BSEFS

Atmospheric nitrogen deposition to the Baltic Sea

Baltic Marine Environment
Protection Commission

Eutrophication

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Atmospheric nitrogen deposition to the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2024

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Key Message

Airborne nitrogen depositions to the Baltic Sea have been calculated for the 1990 – 2022 period with the EMEP MSC-W model at 0.1° x 0.1° resolution.

According to our model calculations, *actual* airborne depositions of oxidized, reduced and total nitrogen were, respectively, 49%, 25% and 40% lower in 2022 than in the reference period 1997 – 2003. There is a clear reduction in *normalized* depositions of nitrogen as well, which is consistent with the change in nitrogen emissions in the HELCOM area. Normalized depositions of oxidized, reduced and total nitrogen in 2022 were 45%, 20% and 35% lower than in the reference period 1997 – 2003.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This fact sheet presents calculated changes in atmospheric deposition of oxidized, reduced and total nitrogen to the Baltic Sea and its nine sub-basins during the 1990 – 2022 period. The calculations of deposition of nitrogen compounds are based on the emission data described in the BSEFS on “Atmospheric nitrogen emissions to the air in the Baltic Sea area”.

Policy relevance and policy references

The HELCOM Copenhagen Ministerial Declaration of 2013 on taking further action to implement the Baltic Sea Action Plan reconfirmed the need of reaching good environmental status for a healthy Baltic Sea. The declaration includes nutrient reduction targets, and thus also concerns airborne nitrogen input to the Baltic Sea. The Declaration sets targets on Maximum Allowed Inputs (MAI) covering both water- and airborne inputs. These targets are maintained in the updated Baltic Sea Action Plan of 2021.

The relevant policy to the control of emissions of nitrogen oxides and ammonia to the atmosphere on a global scale is set in the framework of the UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). For EU member states the policy frame is set by the EU NEC and IED Directives. For the Russian Federation the corresponding policy frame is embraced by Federal Acts on Environment Protection and the Protection of Atmospheric Air. The Gothenburg Protocol (1999, and amended in 2019) requires that nitrogen oxides emissions in 2020 should be reduced by between 18% and 56% in 31 countries with respect to 2005 annual emissions, with the largest relative reductions in Denmark (56%), the United Kingdom (55%) and France (50%). Ammonia emissions should also be reduced, but by smaller percentages (1% to 24%). The largest relative reductions of ammonia emissions should be in Denmark (24%), Finland (20%) and Sweden (15%). In the European Union, the revised Gothenburg Protocol is implemented by the EU NEC Directive 2016/2284/EU, which sets 2020 and 2030 emission reduction commitments for five main air pollutants, including nitrogen oxides and ammonia. The Gothenburg Protocol has recently undergone a review process that will most likely result in a new revision.

Assessment

Atmospheric depositions of oxidized and reduced nitrogen for the period 1990 – 2022 reported here were computed in summer 2024 with the EMEP MSC-W model version rv5.3, using the latest available gridded and gap-filled emission data for the HELCOM countries and all other EMEP sources. The calculations were performed at 0.1° × 0.1° resolution (corresponding approximately to 11 km x 5.5 km at 60°N). Both land-based emissions and emissions from shipping are included in these calculations and have been tabulated in the BSEFS on “Atmospheric nitrogen emissions to the air in the Baltic Sea area”.

Time series of oxidized, reduced and total nitrogen depositions to the Baltic Sea with respect to the reference period of 1997 – 2003 are shown in Figure 1.

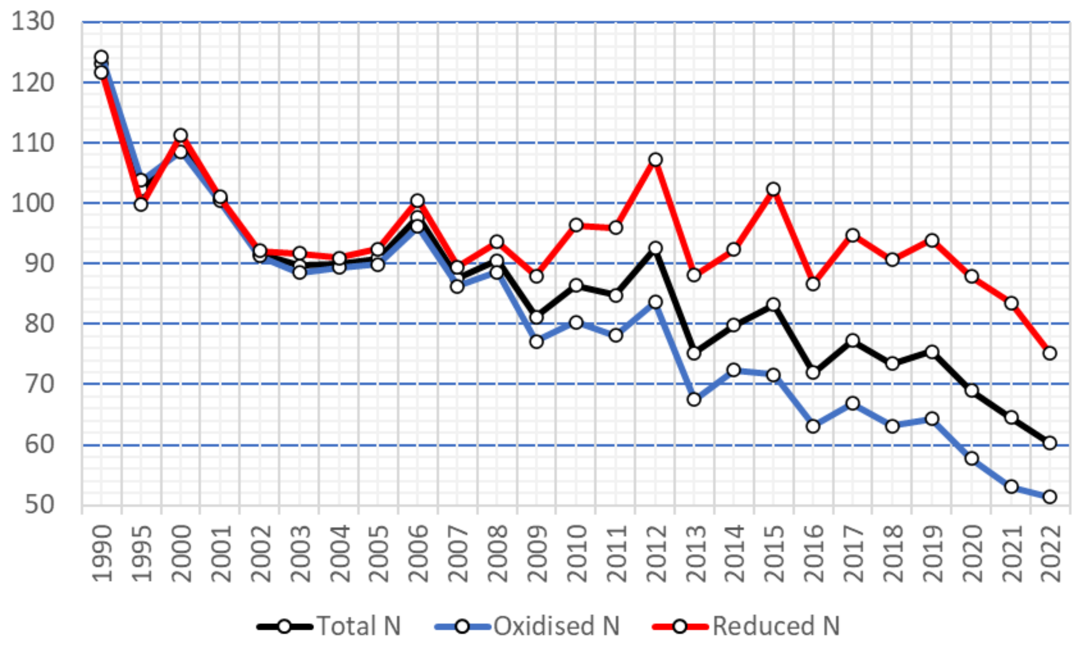

Figure 1. Atmospheric deposition of oxidized, reduced and total nitrogen to the entire Baltic Sea basin for the period 1990-2022, given as percentage of the average values for the 1997 – 2003 reference period.

Large interannual variability in all types of nitrogen deposition to the Baltic Sea basin is seen during the considered period, and large reductions in depositions are calculated for oxidized and total nitrogen in 2022, by 49% and 40%, respectively, as compared to the reference period 1997 - 2003. However, the annual deposition of *reduced* nitrogen was only 25% lower in 2022 than in the reference period 1997 - 2003.

Mainly related to interannual variability in meteorological conditions, nitrogen deposition to the Baltic Sea and its sub-basins varies strongly from year to year. Therefore, it has been common practice to ‘weather-normalize’ depositions to filter out the interannual variability in meteorology. The method is described in Appendix D of Bartnicki et al. (2017). Basically, for each year we ask the question as to what the nitrogen deposition *would have been* with one year’s emissions but with another year’s meteorology. For each year, we calculate the depositions for all other meteorological years by using *transfer coefficients*[1] for these years.

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[1] Transfer coefficients are a measure for how much of the emissions from one country is deposited to a given receptor area (in this case the Baltic Sea). Transfer coefficients largely depend on meteorology, the distance between the source and the receptor, but also on the chemical regime in the atmosphere.

Currently we have data on transfer coefficients for 28 years (1995-2022). In this way we can calculate 28 different deposition values for each emission year. We define the median among these values as the *normalized* deposition, but in addition report the minimum and maximum values for each year (Figure 2). The change in the normalized deposition largely reflects the changes in emissions and is thus most policy-relevant, while the deposition values in Figure 1 show the deposition values based on the respective year's *actual* meteorology, which is why we refer to them as 'actual deposition'.

An inspection of Figure 2 indicates a downward tendency in normalized total deposition of nitrogen, corresponding to the general downward tendency in nitrogen emissions in the HELCOM area, which is most relevant for nitrogen deposition to the Baltic Sea. Normalized depositions of oxidized, reduced, and total nitrogen in 2022 were 45%, 20% and 35% lower than in the reference period 1997 – 2003. It can also be noted that the actual depositions decreased more from 2021 to 2022 than did the normalized depositions. In particular, the 2022 actual depositions are all lower than the normalized ones for both oxidized and reduced nitrogen, indicating that the meteorology of this year was less favorable to nitrogen deposition to the Baltic Sea (averaged over all sub-basins).

Figure 3 shows results from this year's source-receptor analysis. The 12 most important contributors to total nitrogen deposition are shown, as well as the percentage share of each contribution to the total. The numbers in Figure 3 are normalized, and based on emissions of the year 2022.

In addition, numbers are given for how much of each country's emission is deposited to the Baltic Sea (Table 1). These numbers correspond to the transfer coefficients mentioned above and tend to be larger for sources that are close to the Baltic Sea or geographically located upwind of it, or both. However, there are many factors that determine the exact magnitude of transfer coefficients, such has meteorological conditions, the chemical lifetime of the species, and the location of emission sources with respect to receptor areas. For example, *reduced* nitrogen emitted several tens of kilometers away (and upwind) from the coast will have a smaller chance of being deposited to the sea than *oxidized* nitrogen because the latter has a longer chemical lifetime. However, if the emission source is located on the coast, the difference in lifetime may not have any effect because both reduced and oxidized nitrogen will be deposited to the sea located just downwind of the emission source. Indeed, if the adjacent sea area is narrow, e.g. the Kattegat, *reduced* nitrogen emitted from a Danish source close to the coast may even have a larger chance of being deposited to the sea than oxidized nitrogen, because the latter may have a sufficiently long lifetime to get transported to Sweden.

Calculated (actual) nitrogen depositions to the nine sub-basins of the Baltic Sea in the period 1990 – 2022 are presented in Figure 4, while Tables 2 and 3 list trends for actual and normalized depositions that are statistically significant at the 5% level (Mann-Kendall test). Slopes of the linear regression line are calculated for the whole 33-year period, for the 1990s and for the most recent decade. Trends in oxidized (and total) nitrogen are of clearly larger magnitude than those in reduced nitrogen, when the whole period is considered.

Compared to the reference period 1997 – 2003, actual depositions of oxidized nitrogen were clearly lower in 2022 (by 43 to 55%) in all sub-basins. The reduction is particularly large in WEB (55%), SOU (55%) and KAT (52%). Reductions in actual depositions of reduced nitrogen range from 17% (ARC) to 37% (SOU). Consequently, the deposition of total nitrogen was lower in 2022 compared to the reference period 1997 – 2003 in all sub-basins, with reductions ranging from 35% (ARC) to 48% (SOU). There is, however, a large interannual variability in annual nitrogen deposition to individual sub-basins.

For convenience, the definitions of the sub-basins, along with a map of the Baltic Sea, are given in Figure 5.

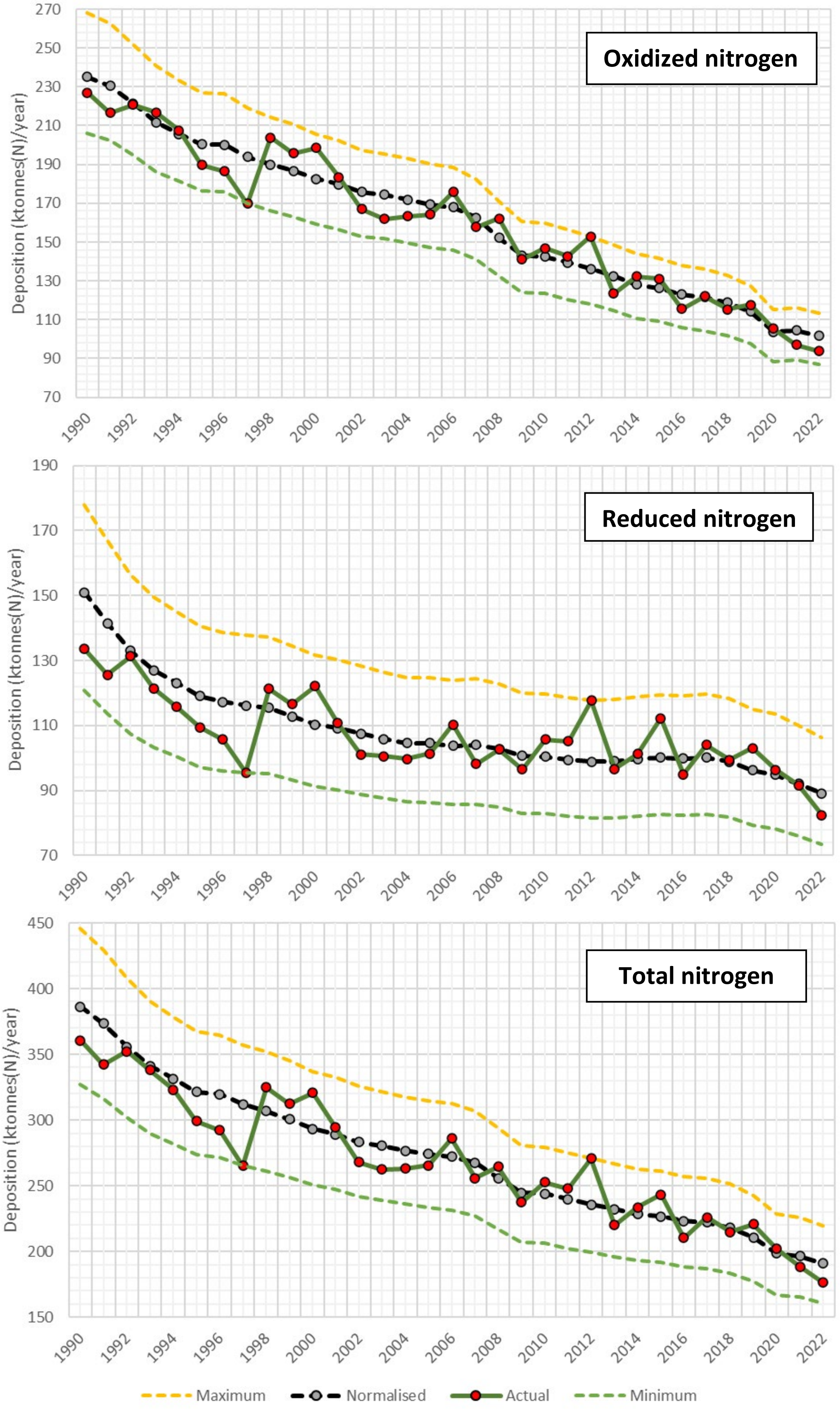


Figure 2. Normalized depositions of oxidized (top), reduced (middle) and total (bottom) nitrogen for the period 1990-2022, depicted by the black dashed line/grey dots. Unit: ktonnes(N)/year. Minimum, maximum and actual values of the depositions are also shown. The actual values correspond to the values listed in Tables 4, 5 and 6, while the normalized values are listed in Table 7. Note that the vertical scale does not start at zero, to make the variability more visible.

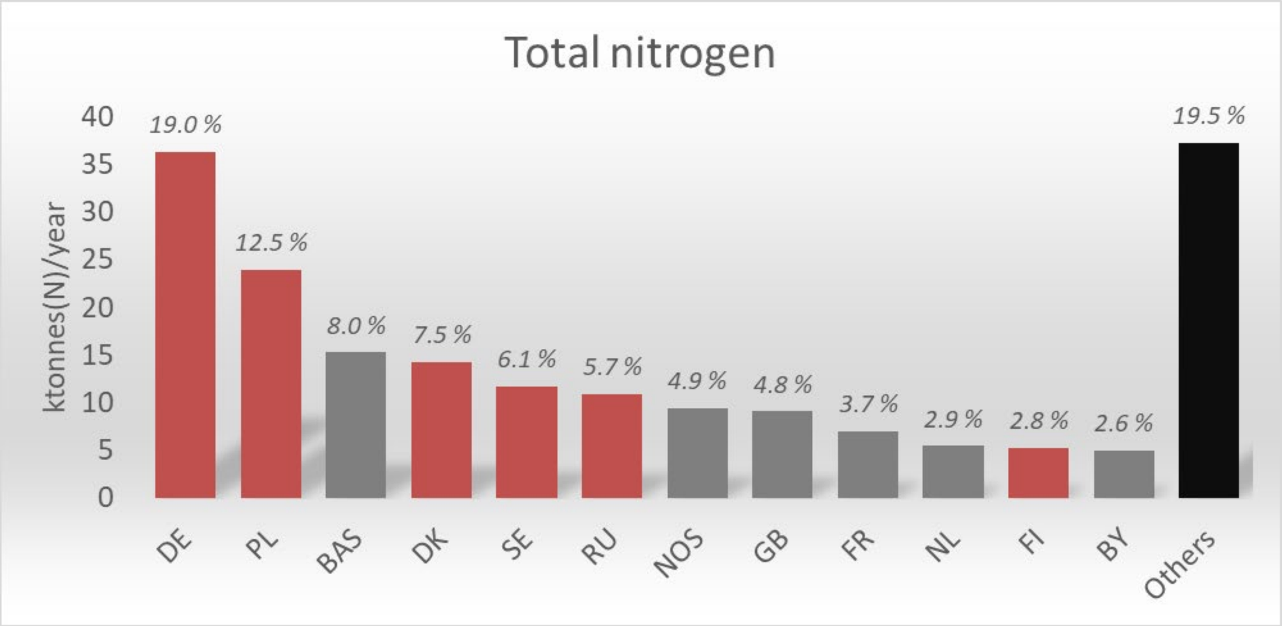
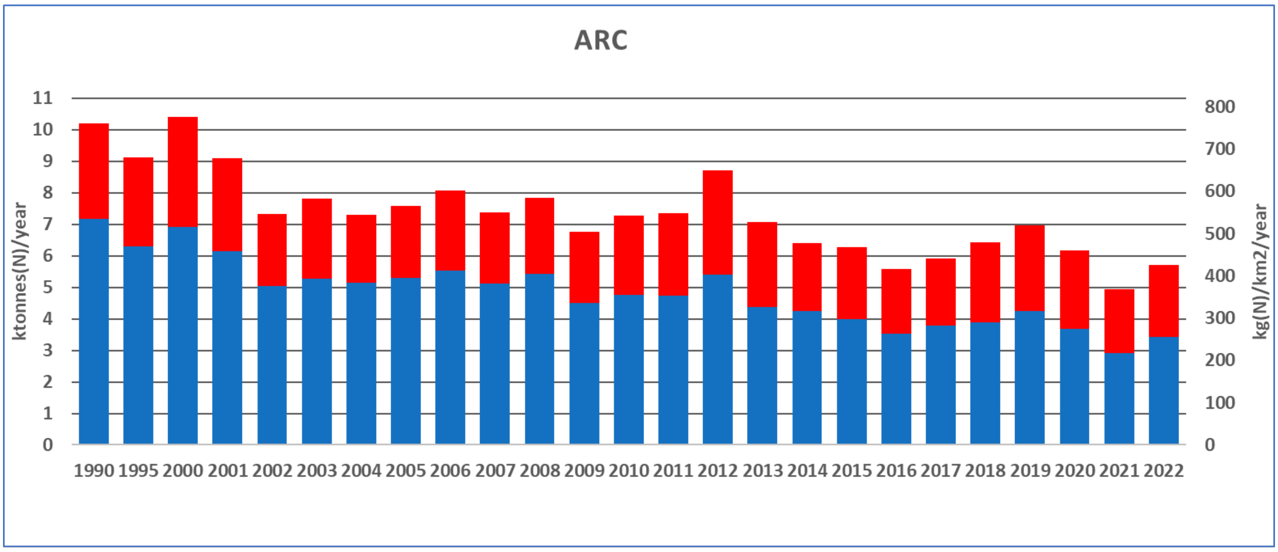
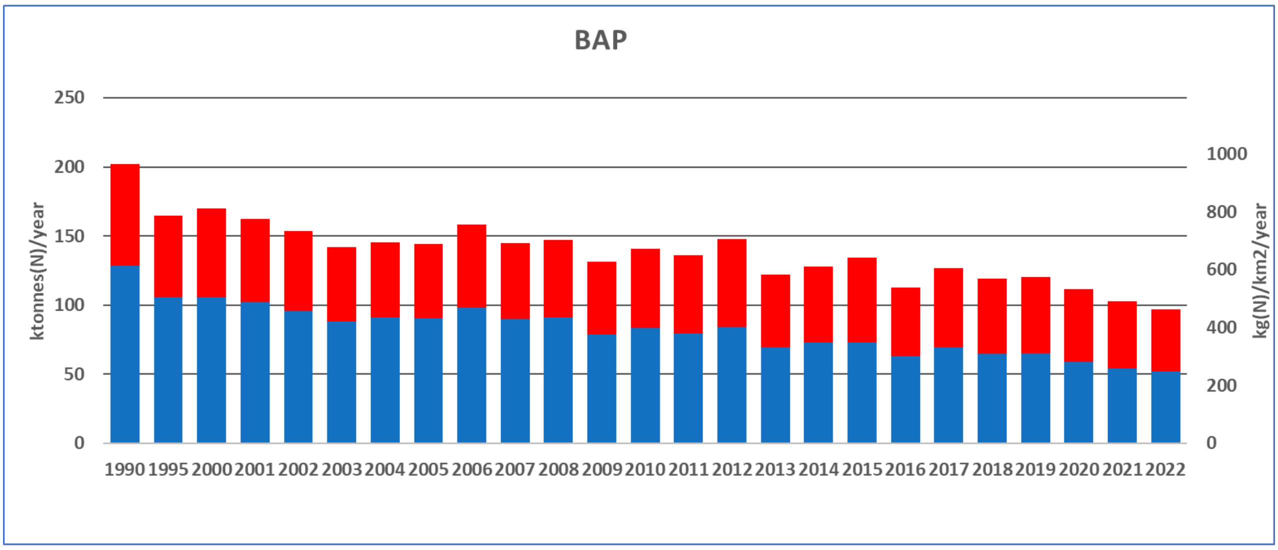


Figure 3. Bar chart showing the top-12 contributions to deposition of total airborne nitrogen to the Baltic Sea (NOS: North Sea Shipping; BAS: Baltic Sea shipping; GB: United Kingdom), based on emissions in the year 2022. “Others”: all countries and regions that are not among the indicated top-12 contributions. Red colour is used for HELCOM contracting parties. The numbers on top of each bar show the percentage share of each contribution to the total. Example: Denmark stands for 7.5% of the airborne nitrogen deposition to the Baltic Sea.

Table 1. Transfer coefficients for oxidized, reduced and total nitrogen from different countries. The table answers the question as to how large a percentage of each country’s domestic emissions is deposited to the Baltic Sea. Numbers are given for oxidized, reduced and total airborne nitrogen separately. Example: 10% of Estonia’s annual emission of oxidized nitrogen (NOx) is deposited to the Baltic Sea. All calculations are normalized and based on emissions of 2022.

	DK	EE	FI	DE	LV	LT	PL	RU	SE	BAS	NOS	FR	GB
Ox-N	10 %	10 %	8 %	5 %	9 %	8 %	7 %	0.7 %	11 %	18 %	5 %	1.6 %	3.0 %
Re-N	19 %	15 %	10 %	5 %	11 %	8 %	6 %	0.4 %	19 %	n.a.	n.a.	0.9 %	1.4 %
Tot-N	16 %	13 %	9 %	5 %	10 %	8 %	6 %	0.5 %	15 %	18 %	5 %	1.1 %	2.2 %





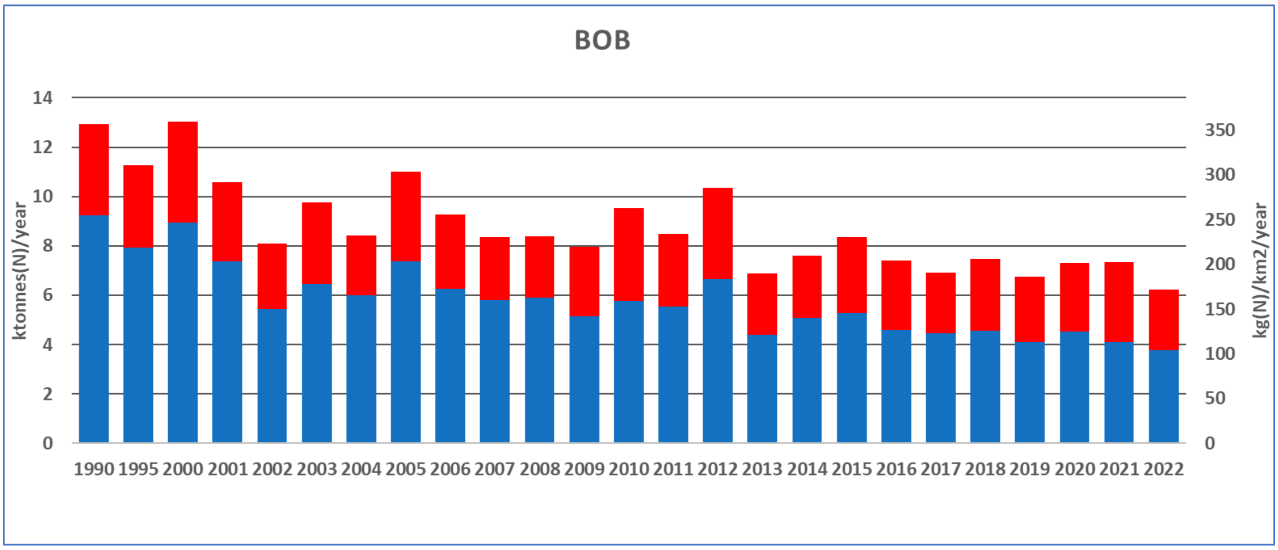
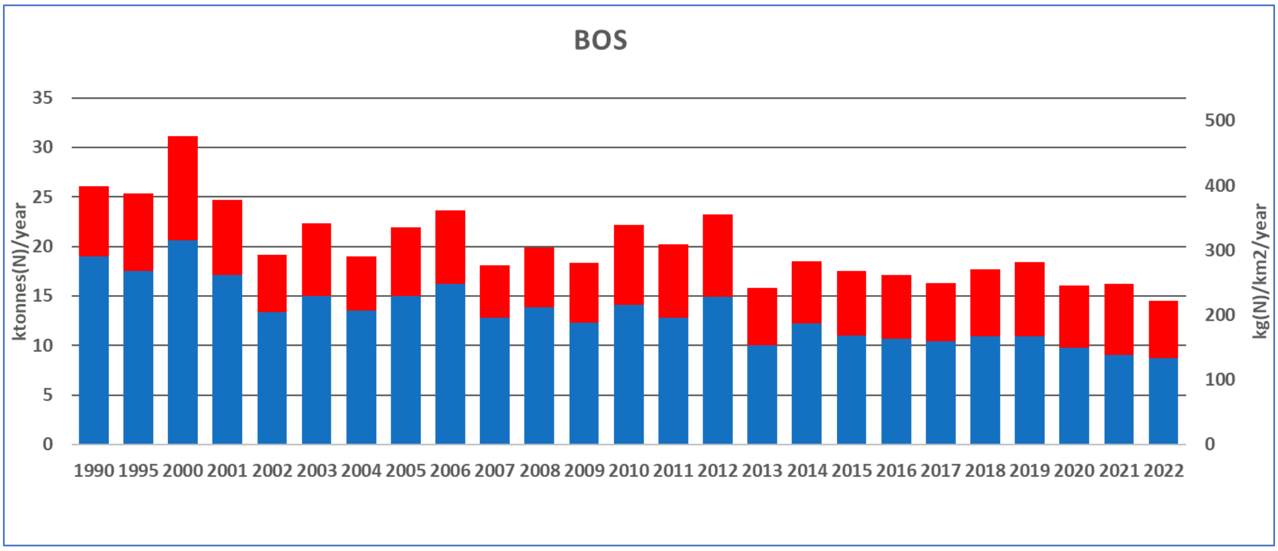
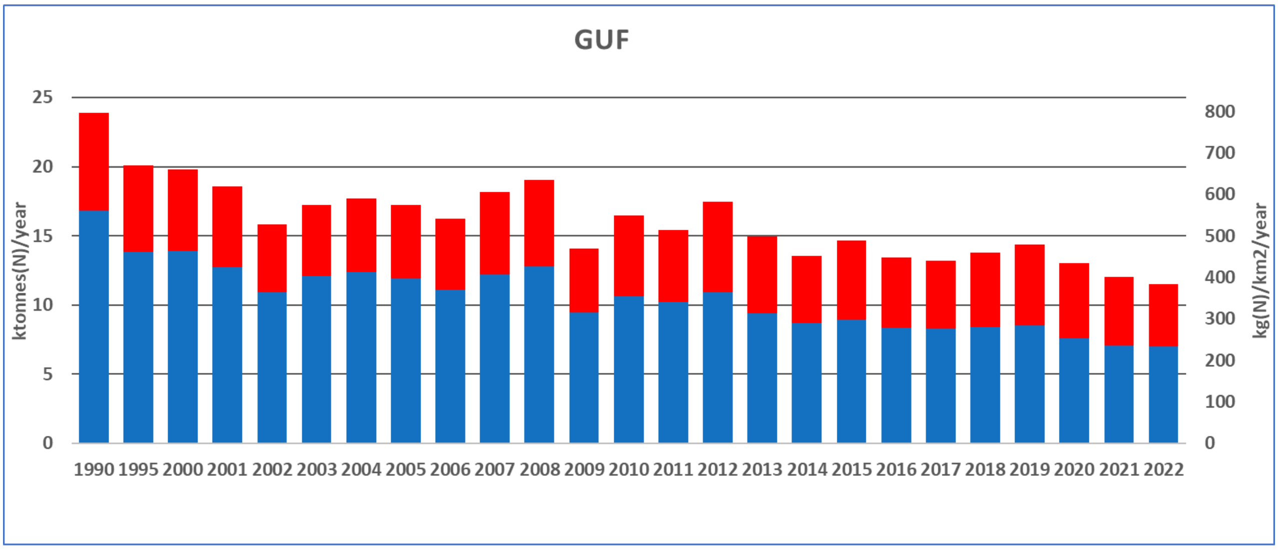


Figure 4. Atmospheric deposition of oxidized nitrogen (blue) and reduced nitrogen (red) to the nine sub-basins of the Baltic Sea in the period 1990 - 2022. Unit: ktonnes(N)/year. Note that the vertical scales in the plots are different. The figure continues on the next two pages. For definitions of sub-basins see Figure 5.





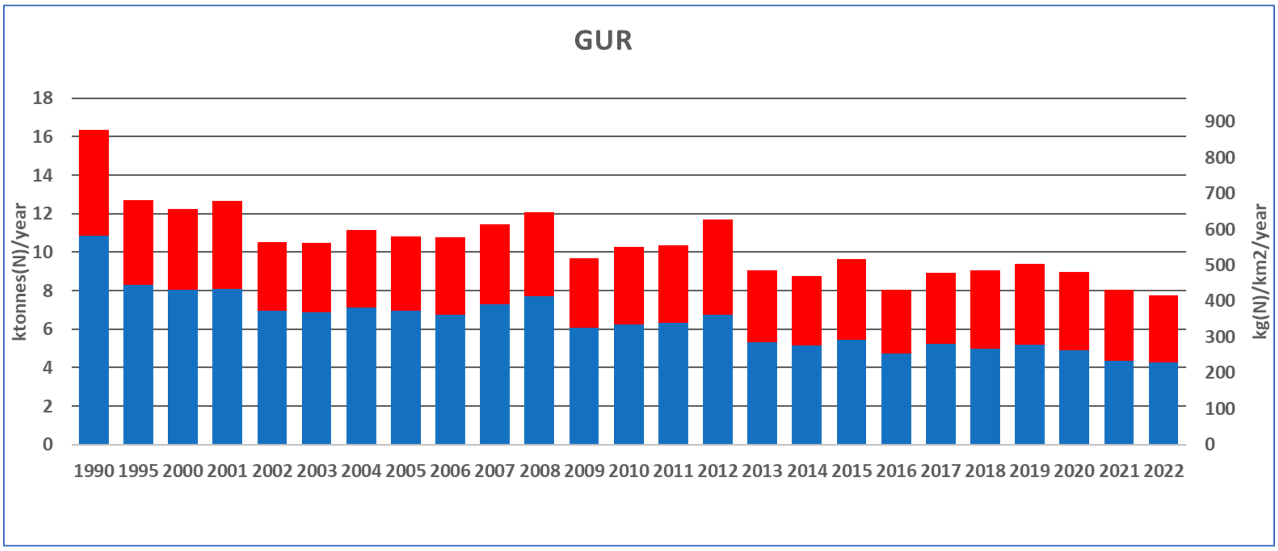
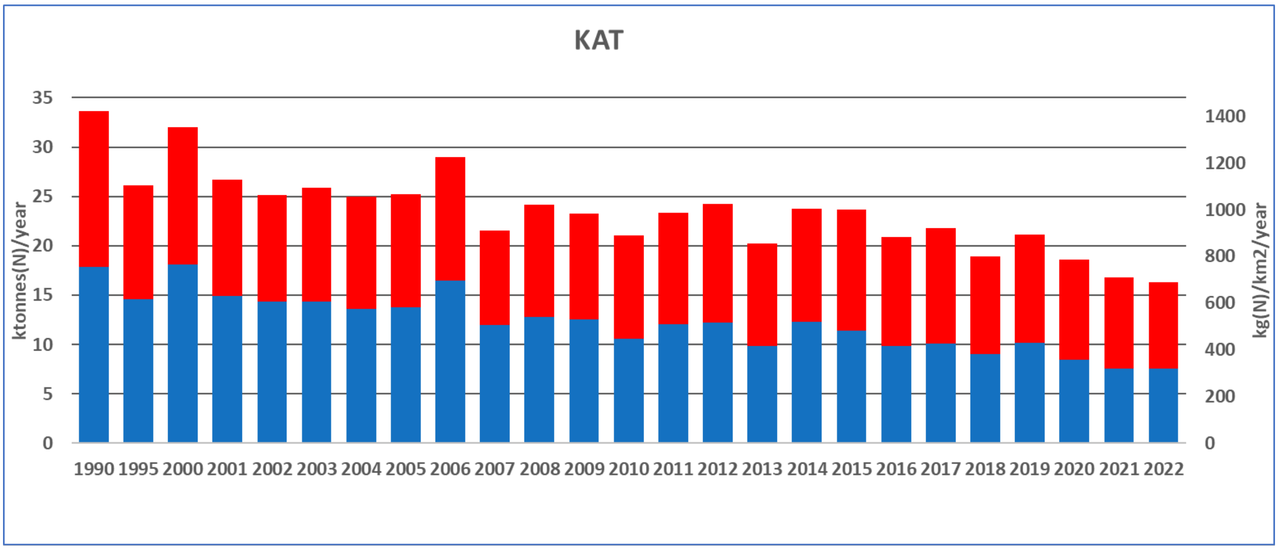
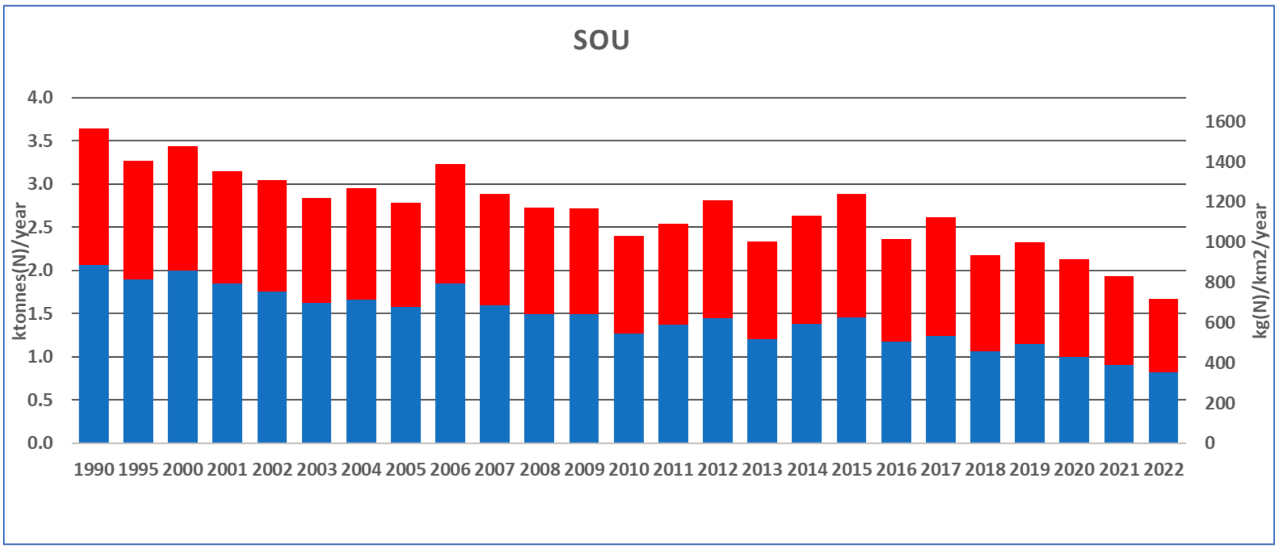


Figure 4. Continued.





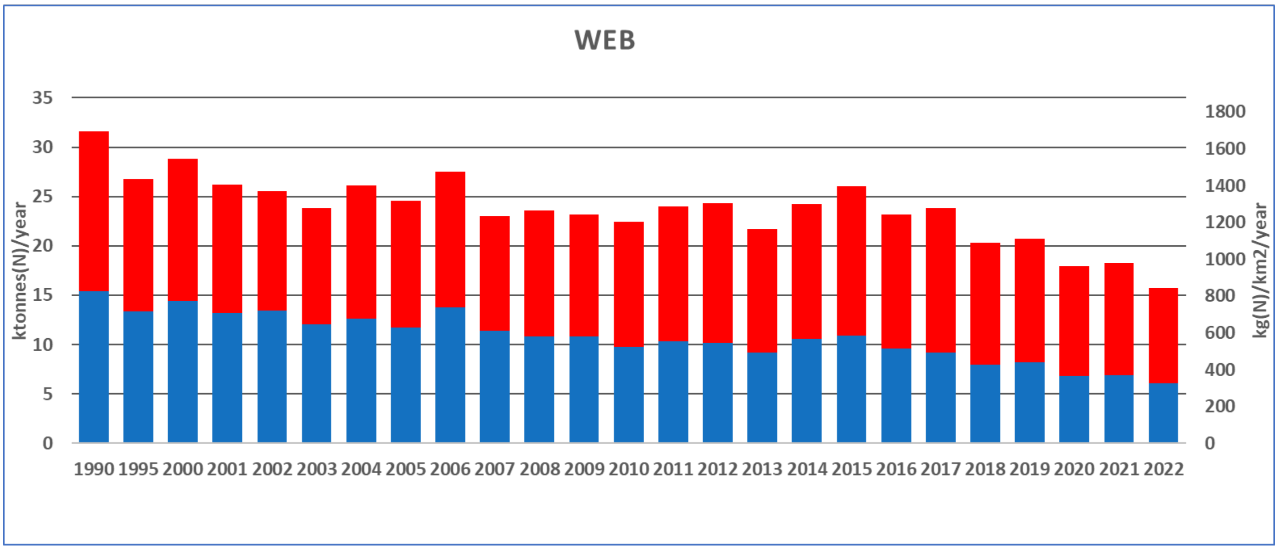


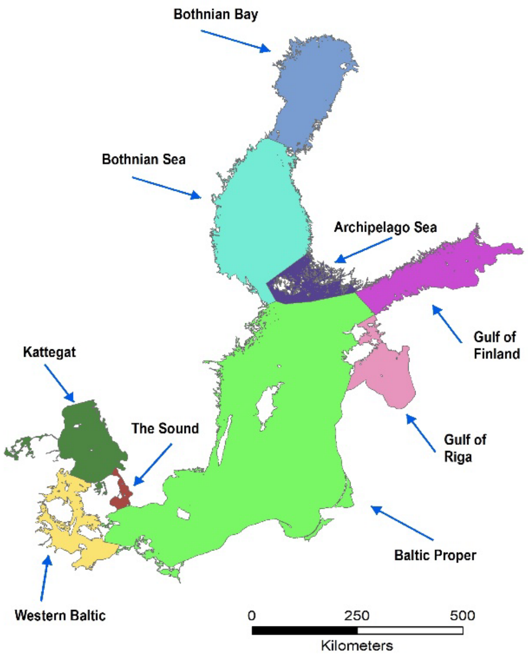
Figure 4. Continued.

Table 2. Trends in actual (non-normalized) depositions of oxidized, reduced, and total nitrogen to the nine sub-basins of the Baltic Sea. The values correspond to the slopes of the linear regression line, given in units of %/decade, calculated for the whole 33-year period (1990 – 2022), for the 1990s and for the most recent decade. Missing values mean that there is no trend that is significant at the 95% confidence level (i.e. the Mann-Kendall test yields a p-value larger than 0.05). Note: in order to estimate the total change over the 1990-2022 period (3.2 decades from mid-year to mid-year) one should multiply the %/decade values by 3.2.

Area	**Oxidized Nitrogen**			**Reduced Nitrogen**			**Total Nitrogen**		
	1990-2022	**1990-2000**	**2012-2022**	**1990-2022**	**1990-2000**	**2012-2022**	**1990-2022**	**1990-2000**	**2012-2022**
ARC	-16.3	-	-36.6	-7.6	-	-	-13.7	-	-34.3
BAP	-18.6	-18.0	-38.2	-12.3	-12.5	-29.7	-16.3	-16.0	-34.5
BOB	-18.5	-	-43.6	-10.3	-	-	-16.2	-	-
BOS	-16.9	-	-41.5	-	-	-	-13.8	-	-
GUF	-18.2	-17.3	-35.7	-11.5	-	-	-16.2	-	-34.1
GUR	-18.9	-26.0	-36.5	-11.6	-23.8	-	-16.4	-25.3	-
KAT	-18.0	-	-38.3	-14.0	-	-27.2	-16.1	-	-32.8
SOU	-18.9	-	-43.3	-14.5	-	-37.8	-17.0	-	-40.6
WEB	-18.9	-	-40.0	-12.6	-	-31.7	-15.7	-	-35.2

Table 3. Same as Table 2, but for normalized depositions.

Area	**Oxidized Nitrogen**			**Reduced Nitrogen**			**Total Nitrogen**		
	1990-2022	**1990-2000**	**2012-2022**	**1990-2022**	**1990-2000**	**2012-2022**	**1990-2022**	**1990-2000**	**2012-2022**
ARC	-17.7	-23.2	-24.5	-11.9	-27.2	-8.1	-15.9	-24.5	-18.8
BAP	-18.1	-23.6	-26.3	-12.4	-26.2	-	-15.9	-24.6	-19.2
BOB	-18.2	-23.4	-25.2	-10.8	-22.6	-9.3	-16.0	-23.2	-19.5
BOS	-18.0	-23.4	-25.3	-11.5	-25.7	-7.3	-16.0	-24.1	-18.9
GUF	-18.0	-26.4	-22.7	-13.2	-37.0	-	-16.4	-30.0	-16.2
GUR	-18.2	-26.4	-25.1	-13.6	-37.3	-6.2	-16.4	-30.6	-17.5
KAT	-18.1	-19.5	-27.4	-13.8	-23.9	-	-16.1	-21.6	-19.8
SOU	-18.2	-20.6	-27.4	-13.2	-22.8	-	-16.0	-21.6	-20.3
WEB	-18.3	-20.4	-27.8	-13.1	-22.0	-15.2	-15.6	-21.2	-20.8



Sub-basin	Abbreviation	Area in km^2
Archipelago Sea	ARC	13405
Baltic Proper	BAP	209258
Bothnian Bay	BOB	36249
Bothnian Sea	BOS	65397
Gulf of Finland	GUF	29998
Gulf of Riga	GUR	18646
Kattegat	KAT	23659
The Sound	SOU	2328
Western Baltic	WEB	18647
Baltic Sea basin	**BAS**	**417587**

Figure 5. Locations of the nine sub-basins of the Baltic Sea, used for all nitrogen deposition calculations presented in this report. The figure with the sub-basins has been provided by the Baltic Nest Institute (BNI).

References

Bartnicki, J., A. Gusev, W. Aas, M. Gauss, J. E. Jonson, 2017: Atmospheric Supply of Nitrogen, Cadmium, Mercury, Lead, and PCDD/Fs to the Baltic Sea in 2015, EMEP MSC-W Technical report 2/2017, available online at http://emep.int/publ/helcom/2017/

Data

Supporting Excel here

Table 4. Actual depositions of oxidized nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2022. The bottom row (‘Ref’) shows the average for the 1997 – 2003 reference period. Unit: ktonnes(N)/year. For definitions of sub-basins see Figure 4. ”BAS”: Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1990	7.2	129	9.2	19.0	16.8	10.9	17.8	2.1	15.4	227
1991	7.2	122	8.6	18.6	16.2	10.7	16.8	2.1	14.7	217
1992	7.1	124	9.3	20.2	16.3	10.2	17.0	2.1	15.0	221
1993	7.1	125	8.1	19.9	14.0	9.1	16.5	2.2	15.0	217
1994	6.5	120	7.0	17.0	14.0	8.9	16.8	2.1	15.7	208
1995	6.3	106	7.9	17.5	13.9	8.3	14.6	1.9	13.4	190
1996	6.5	105	7.0	17.1	13.8	8.2	14.1	1.7	12.7	186
1997	5.5	94.5	5.8	15.0	12.3	7.7	14.7	1.8	12.7	170
1998	6.7	114	8.4	18.4	14.6	8.7	15.7	2.0	15.5	204
1999	6.7	107	7.9	18.9	13.6	8.4	17.7	1.9	13.6	196
2000	6.9	105	9.0	20.7	13.9	8.0	18.1	2.0	14.5	198
2001	6.2	102	7.4	17.1	12.7	8.1	14.9	1.8	13.2	183
2002	5.0	95.6	5.4	13.4	10.9	7.0	14.3	1.8	13.4	167
2003	5.3	88.3	6.4	15.0	12.1	6.9	14.3	1.6	12.0	162
2004	5.1	91.3	6.0	13.6	12.4	7.1	13.6	1.7	12.6	163
2005	5.3	90.7	7.4	15.0	11.9	7.0	13.7	1.6	11.8	164
2006	5.5	97.9	6.3	16.2	11.1	6.8	16.5	1.9	13.7	176
2007	5.1	89.7	5.8	12.8	12.2	7.3	11.9	1.6	11.4	158
2008	5.4	91.2	5.9	13.9	12.8	7.7	12.8	1.5	10.8	162
2009	4.5	78.6	5.2	12.3	9.5	6.1	12.5	1.5	10.8	141
2010	4.8	83.7	5.8	14.1	10.6	6.2	10.6	1.3	9.8	147
2011	4.7	79.3	5.5	12.8	10.2	6.3	12.1	1.4	10.4	143
2012	5.4	84.3	6.7	14.9	10.9	6.8	12.3	1.4	10.1	153
2013	4.4	69.6	4.4	10.0	9.4	5.3	9.9	1.2	9.2	123
2014	4.2	72.7	5.1	12.2	8.7	5.2	12.3	1.4	10.6	132
2015	4.0	72.7	5.3	11.0	8.9	5.4	11.4	1.5	10.9	131
2016	3.5	63.0	4.6	10.7	8.4	4.7	9.9	1.2	9.6	115
2017	3.8	69.5	4.5	10.4	8.3	5.2	10.1	1.2	9.2	122
2018	3.9	64.6	4.6	10.9	8.4	5.0	9.0	1.1	8.0	115
2019	4.3	65.1	4.1	10.9	8.5	5.2	10.2	1.2	8.2	118
2020	3.7	58.8	4.5	9.8	7.6	4.9	8.4	1.0	6.8	105
2021	2.9	54.2	4.1	9.0	7.1	4.3	7.6	0.9	6.9	97
2022	3.4	52.1	3.8	8.7	7.0	4.3	7.6	0.8	6.1	94
Ref	**6.0**	**101**	**7.2**	**16.9**	**12.9**	**7.8**	**15.7**	**1.8**	**13.6**	**183**

Table 5. Actual depositions of reduced nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2022. The bottom row ('Ref') shows the average for the 1997 – 2003 reference period. Unit: ktonnes(N)/year. For definitions of sub-basins see Figure 4. "BAS": Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1990	3.0	73.5	3.7	7.1	7.1	5.5	15.8	1.6	16.2	133
1991	3.0	68.1	3.4	7.2	7.6	5.9	14.4	1.5	14.4	126
1992	3.3	69.7	4.4	8.8	8.9	5.7	14.2	1.5	14.7	131
1993	3.1	67.4	3.2	8.5	6.0	4.6	13.4	1.5	13.9	121
1994	2.4	64.4	2.6	6.0	6.3	4.8	13.2	1.4	14.5	116
1995	2.8	58.5	3.3	7.8	6.2	4.4	11.5	1.4	13.4	109
1996	2.9	58.0	2.7	7.6	6.9	4.6	10.6	1.2	11.2	106
1997	2.1	51.7	2.2	5.2	4.6	3.7	11.9	1.3	12.7	95
1998	2.9	65.7	3.7	7.8	6.5	4.6	13.0	1.6	15.5	121
1999	3.0	62.0	3.6	8.3	6.1	4.6	14.3	1.4	13.3	117
2000	3.5	64.3	4.1	10.5	5.9	4.2	13.9	1.4	14.4	122
2001	2.9	60.6	3.2	7.6	5.8	4.5	11.7	1.3	13.0	111
2002	2.3	57.8	2.7	5.7	4.9	3.5	10.8	1.3	12.1	101
2003	2.5	53.9	3.3	7.3	5.2	3.6	11.6	1.2	11.8	101
2004	2.2	54.2	2.4	5.4	5.3	4.0	11.4	1.3	13.5	100
2005	2.3	53.8	3.6	6.9	5.3	3.9	11.5	1.2	12.8	101
2006	2.5	60.4	3.0	7.4	5.2	4.0	12.5	1.4	13.8	110
2007	2.3	55.4	2.5	5.4	5.9	4.1	9.6	1.3	11.6	98
2008	2.4	55.7	2.5	6.0	6.3	4.4	11.3	1.2	12.8	103
2009	2.3	52.8	2.8	6.0	4.6	3.6	10.8	1.2	12.3	96
2010	2.5	57.2	3.7	8.1	5.8	4.0	10.5	1.1	12.6	106
2011	2.6	56.8	3.0	7.5	5.2	4.0	11.3	1.2	13.6	105
2012	3.3	63.5	3.7	8.3	6.5	4.9	12.0	1.4	14.2	118
2013	2.7	52.3	2.5	5.8	5.5	3.7	10.3	1.1	12.6	97
2014	2.2	55.4	2.5	6.2	4.9	3.6	11.5	1.3	13.6	101
2015	2.3	61.5	3.1	6.5	5.7	4.2	12.2	1.4	15.2	112
2016	2.0	49.6	2.8	6.4	5.1	3.3	11.0	1.2	13.6	95
2017	2.1	57.1	2.5	5.9	4.9	3.7	11.7	1.4	14.7	104
2018	2.5	54.3	2.9	6.7	5.4	4.1	9.9	1.1	12.4	99
2019	2.7	55.5	2.6	7.5	5.9	4.2	11.0	1.2	12.5	103
2020	2.5	52.9	2.8	6.3	5.4	4.1	10.2	1.1	11.1	96
2021	2.0	48.8	3.2	7.2	4.9	3.7	9.2	1.0	11.3	92
2022	2.3	44.6	2.5	5.8	4.5	3.5	8.7	0.8	9.7	82
Ref	**2.8**	**59.4**	**3.2**	**7.5**	**5.6**	**4.1**	**12.5**	**1.4**	**13.3**	**110**

Table 6. Actual depositions of total nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2022. The bottom row (‘Ref’) shows the average for the 1997 – 2003 reference period. Unit: ktonnes(N)/year. For definitions of sub-basins see Figure 4. ”BAS”: Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1990	10.2	202	12.9	26.1	23.9	16.4	33.7	3.6	31.6	360
1991	10.2	190	12.0	25.7	23.8	16.6	31.3	3.6	29.1	342
1992	10.4	193	13.8	29.0	25.2	15.9	31.2	3.7	29.7	352
1993	10.2	192	11.3	28.3	20.0	13.6	29.9	3.6	28.9	338
1994	8.9	184	9.6	23.1	20.3	13.7	29.9	3.5	30.1	323
1995	9.1	164	11.3	25.3	20.1	12.7	26.1	3.3	26.8	299
1996	9.4	163	9.7	24.7	20.7	12.9	24.7	2.9	23.9	292
1997	7.6	146	8.0	20.3	17.0	11.4	26.6	3.1	25.4	265
1998	9.6	180	12.1	26.2	21.1	13.3	28.7	3.6	31.0	325
1999	9.7	169	11.5	27.2	19.7	13.0	32.1	3.2	26.9	312
2000	10.4	170	13.0	31.1	19.8	12.2	32.0	3.4	28.8	321
2001	9.1	163	10.6	24.7	18.6	12.6	26.7	3.2	26.2	294
2002	7.3	153	8.1	19.1	15.8	10.5	25.1	3.0	25.5	268
2003	7.8	142	9.8	22.3	17.2	10.5	25.9	2.8	23.9	262
2004	7.3	145	8.4	19.0	17.7	11.2	25.0	3.0	26.1	263
2005	7.6	145	11.0	21.9	17.2	10.8	25.2	2.8	24.6	266
2006	8.1	158	9.3	23.6	16.3	10.8	29.0	3.2	27.5	286
2007	7.4	145	8.3	18.1	18.1	11.4	21.5	2.9	23.0	256
2008	7.8	147	8.4	19.9	19.1	12.1	24.1	2.7	23.6	265
2009	6.8	131	8.0	18.3	14.1	9.7	23.3	2.7	23.2	237
2010	7.3	141	9.5	22.2	16.4	10.3	21.1	2.4	22.4	253
2011	7.3	136	8.5	20.2	15.4	10.4	23.4	2.5	24.0	248
2012	8.7	148	10.3	23.2	17.4	11.7	24.3	2.8	24.3	271
2013	7.1	122	6.9	15.8	14.9	9.1	20.2	2.3	21.7	220
2014	6.4	128	7.6	18.5	13.5	8.8	23.8	2.6	24.2	234
2015	6.3	134	8.3	17.5	14.6	9.7	23.6	2.9	26.1	243
2016	5.6	113	7.4	17.1	13.4	8.0	20.9	2.4	23.2	211
2017	5.9	127	6.9	16.3	13.2	8.9	21.8	2.6	23.8	226
2018	6.4	119	7.5	17.7	13.8	9.0	18.9	2.2	20.3	215
2019	7.0	121	6.7	18.5	14.4	9.4	21.1	2.3	20.8	221
2020	6.2	112	7.3	16.1	13.0	9.0	18.6	2.1	17.9	202
2021	4.9	103	7.3	16.3	12.0	8.1	16.8	1.9	18.3	189
2022	5.7	97	6.2	14.5	11.5	7.8	16.3	1.7	15.8	176
Ref	**8.8**	**160.4**	**10.4**	**24.4**	**18.5**	**11.9**	**28.1**	**3.2**	**26.8**	**293**

Table 7. Normalized depositions of oxidized, reduced and total nitrogen to the Baltic Sea basin in the period 1990 – 2022. The bottom row ('Ref') shows the average for the 1997 – 2003 reference period. Unit: ktonnes(N)/year. (Normalized deposition of total nitrogen may slightly differ from the sum of normalized depositions of oxidized and reduced nitrogen; this is due to the use of medians during normalization.)

Year	Oxidized Nitrogen	Reduced Nitrogen	Total Nitrogen
1990	235	151	386
1991	230	142	373
1992	222	133	356
1993	212	127	341
1994	206	123	331
1995	200	119	321
1996	200	117	320
1997	194	116	312
1998	190	115	307
1999	187	113	300
2000	183	110	293
2001	180	109	289
2002	176	108	283
2003	174	106	280
2004	172	105	277
2005	169	105	274
2006	168	104	272
2007	163	104	267
2008	152	103	256
2009	143	101	245
2010	142	100	244
2011	139	99.5	240
2012	136	98.8	236
2013	132	98.9	232
2014	128	99.8	228
2015	126	100	227
2016	123	99.9	223
2017	122	100	222
2018	119	98.9	218
2019	114	96.2	211
2020	104	94.8	198
2021	104	92.0	196
2022	102	89.1	191
Ref	**183**	**111**	**295**

Metadata

Technical information

1. Source: EMEP MSC-W.

2. Description of data: The atmospheric depositions of oxidized and reduced nitrogen were calculated with the EMEP MSC-W model, version rv5.3. Emission data based on official data submissions from the HELCOM countries received by June 2024 were used in the model computations. Emissions of two nitrogen compounds for each year of this period were officially reported to the UN ECE Secretariat by the HELCOM Contracting Parties. Missing information is estimated by experts. Both official data and expert estimates were used for modeling atmospheric transport and deposition of nitrogen compounds to the Baltic Sea.

3. Geographical coverage: Atmospheric depositions of oxidized and reduced nitrogen were computed for the entire EMEP domain, including the Baltic Sea basin and its catchment area.

4. Temporal coverage: Time series of annual atmospheric depositions are available for the period 1990 – 2022.

5. Methodology and frequency of data collection:

Atmospheric input and source allocation budgets of nitrogen (oxidized, reduced and total) to the Baltic Sea basins and catchments were computed using the EMEP MSC-W model, version rv5.3. The EMEP MSC-W model is a multi-pollutant, three-dimensional Eulerian model which takes into account processes of emission, advection, turbulent diffusion, chemical transformations, wet and dry depositions and inflow of pollutants into the model domain. A complete description of the model and its applications is available on the web (direct link to web page of the model: https://github.com/metno/emep-ctm)

Calculations of atmospheric transport and deposition of nitrogen compounds are performed annually on the basis of emission data officially submitted by Parties to CLRTAP Convention and expert estimates. In order to filter out interannual variability in meteorology, the depositions are also reported as “weather-normalized” depositions; the method for this is described in Appendix D of Bartnicki et al. (2017).

Quality information

6. Strengths and weaknesses:

Strength: annually updated information on atmospheric input of oxidized and reduced nitrogen to the Baltic Sea and its sub-basins.

Weakness: gaps and uncertainties in the officially submitted time series of nitrogen emissions to air by countries increase the uncertainty of computed depositions.

7. Uncertainty:

The results of the EMEP MSC-W model are routinely compared with available measurements at EMEP and HELCOM stations. The comparison of calculated versus measured data indicates that the model predicts the observed air concentrations of nitrogen within an accuracy of approximately 25%.

8. Further work required:

Continuous work is required on reducing uncertainties in emission data and better parameterization of physical processes in the EMEP MSC-W model.