETC/ACC Report.*

EMEP 2012. Convention on Long-range Transboundary Air Pollution http://www.emep.int/ (date accessed: 30.10.2012).

EC 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for the Community action in the field of water policy (Water Framework Directive, WFD).

EC 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive, MSFD).

EC 2013. Report from the Commission and the European Parliament on the implementation of Council Directive 91/676/ concerning the protection of waters against pollution caused by nitrates from agriculture sources based on Member State reports for the period 2008-2011.

Eurostat database. Eurostat Pocketbooks 2011. Agriculture and fishery statistics. Main results 2009-2010. 2011 edition, 158 p.

Eurostat Pocketbooks 2012. Agriculture, fishery and forestry statistics. Main results 2010-11. 2012 edition, 226 p.

FAOSTAT 2011. Food and Agriculture Organization of the United Nations. http://faostat.fao.org (accessed 5.8.2011).

Federal State Statistics Service of Russia, 2009. http://www.gks.ru/eng/ (accessed 5.8.2011).

Ferguson, R. I. 1986. River loads underestimated by rating curves: Water Resources Research, 22, 1, p. 74-76.

Grimwall, A. & Stålnacke, P. 1996. Statistical methods for source apportionment of riverine loads of pollutants. Environmetrics, 7(2):201–213.

Gustafsson, B.G & Mörth, C.M. In prep. Revision of the Maximum Allowable Inputs and Country Allocation Scheme of the Baltic Sea Action Plan V. 3 with contributions from the BNI team: Bärbel Müller-Karulis, Erik Gustafsson, Bonghi Hong, Christoph Humborg, Steve Lyon, Marmar Nekoro, Miguel Rodriguez-Medina, Oleg Savchuk, Erik Smedberg, Alexander Sokolov, Dennis Swaney, & Fredrik Wulff. Baltic Nest Institute, Stockholm University, SE-106 91 Stockholm.

Gustafsson, B., Schenk, F., Blenckner, T., Eiliola, K., Meier, H.E.M., Müller-Karulis, B., Neumann, T., Ruoho-Airola, T., Savchuk, O.P., & Zorita, E. (2012) Reconstructing the Development of Baltic Sea Eutrophication 1850-2006. AMBIO 2012, 41: 534-548. DOI 10.1007/s13280-012-0318-x.

HELCOM 2014a. Eutrophication status of the Baltic Sea 2007-2011 - A concise thematic assessment. Baltic Sea Environment Proceedings No. 143.

HELCOM 2014b. Information on atmospheric deposition of phosphorus. Document 9-3. Seventh meeting of the HELCOM Expert Group on follow-up of national progress towards reaching BSAP nutrient reduction targets (HELCOM LOAD 7-2014).

HELCOM 2013a. HELCOM Copenhagen Declaration "Taking Further Action to Implement the Baltic Sea Action Plan - Reaching Good Environmental Status for a healthy Baltic Sea". Adopted 3 October 2013.

HELCOM 2013b. Summary report on the development of revised Maximum Allowable Inputs (MAI) and updated Country Allocated Reduction Targets (CART) of the Baltic Sea Action Plan. Document prepared for the 2013 HELCOM Ministerial Meeting. Available online: http://www.helcom.fi/Documents/Ministerial2013/Associated%20documents/Supporting/Summary%20report%20on%20MAI-CART.pdf .

HELCOM 2013c. Review of the Fifth Baltic Sea Pollution Load Compilation for the 2013 HELCOM Ministerial Meeting. Baltic Sea Environment Proceedings No. 141.

HELCOM 2013d. Climate change in the Baltic Sea Area - HELCOM thematic assessment in 2013. Baltic Sea Environment Proceedings No. 137.

HELCOM 2013e. How a complete PLC-5.5 water data set was obtained. Documentation prepared by the HELCOM PLC-5.5 project group. Available via the HELCOM PLC-5.5 project page on the HELCOM website: http://www.helcom.fi/helcom-at-work/projects/completed-projects/plc-5-5/.

HELCOM 2012. Fifth Baltic Sea Pollution Load Compilation – An Executive Summary. Baltic Sea Environment Proceedings No. 128A.

HELCOM 2011. Fifth Baltic Sea Pollution Load Compilation. Baltic Sea Environment Proceedings No. 128.

HELCOM 2007. HELCOM Baltic Sea Action Plan (BSAP). HELCOM Ministerial Meeting. Adopted in Krakow, Poland, 15 November 2007.

HELCOM 2004. Fourth Baltic Sea Pollution Load Compilation. Baltic Sea Environment Proceedings No. 93.

HELCOM 1998. Third Baltic Sea Pollution Load Compilation. Baltic Sea Environment Proceedings No. 70.

HELCOM 1993. Second Baltic Sea Pollution Load Compilation. Baltic Sea Environment Proceedings No. 45.

HELCOM 1992. Convention for the Protection of the Marine Environment of the Baltic Sea Area. Adopted in Helsinki, Finland on 9 April 1992, in force 17 January 2000.

HELCOM 1988. *Declaration* on the Protection of the Environment of the Baltic Sea. Adopted on 15 February 1988 in Helsinki, Finland.

HELCOM 1987. First Baltic Sea Pollution Load Compilation. Baltic Sea Environment Proceedings No. 20.

HELCOM 1974. Convention for the Protection of the Marine Environment of the Baltic Sea Area. Helsinki, 22 March 1974, in force 3 May 1980.

Hellström, S. & Lindström, G. 2008. Regional analys av klimat, vattentillgång och höga flöden. SMHI Rapport Hydrologi nr 110. 23 p.

Herschy, R.W. 2009. Streamflow measurements. Third edition, Routledge Taylor & Francis, 507 p.

Hirsch, R.M., Slack, J.R. & Smith, R. A. 1982. Techniques of trend analysis for monthly water quality data. Water Resources Research, 18, 107-121.

Hong, B., Swaney, D.P., Mörth, C.-M., Smedberg, E., Hägg, H.E., Humborg, C., Howarth, R.W., & Bouraoui, F. 2012. Evaluating regional variation of net anthropogenic nitrogen and phosphorus inputs (NANI/NAPI), major drivers, nutrient retention pattern and management implications in the multinational areas of Baltic Sea basin. Ecological Modelling 227, 117–135.

Hongisto M. 2014. Impact of the emissions of international sea traffic on airborne deposition to the Baltic Sea and concentrations at the coastline. OCEANOLOGIA, 56: 1–24.

Jalkanen, J.-P., Johansson, L. & Kukkonen J., 2013. A Comprehensive Inventory of the Ship Traffic Exhaust Emissions in the Baltic Sea from 2006 to 2009. Ambio, doi:10.1007/s13280-013-0389-3. http://link.springer.com/content/pdf/10.1007%2Fs13280-013-0389-3.pdf.

Jensen, P.N., Boutrup, S., Svendsen, L.M., Blicher-Mathiesen, G., Wiberg-Larsen, P.,Bjerring, R., Hansen, J.W., Ellermann, T., Thorling, L. & Holm, A.G. 2013. Aquatic Environment and Nature 2012. NOVANA. State and development – scientific summary (in Danish). Aarhus University, DCE – Danish Center for Environment and Energy, 86 s. – Scientific Report from DCE – Danish Center for Environment and Energy No. 78. http://dce2.au.dk/pub/SR78.pdf

Johansson, L., Jalkanen J.-P., & Stipa, T. 2011. Baltic Sea ship emissions in 2010. HELCOM Baltic Sea Environment Fact Sheet 2011.

Kronvang, B. & Bruhn, A. 1996. Choice of sampling strategy and estimation methods for calculating nitrogen and phosphorus transport in small lowland streams. Hydrological Processes, vol. 10, 1583-1501.

Kronvang, B., Larsen, S.E., Windolf, J. & Søndergaard, M. 2014. Uncertainties in monitoring – how much do we tolerate. Presentation of NJF Workshop, 19-21 March 2014, Stavanger, Norway.

Larsen, S.E. & Svendsen, L.M. 2013. Statistical aspects in relation to Baltic Sea Pollution Load Compilation. Task 1 under HELCOM PLC-6. Aarhus University, DCE – Danish Centre for Environment and Energy, 34 pp. Technical Report from DCE – Danish Centre for Environment and Energy No. 33. http://dce2.au.dk/pub/TR33.pdf.

National Statistical Committee of the Republic of Belarus 2010. http://belstat.gov.by/homep/en/main.html (accessed 5.8.2011).

Silgram, M. & Schoumans, O. F. (editors). 2004. Modeling approaches: Model parameterization, calibration and performance assessment methods in the EUROHARP project. EUROHARP 8-2004.

Simpson, D., Benedictow, A., Berge, H., Bergström, R., Emberson, L. D., Fagerli, H., Flechard, C. R., Hayman, G. D., Gauss, M., Jonson, J. E. , Jenkin, M. E., Nyíri, A., Richter, C. Valiyaveeti, S., Tsyro, S., Tuovinen, J.-P., Valdebenito, Á. & Wind, P. 2012. The EMEP MSC-W chemical transport model – technical description. *Atmos. Chem. Phys.,* 2012, 12 (16), 7825-7865, Special Issue EMEP, 2012.

Snedecor, G. W. & Cochran, G. W. 1989. Statistical Methods. Iowa State University Press, Ames, Iowa.

Statistische Ämter 2012. Federal Statistical Office and the statistical Offices of the Länder (Germany). http://www.statistik-portal.de/Statistik-Portal/en/ (accessed 30.10.2012).

Statistics Denmark 2012. http://www.dst.dk/en (accessed 30.10.2012).

UNEP 2005. Lääne, A., Kraav, E. & G. Titova. Baltic Sea, GIWA Regional assessment 17. University of Kalmar, Kalmar, Sweden.

Vahtera E., Conley, D.J., Gustafsson, B.G., Kuosa, H., Pitkänen, H., et al. 2007. Internal ecosystem feedbacks enhance nitrogen-fixing cyanobacteria blooms and complicate management in the Baltic Sea. *Ambio* 36:186-194.

Vestreng V. Review and Revision. Emission data reported to CLRTAP. *MSC-W Technical Report 1/2003.*

WMO 2008. Guide to Hydrological Practices Volume I Hydrology – From Measurement to Hydrological Information. WMO-No. 168. Sixth edition, 2008, 296 p.

Wulff, F., Andersen, H. E., Blicher-Mathiesen, G., Czajkowski, M., Elofsson, K., Fonnesbech-Wulff, A., Hasler, B., Hong, B., Humborg, C., Jansons, V., Mörth, C.-M., Smart, J. C., Smedberg, E., Stålnacke, P., Swaney, D. P., Thodsen, H., Adam, W., & Zylicz, T. 2014. Reduction of Baltic Sea Nutrient Inputs and Allocation of Abatement Costs within the Baltic Sea Catchment. Ambio, 43: 11-25.

Ærtebjerg, G., Andersen, J.H. & Hansen, O.S. (eds.) 2003. Nutrients and Eutrophication in Danish Marine Waters. A Challenge for Science and Management. National Environmental Research Institute. 126 pp. http://www2.dmu.dk/1_viden/2_Publikationer/3_Ovrige/rapporter/Nedmw2003_0-23.pdf.

Photo by Seppo Knuuttila

9. Annexes

9.1. Annex 1 – Technical information about the PLC-5 data

Besides the annual data collection, PLC-5 assessment data were collected for the year 2006 as total annual inputs and losses, and average, total, long-term and minimum or maximum flows. Loads and losses were to be reported as tonnes per year, flows of rivers and unmonitored areas as $m^3\ s^{-1}$ and for point sources as $m^3\ a^{-1}$, respectively. The parameters that Contracting Parties should have reported are listed in **Table 9.1**.

Table 9.1. Parameters that were required to be reported for PLC-5 assessment in addition to annual data collection.

Parameters	Point sources (discharging either into inland surface waters or directly to the Baltic Sea)			Diffuse sources[8,9] (discharging either into inland surface waters or directly to the Baltic Sea)	Natural back-ground losses	Monitored rivers*	Unmonitored Areas[9]
	Municipal Effluents*	Industrial Effluents*	Fish farming*				
BOD_5[4]	+	+[3]	+	+[10]		+[1]	+[1]
COD_{Cr}	v	v[4]					
TOC		v[4]				v	v
AOX	**v**	+[3]					
P_{total}	+	+	+	+	+	+	+
P_{PO4}	+[12]	v[3]				+	+
N_{total}	+	+	+	+	+	+	+
N_{NH4}	+	v[3]				+	+
N_{NO2}[7]	v	v[3]				+[7]	+[7]
N_{NO3}[7]	**v**	**v**[3]				+[7]	+[7]
Hg	+[2]	+[3]				+[1]	+[1]
Cd	+[2]	+[3]				+[1]	+[1]
Zn	+[2]	+[3]				+[1]	+[1]
Cu	+[2]	+[3]				+[1]	+[1]
Pb	+[2]	+[3]				+[1]	+[1]
Ni	+[2]	+[3]				v[1]	v[1]
Cr	+[2]	+[3]				v[1]	v[1]
Oil[6]		+[6]		+		+[6]	+[6]
Flow	+	**v**	+[11]			+	+

\+ obligatory
[v] voluntary
[1] Except for rivers where all BOD_5 and heavy metal concentrations are below the detection limit
[2] Heavy metals are obligatory for municipal WWTPs larger than 10,000 PE
[3] BOD_5, AOX, nutrients and heavy metals are obligatory variables for relevant industries if these vari¬ables are regulated by sector-wise HELCOM Recommendations and exceed the threshold according to Annex A1 of the EPER decision (see PLC-5 guidelines)
[4] Only for untreated industrial effluents
[5] If BOD_7 is measured, a conversion factor ($BOD_5 = BOD_7/1.15$) should be used in order to calculate BOD_5
[6] Oil should be reported for the major assessments for the following rivers: Neva, Vistula, Nemunas, Daugava, Oder, Narva, Göta Älv, and at the largest oil refinery in each Contracting Party using the analytical method EN-ISO 9377-2
[7] Can be monitored and reported as $NO_{2,3}$-N
[8] Nutrient losses from diffuse sources can be estimated either as the total for all delivery pathways without dividing into pathways or as losses by each individual pathway
[9] Diffuse sources discharging directly to the sea combine loads from scattered dwellings and from rainwater overflows
[10] Only from diffuse sources discharging directing into the Baltic Sea
[11] For fish farms where it is relevant (outlet for discharges)
[12] Should be measured or calculated
* In those cases where concentrations are below the detection limit, the estimated concentration should be calculated using the equation: Estimation = (100%-A) x LOD, where A=percentage of samples below LOD. This is according to one of the options listed in the guidance document on monitoring adopted by EU under the IPPC Directive Changes in methodology reported by the Contracting Parties.

The PLC-5 report (HELCOM 2011) covered data up to 2006. The Executive Summary of the PLC-5 report, which was published a year later, included also data up to 2008 (HELCOM 2012). The PLC-5.5 report has updated the assessment by including also data from 2009 and 2010.

There were numerous gaps in the PLC-5 data set (including gaps in historical data), which were filled by the PLC-5.5 project group. The "complete PLC-5.5" data set has been adopted by Contracting Parties for use in the PLC-5.5 report and for the calculation of revised BSAP country-wise allocation of nutrient reduction targets.[8]

The PLC-5.5 data set (Excel spreadsheet) as well as documentation on how the data gaps were filled can be downloaded via the PLC-5.5 project page on the HELCOM website.

9.2. Annex 2 - Quality assurance within the PLC-5.5 project

9.2.1. Questionnaire on quality assurance

Since quality assurance data were not directly a part of the PLC-5 reporting, the reporting has been supplemented with a questionnaire on these data. In the questionnaire the Contracting Parties were requested to give information on the data listed in **Table 9.2**.

In contrary to PLC-4, no international laboratory comparison or intercalibration tests were performed between Contracting Parties during the PLC-5 project and therefore the analytical quality cannot be assessed by comparing the performance of the used laboratories. The answers from Contracting Parties on the questionnaire will instead be used for comparing the analytical performances. Besides, this information on the quality of the analytical data can be used if data in the future will be compared with newer data produced under different analytical circumstances.

Table 9.2. Questions in questionnaire on quality assurance data on water analyses in PLC-5.5.

Parameter	Status in the questionnaire
LOQ (limit of quantification)	Mandatory – either LOQ or LOD
LOD (limit of detection)	Mandatory – either LOQ or LOD
Measurement uncertainty	Mandatory
Use of control chart – yes or no	Mandatory
Accredited analysis – yes or no	Voluntary
EN ISO/EC 17025 or equal quality assurance system – yes or no	Voluntary
Participated in proficiency testing – yes or no	Voluntary
Reference material used – yes or no	Voluntary

Answers on the questionnaire were received from all Contracting Parties except Latvia. Information on LOQ of Latvian analyses has been collected from data reported to EEA.

In the questionnaire it was not specified for which years the information cover, but it is reasonable to assume that the information is representative for the last years of the PLC-5.5 period.

8 Russia has not accepted to include the present Russian PLC-5.5 data in the PLC-Water database as official Russian data. See also caption to table 4.1a.

9.2.2. Accreditation of chemical analysis

The accreditation of chemical analyses ensures that the analytical work is done in accordance to a quality assurance system as EN ISO/EC 17025 or similar. The accreditation includes demand on use of control charts, use of reference materials and regular participation in proficiency testing.

It is been recommended that all laboratories involved in PLC monitoring are accredited according to EN ISO/EC 17025 and have a quality assurance program according to the same standard. Accreditation was not mandatory in PLC-5 or in PLC-5.5. Even so, most of the Contracting Parties have reported that the analyses have been performed by accredited laboratories (**Figure 9.1.** and **Tables 9.4a** and **4b**). However, Lithuania has reported that the laboratory was not accredited for most parameters. In Lithuania and other cases where the laboratories have not been accredited, the analytical methods have been documented and validated according to EN ISO/EC 17025 or similar standard. There is no information on accreditation for the Latvian data.

As the majority of chemical data used in the PLC-5.5 assessment have been produced by accredited laboratories or at least documented and validated according to EN ISO/EC 17025 or similar standard, it can be concluded that the analyses have been performed within a quality assurance system that ensures the quality of the analyses and in that way the data are reliable.

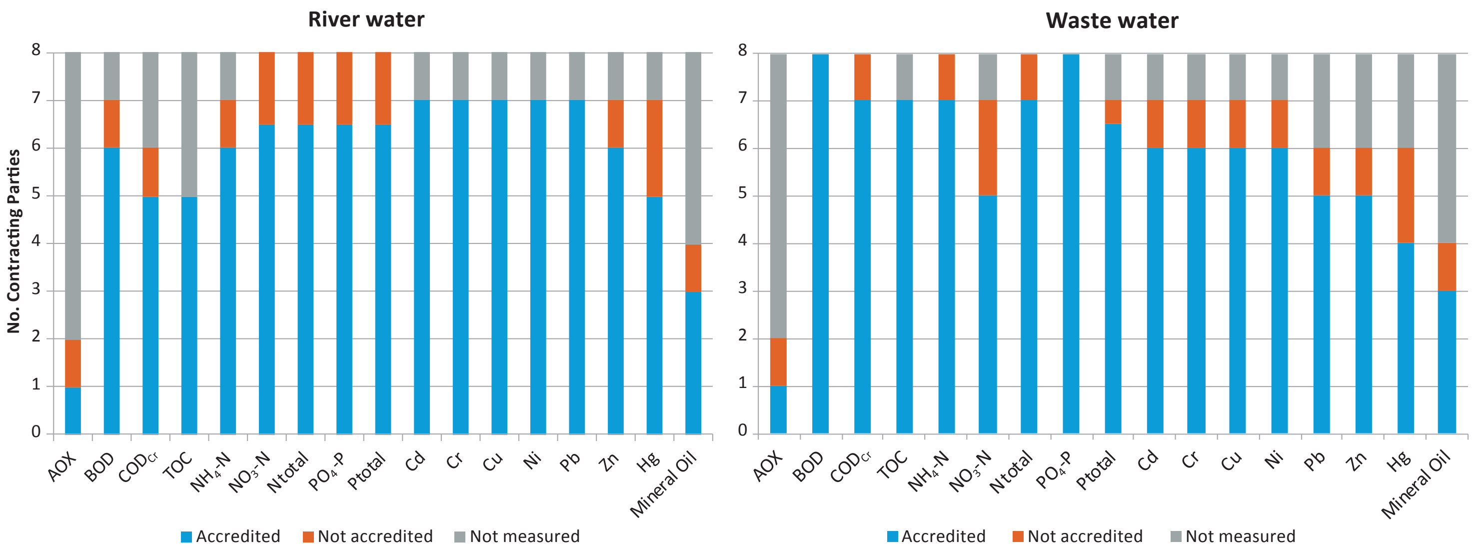


Figure 9.1. Number of Contracting Parties (except Latvia) where PLC-5.5 analyses on river water and wastewater have been accredited or not accredited. The information from Contracting Parties represent in some cases information from several laboratories. Answers form all laboratories within each Contracting Party are compiled to one answer per Contracting Party. In the cases where some laboratories within a Contracting Party were accredited and some were not accredited this is shown as partly accredited/not accredited (number: 0.5).

9.2.3. Quantification limits and detection limits

Quantification limits (LOQ) and detection limits (LOD) are parameters describing the sensitivity of the analytical method. LOQ is the lowest amount that is quantifiable with a certain analytical method and correspondingly LOD is the lowest detectable amount (see definition in box).

> *Definition of LOD and LOD according to Directive 2009/90/EC:*
>
> *"Limit of detection" means the output signal or concentration value above which it can be affirmed, with a stated level of confidence that a sample is different from a blank sample containing no determinand of interest.*
>
> *"Limit of quantification" means a stated multiple of the limit of detection at a concentration of the determinand that can reasonably be determined with an acceptable level of accuracy and precision. The limit of quantification can be calculated using an appropriate standard or sample, and may be obtained from the lowest calibration point on the calibration curve, excluding the blank*

LOQ is usually 2-4 times higher than LOD. It is common that LOQ is defined as 3•LOD e.g. as in the implementation of Directive 2009/90/EC in the Danish legislation.

The PLC-5 guidelines recommend use of limit of quantification (LOQ), and the guidelines include recommended values for LOQ in river water. Ideally LOQ should be lower than the measured concentrations in order to avoid that calculations of annual loads are based on estimated concentrations below LOQs (see below).

All Contracting Parties except Denmark have in the questionnaire reported LOQ while Denmark reported LOD. Some Contracting Parties reported both LOQ and LOD. The intervals for LOQ and LOD are summarized in **Table 9.3**, and the reported data that it is based on are listed in **Tables 9.5a, 9.5b, 9.5c** and **9.5d**.

Table 9.3. Range (min-max) of LOQ (limit of quantification) and LOD (limit of detection) for chemical analyses on river water and wastewater in Contracting Parties.

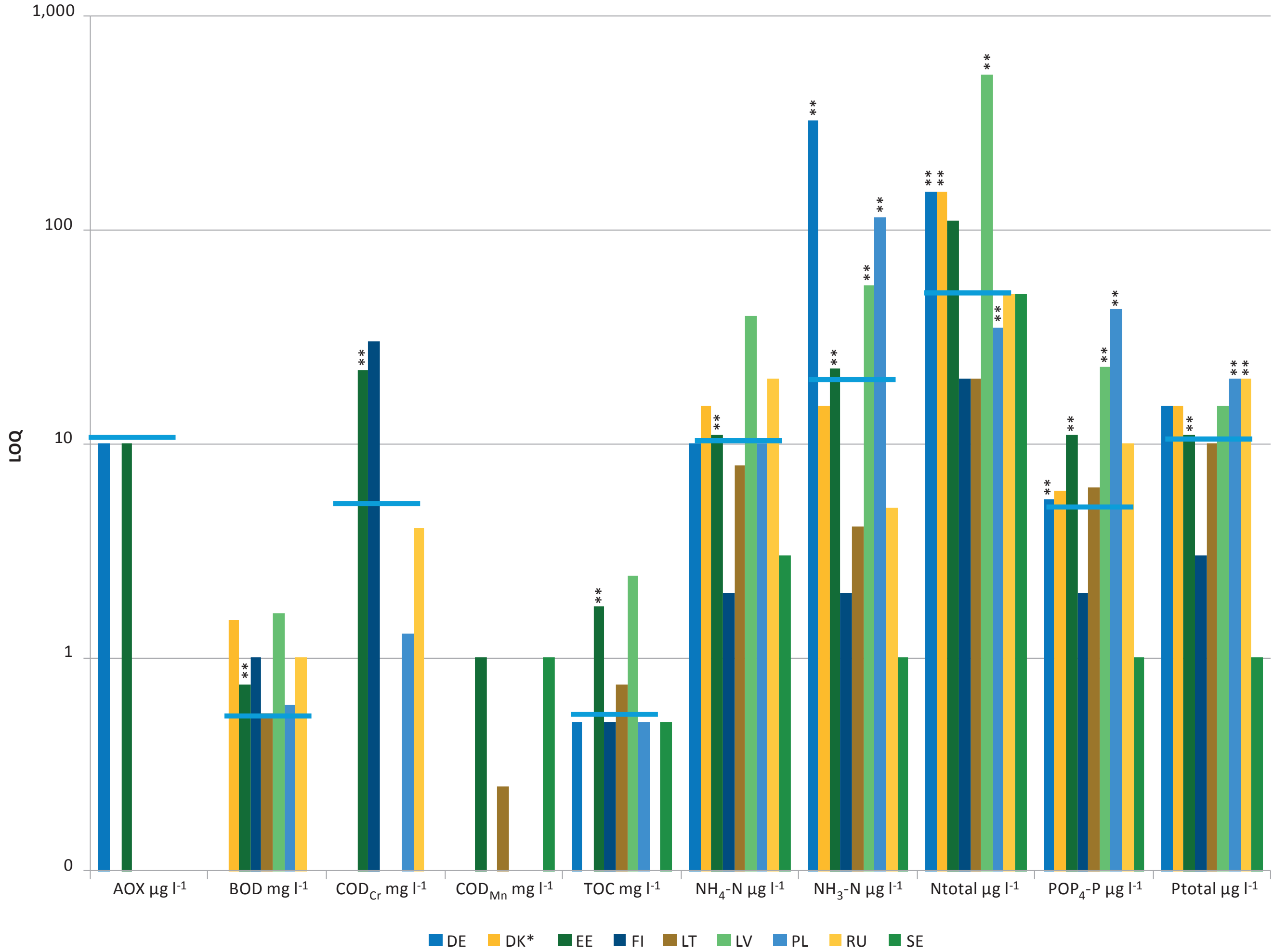
			River water		Wastewater	
	Unit	Guideline, LOQ	LOQ	LOD	LOQ	LOD
AOX	µg l^{-1}	10	10	3	5-10	3
BOD	mg l^{-1}	0.5	0.5-1.6	0.1-0.7	0.6-3	0.1-2
COD_{Cr}	mg l^{-1}	5	1.3-30	0.8-21	1.3-50	0.8-21
COD_{Mn}	mg l^{-1}		0.25-1	0.15-0.7	-	-
TOC	mg l^{-1}	0.5	0.5-3	0.1-0.67	0.5-3	0.1-0.6
NH_4-N	µg l^{-1}	10	2-40	1-10	2-20	2-39
NO_3-N	µg l^{-1}	20[1)]	2-500	0.3-200	2-500	2[1)]-200
Ntotal	µg l^{-1}	50	20-1,000	12-300	20-1,000	10-770
PO_4-P	µg l^{-1}	5	1-44	0.3-13	2-132	2-10
Ptotal	µg l^{-1}	10	1-30	0.3-7	2-200	1-40
Cd	µg l^{-1}	0.01	0.005-0.3	0.0015-0.1	0.02-20	0.007-1
Cr	µg l^{-1}	0.05	0.05-2	0.015-0.6	0.1-20	0.07-1
Cu	µg l^{-1}	0.05	0.04-4	0.012-1	0.2-20	0.2-1
Ni	µg l^{-1}	0.05	0.05-3	0.015-4	0.1-20	0.2-1
Pb	µg l^{-1}	0.05	0.01-1.4	0.006-1	0.1-40	0.07-1
Zn	µg l^{-1}	0.5	0.2-26	0.06-8	0.5-20	0.1-3
Hg	µg l^{-1}	0.005	0.0001-0.21	0.00004-0.06	0.001-0.1	0.0003-0.01
Mineral Oil	µg l^{-1}	100	7-100	2-60	7-2.000	2-630

1) May be the sum of NO_2-N and NO_3-N

LOQ (LOD) varied between the Contracting Parties (**Figure 9.2** and **Tables 9.5a** and **9.5c**). The factor between the highest and lowest LOQ/LOD are generally higher for heavy metals than for nutrient in both river water and wastewater. The frequency of LOQs higher than the recommended LOQs for river water was also higher for heavy metals than for nutrients. Only the Swedish analyses were performed with LOQ below or equal to the recommended LOQ for all parameters.

The Estonian, Latvian, Lithuanian and Polish analyses of heavy metals in river water were performed with LOQs higher than the recommended LOQ. Similarly, the LOD of Russian analyses were higher than the estimated recommended LOD. The estimation is LOD=1/3•LOQ.

In wastewater LOQs (LODs) the analyses in the individual Contracting Parties were performed with LOQs on a more equal level than for river water for nutrients as well as for heavy metals.



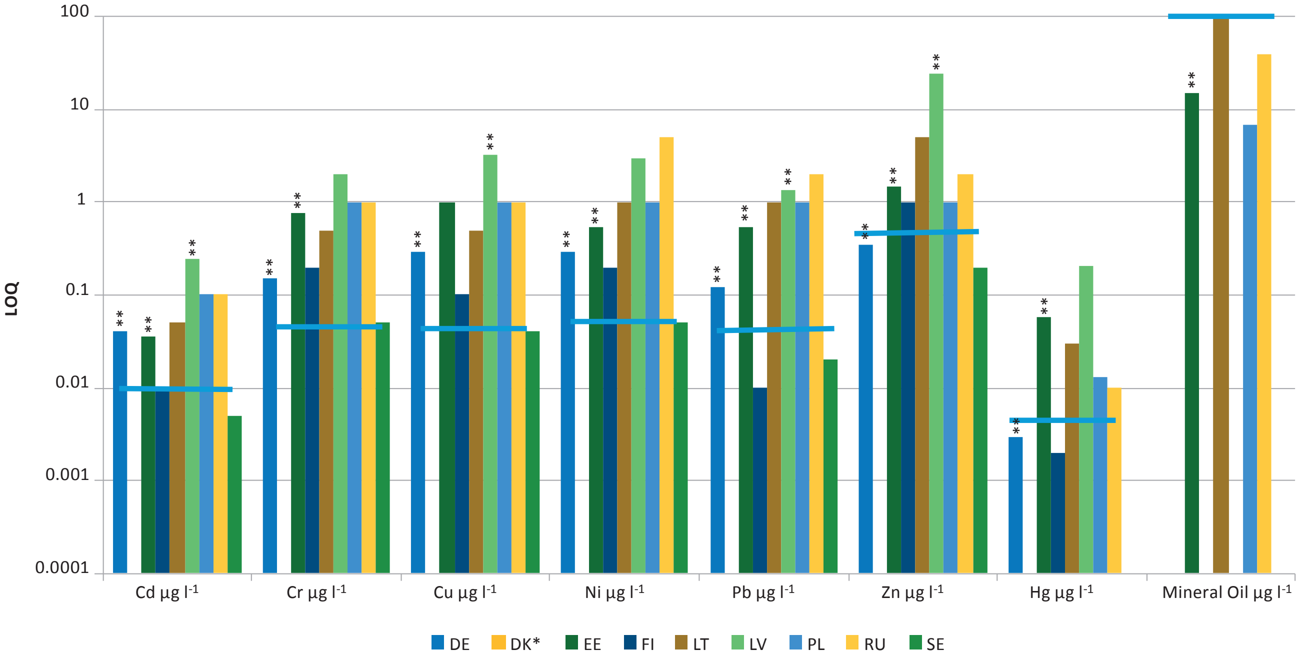


Figure 9.2. LOQ (limit of quantification) of nutrients (top) and heavy metals (below) in river water in Contracting Parties compared to the recommended LOQ according to the PLC-5 guidelines. If CPs have reported LOQs from more than one laboratory the average-LOQs are shown (marked **). The intervals can be found in **Table 9.4a**. LOQ for Denmark is estimated as LOQ=3•LOD (marked *). No data on metal LOQs is given for Denmark as only metals in filtered river water are analysed, whereas the PLC-5 guidelines require total concentrations of metals.

LOQ is critical when concentrations are low, because the LOQ value is used to assign a numeric value when handling low-level data. This is the case for many substances in river water in the Nordic Countries. In Finland and Sweden it is necessary to use highly sensitive methods for certain substances, e.g. in determination of some of the heavy metals.

It is recommended to estimate concentrations for load calculations based on analytical results below LOQ as:

Concentration = (100%-A)/100 • LOQ, where A are the percentage of samples below LOQ.

Low-concentration level data are in some areas frequent for metals while seldom for nutrients, which means that the impact of high LOQ-values will be larger for metals than for nutrients. If LOQ is much higher than the "real" concentration the estimate based on the formula above might be unreliable although it is the best estimate that can be given. Large differences between Contracting Parties in LOQ for substances with high frequency of concentrations below LOQ may lead to low comparability of the results.

9.2.4. Measurement uncertainty

Measurement uncertainties for the different parameters reported by each Contracting Party are listed in **Table 9.6a** and **9.6b**. The uncertainties are reported in different ways, as percentages, as exact values or as combinations, and with differentiations depending on concentration levels. This means that the measurement uncertainties are not directly comparable.

The measurement uncertainties are not included further in the assessment of data quality in PLC-5.5. However, information on measurement uncertainty may be valuable when the PLC-5.5 data are included in future assessments when the analytical quality and the measurement uncertainty have changed.

9.2.5. Section with supplementing tables

Table 9.4a. Accredited analyses of variables in river water

Contracting Party	DE	DK	EE	FI	LT	LV	PL	RU	SE
Year			**2011-2013**		**2010**				
AOX	yes/n.a.		no						
BOD	yes/n.a.	yes	yes	yes	no[1]	n.a.	yes	yes	
COD_{Cr}			yes	yes	no[1]	n.a.	yes	yes	yes
TOC	yes			yes	yes		yes		yes
NH_4-N	yes	yes	yes	yes	no[1]	n.a.	yes		yes
NO_3-N	yes	yes	yes	yes	no[1]	n.a.	no[1]/yes	yes	yes
Ntotal	yes	yes	yes	yes	no[1]	n.a.	no[1]/yes	yes	yes
PO_4-P	yes	yes	yes	yes	no[1]	n.a.	no[1]/yes	yes	yes
Ptotal	yes	yes	yes	yes	no[1]	n.a.	no[1]/yes	yes	yes
Cd	yes		yes	yes	yes	n.a.	yes	yes	yes
Cr	yes		yes	yes	yes	n.a.	yes	yes	yes
Cu	yes		yes	yes	yes	n.a.	yes	yes	yes
Ni	yes		yes	yes	yes	n.a.	yes	yes	yes
Pb	yes		yes	yes	yes	n.a.	yes	yes	yes
Zn	yes		yes	yes	no[1]	n.a.	yes	yes	yes
Hg	yes		yes	yes	no[1]	n.a.	no[1]	yes	yes
Mineral Oil			yes		no[1]		yes	yes	

1) Analytical method documented and validated according to EN ISO/EC 17025 or similar
n.a. = not available
If several laboratories have answered differently, the answered are shown with "/" between

Table 9.4b. Accredited analyses of variables in wastewater

Contracting Party	DE	DK	EE	FI	LT	LV	PL	RU	SE[2]
Year			**2011-2013**		**2010**				
AOX	yes		no						
BOD	yes	yes	yes	yes	yes	n.a.	yes	yes	yes
COD_{Cr}	yes	yes	yes	yes	no[1]	n.a.	yes	yes	yes
TOC	yes	yes	yes	yes	yes		yes		yes
NH_4-N	yes	yes	yes	yes	no[1]	n.a.	yes	yes	yes
NO_3-N	yes		yes	yes	no[1]	n.a.	no[1]	yes	yes
N-total	yes	yes	yes	yes	no[1]	n.a.	yes	yes	yes
PO_4-P	yes	yes	yes	yes	yes	n.a.	yes	yes	yes
Ptotal	yes		yes	yes	yes	n.a.	no[1]/yes	yes	yes
Cd	yes		yes	yes	no[1]	n.a.	yes	yes	yes
Cr	yes		yes	yes	no[1]	n.a.	yes	yes	yes
Cu	yes		yes	yes	no[1]	n.a.	yes	yes	yes
Ni	yes		yes	yes	no[1]	n.a.	yes	yes	yes
Pb	yes		yes	yes	no[1]	n.a.	yes	yes	
Zn	yes		yes	yes	no[1]	n.a.	yes	yes	
Hg	yes		yes	yes	no[1]	n.a.	no[1]	yes	
Mineral Oil			yes		no[1]		yes	yes	

1) Analytical method documented and validated according to EN ISO/EC 17025 or similar.
2) Information from most commonly used laboratory for analysis of wastewater from sewage treatment plants. No information for industrial wastewater.

Table 9.5a. Limits of quantification (LOQ) for variables in river water.

Contracting Party		Guideline	DE	DK	EE	FI	LT	LV5)	PL	RU	SE
Year							2010	2008-2010			
AOX	$\mu g\ l^{-1}$	10	n.a.-10		10						n.a.
BOD	$mg\ l^{-1}$	0.5	n.a.	n.a.	0.5-1	1	0.55	1.6	0.6	1	n.a.
COD_{Cr}	$mg\ l^{-1}$	5		n.a.	14-30	30			1.3	4	
COD_{Mn}	$mg\ l^{-1}$				1		0.25				1
TOC	$mg\ l^{-1}$	0.5	0.5	n.a.	0.5-3	0.5	0.75	2.4	0.5		0.5
NH_4-N	$\mu g\ l^{-1}$	10	10	n.a.	2-20	2	8	40	10	20	3
NO_3-N	$\mu g\ l^{-1}$	201)	150-500	n.a.	5-40	2	4.1	20-90	30-100	5	11)
Ntotal	$\mu g\ l^{-1}$	50	50-250	n.a.	20-200	20	20	60-1,000	30-40	50	50
PO_4-P	$\mu g\ l^{-1}$	5	5-6	n.a.	2-20	2	6.3	1.7-44	15-30	10	1
Ptotal	$\mu g\ l^{-1}$	10	5-25	n.a.	2-20	3	10	4-26	10-30	20	1
Cd	$\mu g\ l^{-1}$	0.01	0.02-0.06		0.02-0.05	0.01	0.05	0.2-0.3	0.1	0.1	0.005
Cr	$\mu g\ l^{-1}$	0.05	0.1-0.2		0.5-1	0.2	0.5	2	1.0	1	0.05
Cu	$\mu g\ l^{-1}$	0.05	0.08-0.5		1	0.1	0.5	2.4-4.0	1.0	1	0.04
Ni	$\mu g\ l^{-1}$	0.05	0.07-0.5		0.1-1	0.2	1.0	3	1.0	5	0.05
Pb	$\mu g\ l^{-1}$	0.05	0.04-0.2		0.1-1	0.01	1.0	1.3-1.4	1.0	2	0.02
Zn	$\mu g\ l^{-1}$	0.5	0.2-0.5		1-2	1	5.0	22-26	1.0	2	0.2
Hg	$\mu g\ l^{-1}$	0.005	0.001-0.005		0.015-0.1	0.002	0.03	0.21	0.013	0.01	0.0001
Mineral Oil	$\mu g\ l^{-1}$	100			10-20		100		7.0	40	n.a.

n.a. not available

Table 9.5b. Limits of detection (LOD) for variables in river water.

Contracting Party		Guide-line [1]	DE	DK	EE	FI	LT	LV [3]	PL	RU	SE
Year							2010	2008-2010			
AOX	$\mu g\ l^{-1}$	3	n.a.-3								n.a.
BOD	$mg\ l^{-1}$	0.2	n.a.	0.5	0.3-0.7	n.a.	0.33	0.5-0.6	0.1	0.5	n.a.
COD_{Cr}	$mg\ l^{-1}$	2	n.a.		21	n.a.			0.8	3	
COD_{Mn}	$mg\ l^{-1}$				0.7		0.15				0.3
TOC	$mg\ l^{-1}$	0.17	0.167-0.2			n.a.	0.45	0.67	0.1		0.15
NH_4-N	$\mu g\ l^{-1}$	3	3	5	5-6	n.a.	5	10	2.0	5	1
NO_3-N	$\mu g\ l^{-1}$	7	50-200	5	7-30	n.a.	1.2	6-25	7.0	3	0.3
Ntotal	$\mu g\ l^{-1}$	17	17-83	50 [2]	13-30	n.a.	12	300	80	40	15
PO_4-P	$\mu g\ l^{-1}$	1.7	2	2	3-10	n.a.	4	0.5-13	4.0	2	0.3
Ptotal	$\mu g\ l^{-1}$	3	2-8	5	3-6	n.a.	7	1.4-7	2.0	5	0.3
Cd	$\mu g\ l^{-1}$	0.003	0.007-0.02			n.a.	0.03	0.06-0.1	0.05	0.1	0.0015
Cr	$\mu g\ l^{-1}$	0.02	0.03-0.07			n.a.	0.3	0.6	0.1	0.5	0.015
Cu	$\mu g\ l^{-1}$	0.02	0.03-0.2			n.a.	0.3	0.7-1.0	0.6	0.5	0.012
Ni	$\mu g\ l^{-1}$	0.02	0.02-0.2			n.a.	0.6	0.9-1.0	0.6	4	0.015
Pb	$\mu g\ l^{-1}$	0.02	0.01-0.07			n.a.	0.6	0.4	0.4	1	0.006
Zn	$\mu g\ l^{-1}$	0.2	0.07-0.2			n.a.	3	7-8	0.1	1	0.06
Hg	$\mu g\ l^{-1}$	0.002	0.0003-0.0015			n.a.	0.01	0.06	0.004	0.005	0.00004
Mineral Oil	$\mu g\ l^{-1}$	30					60		2.0	20	n.a.

Intervals: lowest and highest from two or more laboratories. n.a.: not available

[1] Estimated recommended LOD. Estimation: LOD=1/3•LOQ; 2) Demand due to legislation, no conc. below LOD.3) Information from data reported to EEA

Table 9.5c. Limits of quantification (LOQ) for variables in wastewater.

Contracting Party		DE	DK	EE	FI	LT	LV[2)]	PL	RU	SE[1)]
Year						2010	2008-2010			
AOX	µg l^{-1}	5-10	n.a.	10		n.a.				n.a.
BOD	mg l^{-1}	1-3	n.a.	0.7-3	3	3	n.a.	0.6	n.a.	3
COD_{Cr}	mg l^{-1}	15	n.a.	14-50	30	23	n.a.	1.3	n.a.	30
COD_{Mn}	mg l^{-1}									
TOC	mg l^{-1}	0.5	n.a.	0.5-3	0.5	0.75	n.a.	0.5		1
NH_4-N	µg l^{-1}	10-20	n.a.	2-20	2	6	n.a.	10	n.a.	10
NO_3-N	µg l^{-1}	92-500	n.a.	5-40	2	3	n.a.	30	n.a.	10
Ntotal	µg l^{-1}	50-130	n.a.	20-1,000	20	490	n.a.	40-300	n.a.	10-100
PO_4-P	µg l^{-1}	5-132	n.a.	2-20	2	5	n.a.	30	n.a.	5
Ptotal	µg l^{-1}	5-10	n.a.	2-200	3	8	n.a.	10-30	n.a.	5
Cd	µg l^{-1}	0.02	n.a.	0.05-20	0.1	0.05	n.a.	0.1	n.a.	0.1
Cr	µg l^{-1}	0.1-0.2	n.a.	1-20	2	0.5	n.a.	1.0	n.a.	1
Cu	µg l^{-1}	0.2-0.5	n.a.	1-20	1	0.5	n.a.	1.0	n.a.	1
Ni	µg l^{-1}	0.1-0.5	n.a.	1-20	2	1.0	n.a.	1.0	n.a.	1
Pb	µg l^{-1}	0.1-0.2	n.a.	1-40	0.1	1.0	n.a.	1.0	n.a.	0.5
Zn	µg l^{-1}	0.5	n.a.	2-20	10	5.0	n.a.	1.0	n.a.	5
Hg	µg l^{-1}	0.001-0.01	n.a.	0.015-0.1	0.002	0.03	n.a.	0.013	n.a.	0.1
Mineral Oil	µg l^{-1}			20-2,000		930		7.0	n.a.	n.a.

1) Information from the most commonly used laboratory for analysis of wastewater from sewage treatment plants. No information for industrial wastewater.
2) Information from data reported to EEA

Table 9.5d. Limits of detection for variables in wastewater.

Contracting Party		DE	DK	EE	FI	LT	LV[1)]	PL	RU	SE
Year						2010	2008-2010			
AOX	µg l^{-1}	3								n.a.
BOD	mg l^{-1}	n.a.	1	1.8-2		0.9	n.a	0.1	1.0	n.a.
COD_{Cr}	mg l^{-1}	-	5	15-21		6.8	n.a.	0.8	10	n.a.
TOC	mg l^{-1}	0.2	0.6			0.45		0.1		n.a.
NH_4-N	µg l^{-1}	3	30	5-6		4	n.a.	2.0	39	n.a.
NO_3-N	µg l^{-1}	200		7-30		2	n.a.	7.0	23	n.a.
Ntotal	µg l^{-1}	17	50	600-770		150	n.a.	80	10	n.a.
PO_4-P	µg l^{-1}	2		3-10		3	n.a.	4.0	10	n.a.
Ptotal	µg l^{-1}	2	5	3-6		5	n.a.	1.0	40	n.a.
Cd	µg l^{-1}	0.007				0.03	n.a.	0.05	1.0	n.a.
Cr	µg l^{-1}	0.07				0.3	n.a.	0.1	1.0	n.a.
Cu	µg l^{-1}	0.2				0.3	n.a.	0.6	1.0	n.a.
Ni	µg l^{-1}	0.2				0.6	n.a.	0.6	1.0	n.a.
Pb	µg l^{-1}	0.07				0.6	n.a.	0.4	1.0	n.a.
Zn	µg l^{-1}	0.2				3.0	n.a.	0.1	1.0	n.a.
Hg	µg l^{-1}	0.0003				0.01	n.a.	0.004	0.01	n.a.
Mineral Oil	µg l^{-1}					630		2.0	5.0	n.a.

Intervals: lowest and highest from two or more laboratories.
n.a.: not available.
1) Information from data reported to EEA

Table 9.6a. Measurement uncertainty for variables in river water. Intervals show lowest and highest value for two or more laboratories.

Contracting Party	DE	DK[1)]	EE	FI	LT	LV	PL	RU	SE
Year					2010	2008-2010			
AOX	n.a./30%		10%						n.a.
BOD	n.a./25%	20%	5.6-16%	1-3 mg l^{-1}: 0.6 mg l^{-1} >3 mg l^{-1}: 20%	n.a.	n.a.	14%	0.3 mg+6%	n.a.
COD_{Cr}	n.a.		8-27%	30-50 mg l^{-1}: 10 mg l^{-1} >50 mg l^{-1}:10%	n.a.	n.a.	17%	20%	
COD_{Mn}			2-17%						12%[2)]
TOC	5.4-20%		10-14%	0.5-2.5 mg l^{-1}: 0.4 mg l^{-1} >2,500 µg l^{-1}: 15%	5%	n.a.	15%		11%[2)]
NH_4-N	6.2-15%	15%	7-14%	2-20 µg l^{-1}: 2 µg l^{-1} >20 µg l^{-1}: 10%	n.a.	n.a.	14%	20-50 µg l^{-1}: 10 µg l^{-1} 50-500 µg l^{-1}: 22%	16%[2)]
NO_3-N	5.4-10%	15%	5-15%	2-50 µg l^{-1}: 2 µg l^{-1} >50 µg l^{-1}: 6%	n.a.	n.a.	12%	10-80 µg l^{-1}: 4 µg l^{-1}+24%; 80-300 µg l^{-1} :6 µg l^{-1}+24%	11%[2)]
Ntotal	5.0-25%	15%	5.5-20%	15%	n.a.	n.a.	14%	30 µg l^{-1} +8%	10-18%[3)]
PO_4-P	5-5.6%	15%	5-24%	2-10 µg l^{-1}: 1.5 µg l^{-1} >15 µg l^{-1}: 15%	n.a.	n.a.	15%	2 µg l^{-1} +9.2%	13%[2)]
Ptotal	4.5-25%	15%	8-18%	3-10 µg l^{-1}: 1.5 µg l^{-1} >15 µg l^{-1}: 15%	n.a.	n.a.	12%	4 µg l^{-1} +6.3%	10%[2)]
Cd	20-22%		15-17%	0.01-0.07 µg l^{-1}: 0.01 µg l^{-1} 0.07-1.0 µg l^{-1}: 15% >1.0 µg l^{-1}: 10%	Measurement uncertainty fulfils the requirement of EC Directive 3009/90/EC	n.a.	29%	0.05 µg l^{-1} +10%	10-41%[3)]
Cr	7.7-10%		11-16%	0.2-1.0 µg l^{-1}: 0.15 µg l^{-1} 1.0-10 µg l^{-1}: 15% >1.0 µg l^{-1}: 10%		n.a.	23%	0.4 µg l^{-1} +22%	30%[2)]
Cu	9.7-15%		12-13%	0.1-0.5 µg l^{-1}: 0.1 µg l^{-1} 0.5-10 µg l^{-1}: 15% >10 µg l^{-1}: 10%		n.a.	17%	0.2 µg l^{-1} +19%	12-14%[3)]
Ni	6.5-30%		13-16%	0.2-1.0 µg l^{-1}: 0.15 µg l^{-1} 1.0-10 µg l^{-1}: 15% >10 µg l^{-1}: 10%		n.a.	27%	2 µg l^{-1} +12%	11-29%[3)]
Pb	4.9-15%		12-14%	0.01-0.07 µg l^{-1}: 0.01 µg l^{-1} 0.07-1.0 µg l^{-1}: 15% >1.0 µg l^{-1}: 10%		n.a.	23%	1 µg l^{-1} +12%	10-17%[3)]
Zn	8.7-15%		9-16%	1.0-10 µg l^{-1}: 1.0 µg l^{-1} >10 µg l^{-1}: 10%	EU-dir. Requirement not fulfilled	n.a.	29%	1 µg l^{-1} +17%	17-33%[3)]
Hg	8-9%		13-14%	0.002-0.005 µg l^{-1} : 0.0015 µg l^{-1} >0.005 µg l^{-1}: 25%	n.a.	n.a.	48%	0.01-0.04 µg l^{-1} : 0.04 µg l^{-1} 0.04-0.1 µg l^{-1}:0.01 µg l^{-1} +11%	Conc. near LOQ: 10-15% Otherwise: 5%
Mineral Oil			20-45%		n.a.		26%		n.a.

n.a.: not available;
[1)] According to legislation;
[2)] Measurement uncertainty depends on concentration range. For low range concentration a fixed precision is given. Further information on: http://www.slu.se/aquatic-sciences/water-chemical-analyses;
[3)] Measurement uncertainty depends on concentration range.

Table 9.6b. Measurement uncertainty for variables in wastewater. Intervals show lowest and highest value for two or more laboratories.

Con-tracting Party	DE	DK[1]	EE	FI	LT	LV	PL	RU	SE
Year					**2010**	**2008-2010**			
AOX	25-30%		10%						n.a.
BOD	25-30%	20%	5.6-12%	20%	8.5%	n.a.	14%	0.3 mg l^{-1}+6%	n.a.
COD_{Cr}	n.a./35%	15%	4-12%	30-50 mg l^{-1}: 10 mg l^{-1} >50 mg l^{-1}:10%	n.a.	n.a.	17%	10-100 mg l^{-1}:25%; 100-500 mg l^{-1}:20%; 500-30,000 mg l^{-1}:15%	n.a.
TOC	20-30%	40%	7-10%	0.5-2.5 mg l^{-1}: 0.4 mg l^{-1} >2.5 mg l^{-1}: 15%	5%	n.a.	15%		n.a.
NH_4-N	15-30%	15%	7-11%	2-20 µg l^{-1}: 3 µg l^{-1} >20 µg l^{-1}: 15%	n.a.	n.a.	14%	39-78 µg l^{-1} :39% 78-780 µg l^{-1} : 35% 78-62,000 µg l^{-1} : 21%	n.a.
NO_3-N	10-30%		4.9-15%	2-50 µg l^{-1}:2 µg l^{-1} >50 µg l^{-1}: 6%	n.a.	n.a.	12%	15%	n.a.
Ntotal	25-30%	15%	5.5-14%	15%	n.a.	n.a.	17%	5.90%	n.a.
PO_4-P	5-30%	15%	3-12%	2-10 µg l^{-1}:1.5 µg l^{-1} >15 µg l^{-1}: 15%	3.20%	n.a.	15%	10-200 µg l^{-1}: 2 µg l^{-1} + 9.2%; 200-1,000 µg l^{-1}: 2 µg l^{-1} +9.2%	n.a.
Ptotal	25-30%		6-10%	3-10 µg l^{-1}: 1.5 µg l^{-1} >15 µg l^{-1} 15%	3.50%	n.a.	12%	40-100 µg l^{-1}:40%; 100-200 µg l^{-1}:35%; 200-400 µg l^{-1}:25%; 400-10,000 µg l^{-1}: 25%	n.a.
Cd	20-40%		6-15%	0.01-0.07 µg l^{-1}:0.01 µg l^{-1} 0.07-1.0 µg l^{-1}: 15% > 1.0 µg l^{-1}: 10%	Measurement uncertainty fulfills the requirement of EC Directive 3009/90/EC	n.a.	29%	1-50 µg l^{-1} : 32%; 50-500 µg l^{-1}:24%; 500-10,000 µg l^{-1}: 15%	n.a.
Cr	10-40%		5-11%	2.0-10 µg l^{-1}: 1.5 µg l^{-1} 10-100 µg l^{-1}: 15% >100 µg l^{-1}: 10%		n.a.	23%	1-50 µg l^{-1}: 26%; 50-500 µg l^{-1}:20%; 500-10,000 µg l^{-1}: 15%	n.a.
Cu	15-30%		11-13%	1.0-5.0 µg l^{-1}:1.0 µg l^{-1} 5.0-100 µg l^{-1}: 15% >100 µg l^{-1}: 10%		n.a.	17%	1-50 µg l^{-1}: 42%; 50-500 µg l^{-1}: 26%; 500-250,000 µg l^{-1}l: 16%	n.a.
Ni	30%		5-13%	2.0-10 µg l^{-1}: 1.5 µg l^{-1} 10-100 µg l^{-1}: 15% >100 µg l^{-1}: 10% level		n.a.	27%	1-50 µg l^{-1}: 42%; 50-500 µg l^{-1}: 26%; 500-10,000 µg l^{-1}: 16%	n.a.
Pb	15-30%		7-12%	0.01-0.07 µg l^{-1}: 0.01 µg l^{-1} 0.07-1.0 µg l^{-1}: 15% > 1.0 µg l^{-1}: 10%		n.a.	23%	1-50 µg l^{-1}: 42%; 50-500 µg l^{-1}: 26%; 500-10,000 µg l^{-1}: 16%	n.a.
Zn	15-40%		5-9%	10-100 µg l^{-1}: 10 µg l^{-1} >100 µg l^{-1}: 10%	EU-dir. Requirement not fulfilled	n.a.	29%	1-50 µg l^{-1}: 26%; 50-500 µg l^{-1}: 20%; 500-10,000 µg l^{-1}: 15%	n.a.
Hg	8-30%		13-14%	0.002-0.005 µg l^{-1}: 0.0015 µg l^{-1} 0.005 µg l^{-1}:25%	n.a.	n.a.	48%	0.01-0.1 µg l^{-1}:50% 0.1-10 µg l^{-1}:25%	n.a.
Mineral Oil			20-45%		n.a.		26%	5-10 µg l^{-1}:50%; 10-500 µg l^{-1}:35%; 500-50,000 µg l^{-1}:25%	

n.a.: not available;
[1] According to legislation

9.3. Annex 3 - Calculation of nitrogen deposition to the Baltic Sea using the EMEP Model

This annex describes procedures and algorithms used at MSC/W of EMEP for calculating annual depositions of nitrogen to the Baltic Sea and its sub-basins, as well as, source allocation budgets, source receptor matrices and normalized depositions.

9.3.1. Introduction

In the frame of co-operation between HELCOM and EMEP, estimation of atmospheric nitrogen deposition has been carried out for each year of the period 1995-2010. Annual depositions, monthly depositions, as well as annual source-allocation budgets for nitrogen deposition have been calculated using the EMEP MSC-W model. The main purpose of this document is a description and explanation how nitrogen depositions and source-allocation budget are calculated. In addition, the procedure for calculation of normalized atmospheric nitrogen deposition to the Baltic Sea is also described and explained here. A full documentation of the EMEP MSC-W model is published in the special issue of the Journal of Atmospheric Chemistry and Physics dedicated to EMEP (Simpson et al. 2012). The latest updates and developments of the EMEP model can also be followed on the EMEP web site.

9.3.2. Annual deposition

The routine runs of the EMEP MSC-W model are performed every ear with updated input data for the purpose of LRTAP Convention and in the frame of co-operation between HELCOM and EMEP. The input data necessary for routine runs of the EMP model are: emissions, meteorological data and land use data. Emissions and meteorological fields must be updated each year for routine runs. The land used data are updated each time when better information about the land use is available.

All input data are provided in the model grid with 50 km horizontal resolution and 20 vertical layers. The model grid system is defined in Polar Stereographic Projection true at 60ºN. The operational model grid system until 2009 included 170 nodes in x- and 133 nodes in y-direction. The dimension of the new model grid (starting from 2009) is 170•170 nodes and the model results including nitrogen deposition are available in this new grid for the years 2007-2010. The concentrations are calculated as average over the each grid square of the size 50 km•50 km with the height of first vertical layer in the model. Dry and wet deposition is also calculated for each model grid square.

Both anthropogenic and biogenic emissions are required for the EMEP MSC-W model runs. Concerning anthropogenic emissions, as much as possible, data officially reported by EMEP Contracting Parties are used for the purpose of modelling. Annual national totals for each country should be reported every year to EMEP and they are distributed to each grid cell of the model. In addition, approximately every five years, the distribution of national emissions in the EMEP gird is updated by the Contracting Parties. The main conditions for using official data are availability and quality good enough. When the officially reported data is not available or the data quality is not good enough, the expert estimates are used instead for the model runs. The procedures used for collecting anthropogenic emissions, filling-in gaps, and for spatial distribution can be found in Vestreng (2003). Emissions of eight species are necessary for routine runs of the EMEP model: SO_2, NO_x NH3, CO, NMVOC, primary $PM_{2.5}$ and PM_{10}. These emission fields must be available and updated in the model grid for routine annual runs.

Meteorological data include both, three-dimensional fields and two-dimensional fields on the surface layer. Meteorological fields available in 3-D are the following: velocity, pressure, temperature and humidity. Precipitation is one example of 2-D meteorological data.

The land use data include matrices with different types of land cover that are variable in space in time, especially for different seasons of the year.

Computational diagram for calculating atmospheric oxidized, reduced and total nitrogen deposition to sub-basins of the Baltic Sea and to the entire Baltic Sea Basin using the EMEP MSC-W model is illustrated in **Figure 9.3.**

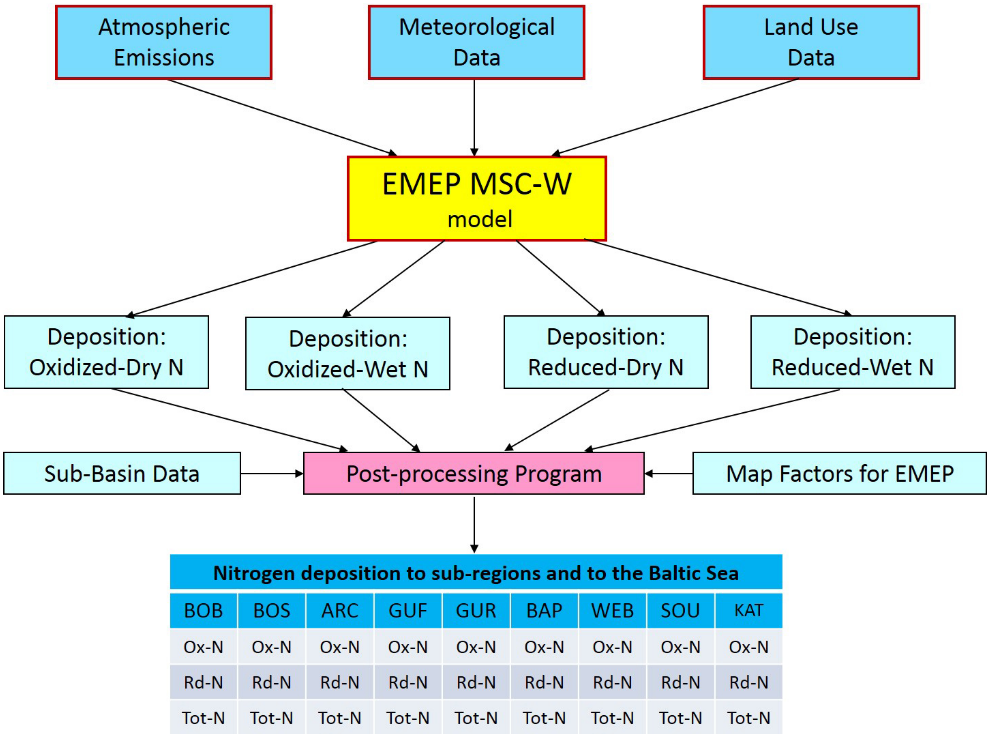


Figure 9.3. Computational diagram for calculating oxidized, reduced and total nitrogen deposition to sub-basins of the Baltic Sea and to the entire Baltic Sea Basin using the EMEP MSC-W model.

Using input data with updated emissions, land use and meteorology for the current year, the EMEP MSC-W model is run to calculate annual, monthly and daily values of oxidized-dry, oxidized-wet, reduced-dry and reduced-wet nitrogen deposition (in mg N m^{-2}) in each grid square of the EMEP grid systems shown in **Figure 9.4.** Calculated annual and monthly depositions are used for the purpose of HELCOM.

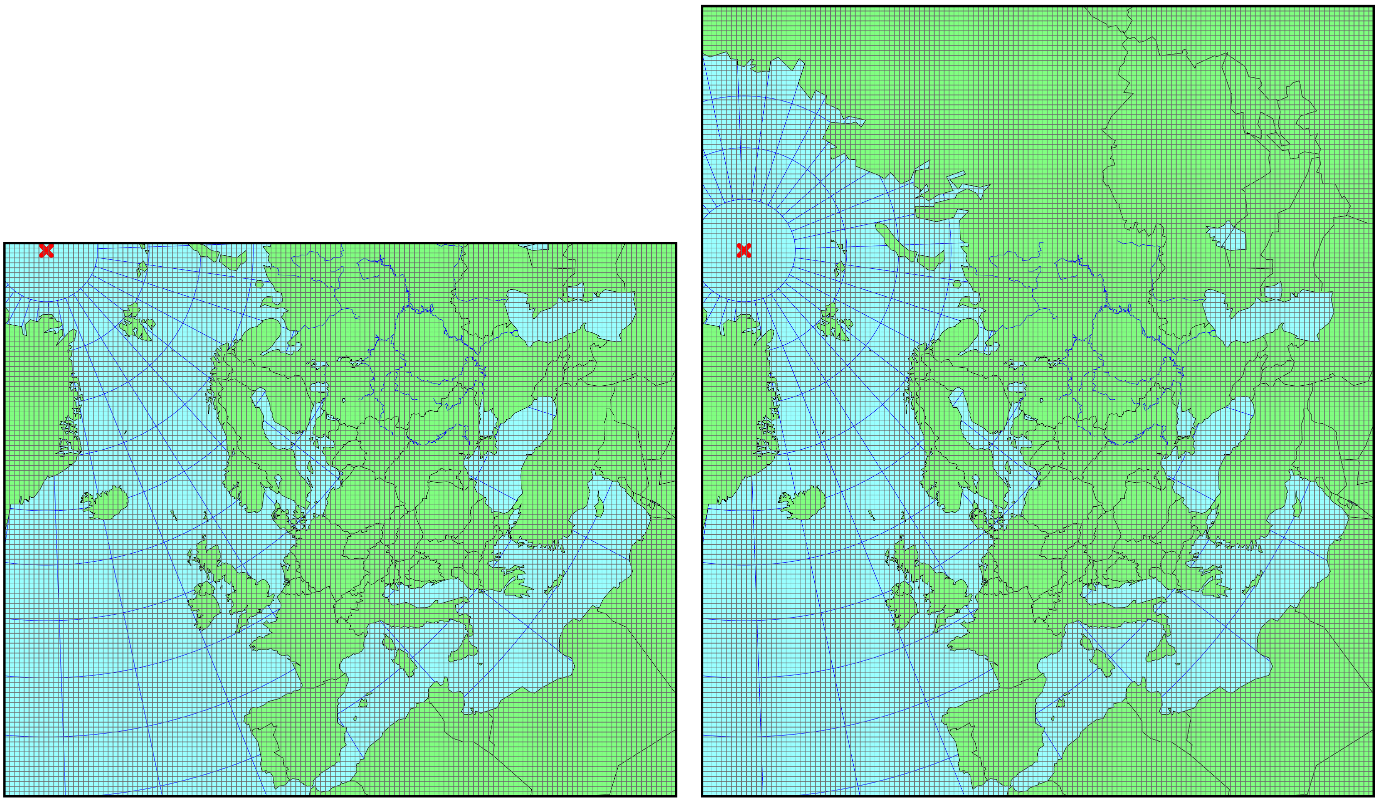


Figure 9.4. Comparison of old official EMEP domain (on the left) and new official EMEP domain (on the right). The old model domain was used for the years 1995-2006 and new model domain has been used for all years starting from 2007.

Four output files from the EMEP model run, with annual nitrogen depositions, are then used as input for the post-processing program. The file defining the sub-basins of the Baltic Sea in the EMEP grid and the file with map factors for the EMEP grid system are also used by the post-processing program. The output from the post-processor program includes annual total depositions (in tonnes of N) of oxidized, reduced and total (oxidized + reduced) nitrogen to each of ten sub-basins of the Baltic Sea, as requested by HELCOM. Annual depositions of oxidized, reduced and total nitrogen the entire Baltic Sea basin are also calculated as the sum of depositions to all sub-basins.

The deposition files shown in Figure 9.3 are also used for creating annual deposition maps for HELCOM. Examples of such maps for the year 2010 are shown in **Figure 9.5.**

Similar maps to those shown in Figure 9.5 are also made for annual dry deposition, wet deposition and total (dry + wet) deposition of nitrogen. Another example of the EMEP model products for the year 2010 are the values of annual deposition of oxidized, reduced and total nitrogen to each of ten sub-basins of the Baltic Sea as shown in **Table 9.7.**

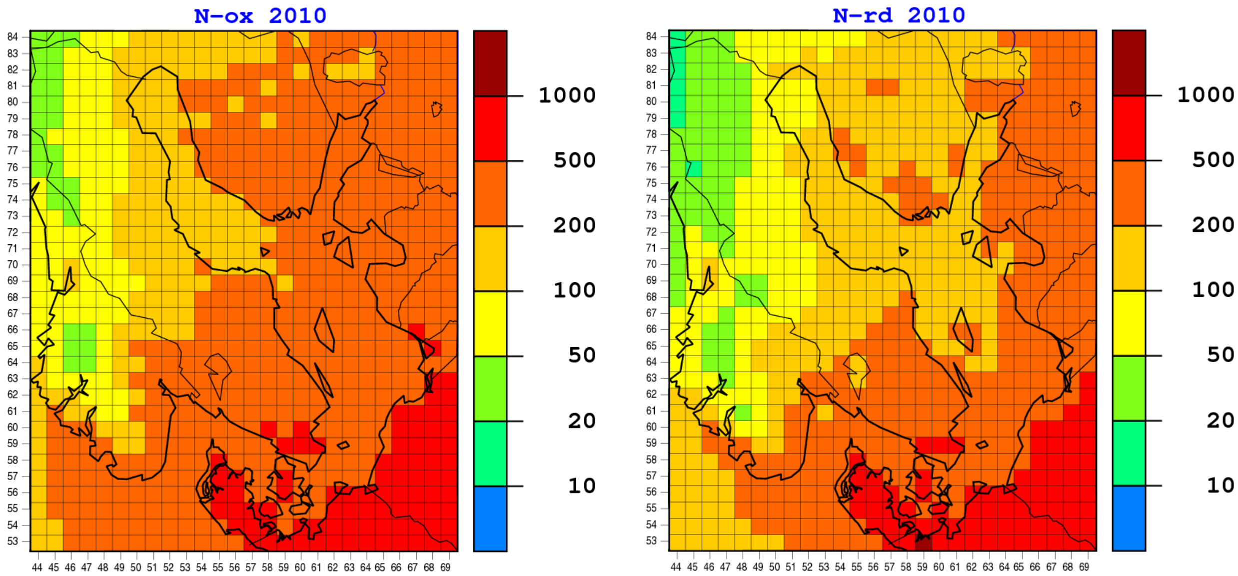


Figure 9.5 The maps of annual oxidized nitrogen deposition (left) and annual reduced nitrogen deposition (right) in the year 2010. Unit: tonnes N per year and per model grid cell.

Table 9.7. Annual 2010 deposition of oxidized, reduced and total nitrogen to each of nine sub-basins of the Baltic Sea and to the entire Baltic Sea basin. Units: kilo tonnes per year. (Source: Bartnicki & Valiyaveetil 2013)

Nitrogen deposition	BOB	BOS	ARC	GUF	GUR	BAP	WEB	SOU	KAT	Entire Baltic Sea
Oxidized	5.4	12.8	3.5	8.4	5.9	71.1	7.5	1.0	8.8	124.2
Reduced	3.8	7.7	2.2	5.2	4.1	51.8	9.9	0.9	8.8	94.4
Total	**9.1**	**20.4**	**5.7**	**13.6**	**10**	**122.9**	**17.4**	**1.9**	**17.6**	**218.6**

9.3.3. Monthly depositions

As was mentioned earlier, the deposition files for oxidized-dry, oxidized-wet, reduced-dry and reduced-wet nitrogen, shown in in the computational diagram in Figure 9.3, include not only annual values but monthly values as well. The post-processing program (Figure 9.3) is using these files as input to calculate monthly depositions of oxidized, reduced and total nitrogen to each sub-basin of the Baltic Sea, and to the entire basin of the Baltic Sea. An example of such calculations for the year 2010 is shown in **Figure 9.6.**

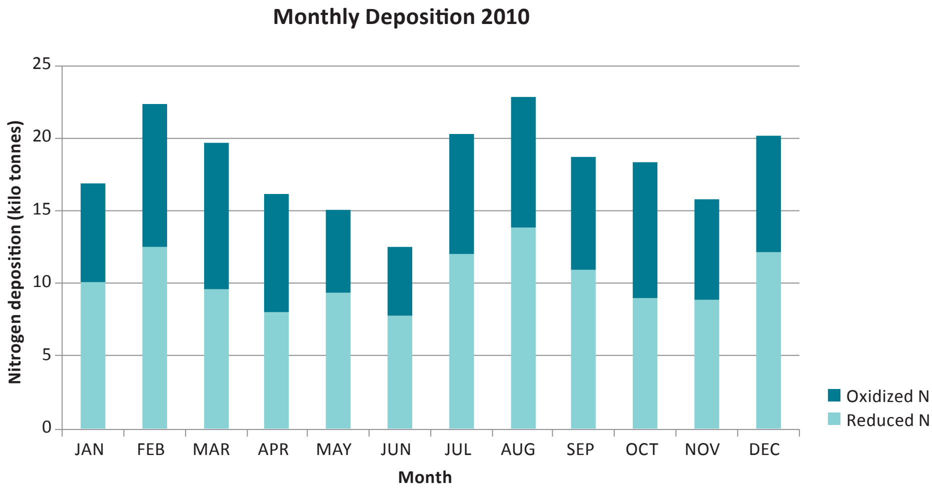


Figure 9.6. An example of monthly deposition to the Baltic Sea for the year 2010, as computed by the EMEP MSC-W model.

9.3.4. Contributions from individual sources

The procedure for calculating contribution of individual emission sources to nitrogen deposition is a bit complicated in that sense that nitrogen deposition depends not only on nitrogen emissions, but other emissions as well (EMEP Status Report, 2006). As emission sources we consider both country sources (emissions from individual EMEP contracting Parties) and other sources (international ship emissions, volcanoes etc.). There are altogether 55 country sources and other sources that are taken into account in the EMEP model calculations every year.

To calculate the contributions from individual sources to nitrogen deposition into the Baltic Sea and its sub-basins the model is run with complete emissions first. In the next step, four model runs are performed for each contributing source. In the first run emissions of nitrogen oxides from the source under consideration are reduced by 15%. In the second run, emissions of ammonia are reduced by 15%. In the third model run, VOC emissions are reduced by 15% and finally in the fourth run emissions of SO_x are reduced by 15%. Atmospheric deposition of oxidized dry, oxidized wet, reduced dry and reduced wet nitrogen is calculated for each of the model runs. The contribution of country (or other source) ***n*** to oxidized nitrogen deposition to each grid of the model domain is calculated as:

$$d^{n}_{oxdry}(i,j) = \Big[\Big(d^{tot}_{oxdry}(i,j) - d^{SOx-15\%}_{oxdry}(i,j)\Big) + \Big(d^{tot}_{oxdry}(i,j) - d^{NOx-15\%}_{oxdry}(i,j)\Big) + \Big(d^{tot}_{oxdry}(i,j) - d^{NO3-15\%}_{oxdry}(i,j)\Big) + \Big(d^{tot}_{oxdry}(i,j) - d^{VOC-15\%}_{oxdry}(i,j)\Big)\Big] \times \frac{100}{15} \qquad (1)$$

where:

$d^{n}_{oxdry}(i,j)$ - is the contribution of source n to oxidized nitrogen deposition in model grid ***(i,j)***,

$d^{tot}_{oxdry}(i,j)$ - is the oxidized nitrogen deposition in model grid ***(i,j)*** calculated with all emission sources,

$d^{SOx-15\%}_{oxdry}(i,j)$ - is the deposition calculated with 15% reduction of SO_x emissions in source ***n***,

$d^{NOx-15\%}_{oxdry}(i,j)$ - is the deposition calculated with 15% reduction of NO_x emissions in source ***n***,

$d^{NH3-15\%}_{oxdry}(i,j)$ - is the deposition calculated with 15% reduction of ammonia emissions in source ***n***,

$d^{VOC-15\%}_{oxdry}(i,j)$ - is the deposition calculated with 15% reduction of VOC emissions in source ***n***.

The same procedure is used to calculate contributions of source ***n*** to oxidized wet - $d^{n}_{oxwet}(i,j)$, reduced dry - $d^{n}_{rddry}(i,j)$ and reduced wet - $d^{n}_{rdwet}(i,j)$ nitrogen deposition to each grid of the EMEP model. The contribution of the source ***n*** to nitrogen deposition into the Baltic Sea is calculated as a sum of contributions from each model grid square belonging to the Baltic Sea basin. For example, contribution of source n to oxidized nitrogen deposition into the Baltic Sea is calculated in the following way:

$$D^{n}_{oxdry} = \sum_{(i,j)\in Baltic} \Big(d^{n}_{oxdry}(i,j) \times S(i,j)\Big) \qquad (2)$$

Where D^{n}_{oxdry} is the contribution of source ***n*** to deposition of oxidized dry nitrogen into the Baltic Sea basin and $S(i,j)$ is the surface of the grid ***(i,j)*** belonging to the Baltic Sea basin. Similar calculations are made for contribution of source n to oxidized wet - D^{n}_{oxwet}, reduced dry - D^{n}_{rddry} and reduced wet - D^{n}_{rdwet} nitrogen deposition. The most important for HELCOM are depositions of oxidized nitrogen - D^{n}_{ox}, reduced nitrogen – D^{n}_{rd} and total nitrogen - D^{n}_{tot} to the Baltic Sea basin. These depositions are defined as:

$$D^n_{ox} = D^n_{oxdry} + D^n_{oxwet}$$

$$D^n_{rd} = D^n_{rddry} + D^n_{rdwet}$$

$$D^n_{tot} = D^n_{ox} + D^n_{rd} \qquad (3)$$

The calculations described by Equations (1)-(3) are performed for all emissions sources in the EMEP domain in order to calculate all contributions. The sum of these contributions is equal to total deposition of nitrogen to the Baltic Sea basin.

9.3.5. Source-receptor matrices

Assuming linearity, or at least local linearity, the source-receptor matrices describe the relation between emissions of nitrogen in the EMEP sources and nitrogen deposition to the Baltic Sea basin. With the simplified linearity assumption, the source-receptor matrices are defined in the following as:

$$A_{ij}(iy) = \frac{D_i(iy)}{E_j(iy)}$$

where:

$E_j(iy)$ - is the annual emission from the source ***j*** in year ***iy***,

$D_i(iy)$ - is the annual deposition in the receptor ***i*** in year ***iy***,

$A_{ij}(iy)$ - is the source-receptor matrix for the year ***iy***,

The source-receptor matrix gives the amount of annual emission in the source **j** deposited in the receptor I for a given year. The dimension of the source-receptor matrix for a given year is

$(ne \times ns)$,

where ***ne*** is the number of receptors and ***ns*** is the number of emission sources. In our case, we are only interested in one receptor, namely the Baltic Sea basin and the index ***I*** can be omitted. In this case, the source-receptor matrices for oxidized and reduced nitrogen becomes vectors and are defined as:

$$A_i^{ox}(iy) = \frac{D_i^{ox}(iy)}{E_i^{ox}(iy)}$$

$$A_i^{rd}(iy) = \frac{D_i^{rd}(iy)}{E_i^{rd}(iy)} \qquad (4)$$

where:

$E_i^{ox}(iy)$ - is the annual emission of nitrogen oxides from the source ***i*** in the year ***iy***,

$E_i^{rd}(iy)$ - is the annual emission of ammonia from the source ***i*** in the year ***iy***,

$D_i^{ox}(iy)$ - is the annual deposition of oxidized nitrogen from the source ***I*** in the year ***iy***,

$D_i^{rd}(iy)$ - is the annual deposition of reduced nitrogen from the source ***I*** in the year ***iy***,

$A_i^{ox}(iy)$ - is the source-receptor matrix (vector) for oxidized nitrogen the year ***iy***,

$A_i^{rd}(iy)$ - is the source-receptor matrix (vector) for reduced nitrogen for the year ***iy***.

The total nitrogen deposition to the Baltic Sea basin in the year ***iy*** can be calculated as:

$$D^{tot}(iy) = D^{ox}(iy) + D^{rd}(iy) = \sum_{i=1}^{ns1} A_i^{ox}(iy) \times E_i^{ox}(iy) + \sum_{i=1}^{ns2} A_i^{rd}(iy) \times E_i^{rd}(iy) \quad (5)$$

Where

$D^{ox}(iy)$ and $D^{rd}(iy)$

is the annual total deposition of oxidized and reduced nitrogen, respectively, to the Baltic Sea in the year iy. The numbers of emission sources contributing to oxidized nitrogen deposition (*ns1*) and reduced nitrogen (*ns2*) are different in general, because some sources (e.g. ship traffic) emit only oxidized nitrogen.

9.3.6. Normalized depositions

The calculated nitrogen depositions to the Baltic Sea vary from one year to another, not only because of different emissions, but also because of different meteorological conditions for each year. Some model runs with constant emissions and variable meteorology performed for 12 years period (Bartnicki et al. 2011) show that calculated annual nitrogen depositions can differ up to 60% for different years. Therefore, the best way to reduce the influence of meteorology on computed annual nitrogen depositions would be to run the EMEP model with the same emissions from one particular year, but with all available different meteorological years and then average the results over the years or calculate the median depositions. The annual depositions calculated in this way can be called as "normalized" in the sense of meteorological variability. Unfortunately, the direct calculations of "normalized" nitrogen depositions are difficult, time consuming and expensive. Therefore, a simplified approach was applied using the source-receptor matrices for oxidized and reduced nitrogen, described in the previous section. The source receptor matrices differ from one year to another depending mainly on meteorological conditions. Therefore, they are often used for prediction of future depositions with a given scenario when meteorological conditions are not known. They have been also used in our approach for calculating normalized depositions to the Baltic Sea basin. In this approach, we have used the source-receptor matrices and depositions as defined in Eq. (5-6) and calculated for each of 16-year period 1995-2010 with available EMEP model runs. The "normalized" depositions to the Baltic Sea were calculated for oxidized, reduced and total nitrogen and for each year of the period 1995-2010. In the first step of this process, the annual depositions were calculated for each combination of meteorological and emission year:

$$D^{ox}(ie,im) = \sum_{i=1}^{ns1} A^{ox}(im) \times E^{ox}(ie) + R^{ox}(ie,im)$$

$$D^{rd}(ie,im) = \sum_{i=1}^{ns2} A^{rd}(im) \times E^{rd}(ie) + R^{rd}(ie,im) \quad (6)$$

Terms

$R^{ox}(ie,im)$ and $R^{rd}(ie,im)$

are introduce mainly because of the contribution of BIC (Boundary and Initial Conditions) in the model calculations, additional source for which emissions cannot be specified. For the Baltic Sea basin this additional source is only contributing to oxidized nitrogen deposition, so

$R^{rd}(ie,im) = 0$

The normalized deposition of total nitrogen for the emission year ***ie*** - ***DN(ie)*** is defined as:

$$DN(ie) = MED\left\{D^{ox}(ie,1) + D^{rd}(ie,1),...,D^{ox}(ie,im) + D^{rd}(ie,im),...,D^{ox}(ie,16) + D^{rd}(ie,16)\right\}$$

Where MED is the median take over 16 values which correspond to 16 meteorological years. In addition, the maximum and minimum values are also calculated for each emission year. The results of these calculations for the years 1995-2010 are shown in **Figure 9.7** for oxidized, reduced and total nitrogen deposition.

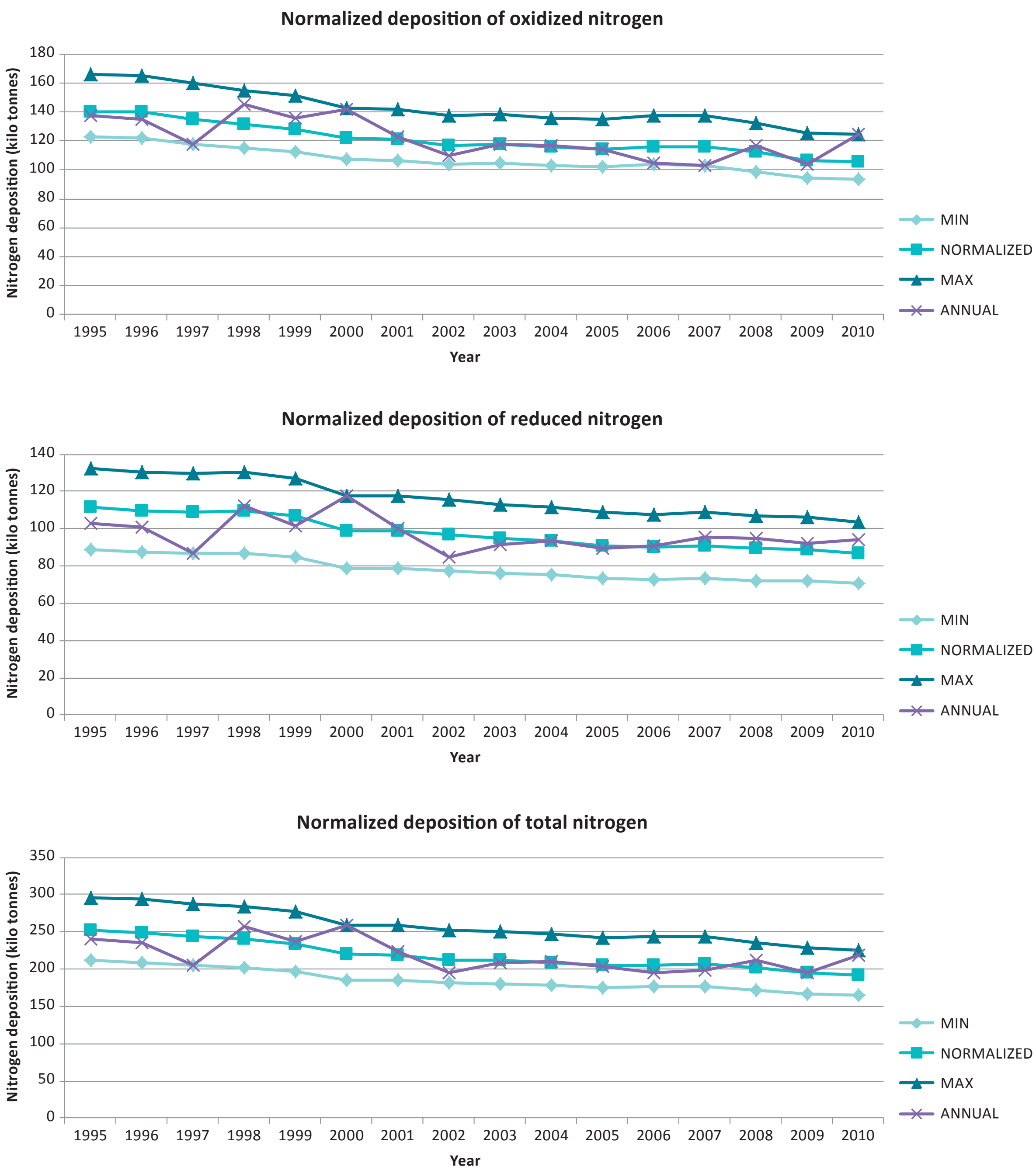


Figure 9.7. Normalized depositions of oxidized (top), reduced (middle) and total (bottom) nitrogen for the period 1995-2010. Minimum, maximum and actual annual values of the deposition are also shown.

9.4. Annex 4 - Normalization of riverine inputs (flow normalization)

The annual riverine inputs of nutrients show large variations between reported years. Variation in water flow is one main reason behind annual variations in riverine inputs and is mainly caused by meteorological conditions effecting hydrological factors such as precipitation including accumulation and melting of snow/ice, evapotranspiration, but also anthropogenic damming will effect water flow etc. In order to remove at least the main part of the variation introduced by hydrological factors the annual nutrient inputs are flow normalized. It has to be pointed out that care must be taken when normalizing data when there is a large impact in the calculated inputs from point sources, especially during periods with low water flow. Normalization should therefore not be applied on inputs from point sources discharging directly to the sea or only with care when point sources have a significant impact on the riverine inputs.

Normalization of riverine inputs is a statistical process/method and the result of the normalization is a new time series of nutrient inputs with the major part of the variation due to hydrology, removed. The normalized time series has a reduced between-year variation, which results in a much more precise trend analysis. Any significant trends in the normalized series can now be more probably attributed to the effect of human activities.

Different methods for normalizing inputs are described in Silgram and Schoumans (2004) in Chapter 4. In this report we focus on methods based on empirical data. The empirical hydrological normalization method is based on the regression of the annual loads and the annual water flow, so in fact the method normalizes the loads to average water flow (averaged over the time series period). In this way the variation from the annual amount of water flow is removed - the effect of differences in the distribution of water flow over the year is not removed. In Silgram and Schoumans (2004) they base the normalization on un-transformed loads and water flows. In our experience the regression explains slightly more of the variation if both the annual inputs and the annual water flows are transformed by the natural logarithmic function before normalizing.

The hydrological normalization should be seen as a kind of prerequisite for analysing trends and the trend analysis is done in two parts (two steps) with the first step being the normalization and the second step the actual trend analysis.

According to Silgram and Schoumans (2004) the empirical hydrological normalization method should be based on the linear relationship between annual water flow (Q) and annual load (L) of a nutrient

$$L_i = \alpha + \beta \cdot Q_i + \varepsilon_i , \quad (4.1)$$

where α and β are parameters associated with linear regression and εi stands for the residual/error in the linear regression. Then the normalized load is calculated as

$$L_{iN} = L_i - (Q_i - \bar{Q}) \cdot \hat{\beta} , \quad (4.2)$$

where $\bar{Q}$ is the average river flow for the whole time series period. To avoid possible negative loads use the formula

$$L_{iN} = L_i \cdot \frac{\hat{\alpha} + \hat{\beta} \cdot \bar{Q}}{\hat{\alpha} + \hat{\beta} \cdot Q_i} , \quad (4.3)$$

Normally the relationship is modelled after ln-ln transformation, which decrease the influence of large loads and water flow, and which results in a slightly more precise fit with residuals more likely to be Gaussian distributed, which is a statistical prerequisite for the regression method. So the normalization needs to be done on the basis on of a ln-ln regression between load and river flow:

$$\ln L_i = \alpha + \beta \cdot \ln Q_i + \varepsilon_i, \quad (4.4)$$

This gives the following formulae for normalized loads

$$L_{iN} = \exp\left(\ln L_i - (\ln Q_i - \overline{\ln Q}) \cdot \hat{\beta}\right) \cdot \exp(0.5 \cdot \mathrm{MSE}), \quad (4.5)$$

or to avoid negative loads

$$L_{iN} = \exp\left(\ln L_i \cdot \frac{\hat{\alpha}+\hat{\beta} \cdot \overline{lnq}}{\hat{\alpha}+\hat{\beta} \cdot \ln Q_i}\right) \cdot \exp(0.5 \cdot \mathrm{MSE}). \quad (4.6)$$

In the above formula (4.6) "ln" is the natural logarithmic function, "exp" the exponential function and MSE stands for Mean Squared Error and is derived by the regression analysis (Snedecor and Cochran, 1989). The MSE is normally calculated in every standard statistical software and is defined as

$$\mathrm{MSE} = \frac{1}{n-2} \sum_{i=1}^{n} \left(\ln L_i - (\hat{\alpha} - \hat{\beta} \cdot \ln Q_i)\right)^2,$$

where n is the number of observations in the time series.

The factor "exp(0.5•MSE)" in the formulae is a bias correction factor and is derived as described by Ferguson (1986). The factor is needed in order to back-transform to a mean value and not to the geometric mean as is done without the factor. The main reason for transforming by the natural logarithmic function is that the variance among residuals is stabilized. Without the transformation residuals are often distributed with a heavy tail to the right. Formula (4.6) is the recommended method for PLC-5.5 and onwards.[9]

The use of the natural logarithmic function has a more solid foundation in statistics than the base 10 logarithmic function. In principle, the presented methods can be applied even with a significant trend in the river flow time series as long as the relationship between river flow and load is unchanged. Usually the relationship changes with a significant change in the amount of river flow over time. This implies that a trend analysis of the river flow time series is needed in order to determine whether an upward or downward trend in the flow is present. If a trend in the river flow is present we refer to Silgram and Schoumans (2004) for a method for normalizing loads in this situation.

In general the differences between the methods are small, but especially for time series with a large year-to-year variation, methods without a correction term will give biased values with an underestimation of the normalized loads. This can have an unwanted effect when testing fulfilment of targets.

It is best to carry out the hydrological normalization catchment-wise, i.e. nutrient loads are normalized for each catchment separately. Is the normalization done country-wise or sub-basin-wise, the result will not be the same as when the catchment-wise normalized nutrient loads are summed to country or sub-basin level.

9 In PLC-5 the following method was used:

$$\log_{10} L_{iN} = \log_{10} L_i \cdot \frac{\hat{\alpha}+\hat{\beta} \cdot \overline{\log_{10} Q}}{\hat{\alpha}+\hat{\beta} \cdot \log_{10} Q_i}, \quad (4.7)$$

and then using the power function to back transform formula 4.7. This method gives normalized loads which are slightly too low.

Some further details on flow normalization is given in the report "Statistical Aspects in relation to Baltic Sea Pollution Load Compilation" (Larsen & Svendsen, 2013).

The procedure for normalizing a time series of loads is as follows:

1. Transform the load and runoff time series by the natural logarithmic function (ln) to get the series $\{\ln L_i\}$ and $\{\ln Q_i\}$.

2. Calculate the mean of $\{\ln Q_i\}$ to get $\overline{\ln Q}$.

3. Estimate parameters α and β by linear regression $\ln L_i = \alpha + \beta \cdot lnQ_i + \varepsilon_i$, to get $\hat{\alpha}$ and $\hat{\beta}$.

4. Calculate MSE by $\frac{1}{n-2} \sum_{i=1}^{n} \left(\ln L_i - (\alpha - \beta \cdot \ln Q_i)\right)^2$.

5. Calculate normalized loads as $L_{iN} = \exp\,(\ln L_i - (\ln Q_i - \overline{\ln Q}) \cdot \hat{\beta}) \cdot \exp\,(0.5 \cdot \mathrm{MSE})$

or as $L_{iN} = \exp\left(\ln L_i \cdot \frac{\hat{\alpha} + \hat{\beta} \cdot \overline{lnq}}{\hat{\alpha} + \hat{\beta} \cdot \ln Q_i}\right) \cdot \exp\,(0.5 \cdot \mathrm{MSE})$

to avoid the negative normalized loads.

9.5. Annex 5 - List of definitions and abbreviations

Airborne (or windborne)	Nutrients carried or distributed by air.
AIS	Automatic Identification System with devices on ships that allow for real-time surveillance and statistics of movement of ships.
Anthropogenic	Caused by human activities.
ARC	Archipelago Sea
Atmospheric deposition	Airborne nutrients or other chemical substances originating from emissions to the air and deposited from the air on the surface (land and water surfaces).
BAP (or BP)	Baltic Proper
BAS	The entire Baltic Sea (as a sum of the Baltic Sea sub-basins). See the definition of sub-basins.
BNI	Baltic Nest Institute, Stockholm University, Sweden.
BOB (or BB)	Bothnian Bay
BOS (or BS)	Bothnian Sea
BSAP	Baltic Sea Action Plan
BY	Belarus
Catchment area	The area of land bounded by watersheds draining into a body of water (river, basin, reservoir, sea).
Contracting Parties	Signatories of the Helsinki Convention (Denmark, Estonia, European Commission, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden).
Country-Allocated Reduction Targets (CART)	Country-wise requirements to reduce waterborne and airborne nutrient inputs (in tonnes per year) to reach the maximum allowable nutrient input levels in accordance to the Baltic Sea Action Plan.
DCE	Danish Centre for the Environment and Energy, Aarhus University, Denmark.
DE	Germany
Diffuse sources	Sources without distinct points of emission e.g. agricultural and forest land, natural background sources, scattered dwellings, atmospheric deposition (mainly in rural areas)
DIN and DIP	Dissolved inorganic nitrogen and dissolved inorganic phosphorus compounds.
Direct Sources	Point sources discharging directly to coastal or transitional waters.
DK	Denmark
DS	Danish Straits
EE	Estonia
EMEP	Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
Eutrophication	Condition in an aquatic ecosystem where increased nutrient concentrations stimulate excessive primary production, which leads to an imbalanced function of the ecosystem.
FI	Finland
Flow normalization	A statistical method that adjusts a data time series by removing the influence of variations imposed by river flow, e.g. to facilitate assessment of development in e.g. nitrogen or phosphorus inputs.
FR	France
GB	Great Britain
GUF (or GF)	Gulf of Finland
GUR (or GR)	Gulf of Riga
Input ceiling	The allowable amount of nitrogen and phosphorus input per country and sub-basin. It is calculated by subtracting the national CART from the input of nitrogen and phosphorus during the reference period of the BSAP (1997-2003).
KAT (or KT)	Kattegat
HELCOM LOAD	HELCOM Expert Group on follow-up of national progress towards reaching BSAP nutrient reduction targets
LT	Lithuania
LV	Latvia

Maximum Allowable Input (MAI)	The maximum annual amount of a substance that a Baltic Sea sub-basin may receive and still fulfil HELCOM's ecological objectives for a Baltic Sea unaffected by Eutrophication.
Monitored areas	The catchment area upstream of the river monitoring station. The chemical monitoring decides the monitored area in cases where the locations of chemical and hydrological monitoring stations do not coincide.
Monitoring stations	Stations where hydrographic and/or chemical parameters are monitored.
MSFD	EU Marine Strategy Framework Directive
MWWTP	Municipal wastewater treatment plant
NL	Netherlands
Non-contracting parties	Countries that are not partners to the Helsinki Convention 1992, but t hat have an indirect effect on the Baltic Sea by contributing with inputs of nutrients or other substances via water and/or air.
NOS	North Sea Shipping
OC	Other countries (sources of transboundary inputs)
PL	Poland
PLC	Pollution Load Compilation
Point sources	Municipalities, industries and fish farms that discharge (defined by location of the outlet) into monitored areas, unmonitored areas or directly to the sea (coastal or transitional waters).
QA	Quality assurance
Reference period	1997-2003
Reference input	The average normalized water + airborne input of nitrogen and phosphorus during 1997-2003 used to calculate CART and input ceilings.
Retention	The amount of a substance lost/retained during transport in soil and/or water including groundwater from the source to a recipient water body. Often retention is only related to inland surface waters in these guidelines.
Riverine inputs	The amount of a substance carried to the maritime area by a watercourse (natural or man-made) per unit of time.
RU	Russia
SOU	The Sound
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 a result to occur by chance is less than 5%.
Sub-basins	Sub-division units of the Baltic Sea: the Kattegat (KAT), Belt Sea (BES), Western Baltic (WEB), Baltic Proper (BAP), Gulf of Riga (GUR), Gulf of Finland (GUF), Archipelago Sea (ARC) Bothnian Sea (BOS) and Bothnian Bay (BOB). The whole Baltic Sea is abbreviated BAS.
SE	Sweden
SS	Baltic Sea Shipping
Transboundary input	Transport of an amount of a substance (via air or water) across a country border.
TN and TP	Total nitrogen and total phosphorus which includes all fractions of nitrogen and phosphorus.
Unmonitored area	Any sub-catchment(s) located downstream of the (riverine) chemical monitoring point within the catchment and further all unmonitored catchments; e.g. partly monitored rivers, unmonitored part of monitored rivers, unmonitored rivers and coastal areas including unmonitored islands. In previous versions of the guidelines, direct diffuse sources (scattered dwellings and storm waters overflows) were reported separately and some countries also reported coastal areas separately. These are now reported as part of the unmonitored area.
Waterborne	Substances carried or distributed by water.
WEB	Archipelago Sea
WFD	EU Water Framework Directive

HELCOM

www.helcom.fi