Atmospheric nitrogen deposition to the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2022

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Key Message

Airborne nitrogen depositions to the Baltic Sea have been calculated for the 1990 – 2020 period with the EMEP MSC-W model on 0.1° x 0.1° resolution. This was possible this year as the EMEP emission centre CEIP has extended the data series for nitrogen emissions to the 1990s. According to our model calculations, airborne depositions of oxidised, reduced and total nitrogen were, respectively, 40%, 8% and 28% lower in 2020 than in the reference period 1997 – 2003. There is a clear reduction in *normalised* depositions of nitrogen as well, which is consistent with the change in nitrogen emissions in the HELCOM area. Normalised depositions of oxidised, reduced and total nitrogen in 2020 were 43%, 13% and 32% lower than in the reference period 1997 – 2003.

(Using the period 1997 – 2003 as the 100% reference level was a decision taken by PLC-8 IG in order to use the same reference period as for the waterborne nutrient inputs under the Baltic Sea Action Plan.)

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This fact sheet presents calculated changes in atmospheric deposition of oxidised, reduced and total nitrogen to the Baltic Sea and its nine sub-basins during the 1990 – 2020 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 revised in 2012) 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 currently undergoes a review process that will most likely result in another revision.

Assessment

Atmospheric depositions of oxidised and reduced nitrogen for the period 1990 – 2020 reported here were computed in summer 2022 with the EMEP MSC-W model version rv4.45, using the latest available gridded and gap-filled emission data for the HELCOM countries and all other EMEP sources. The calculations were performed on 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.

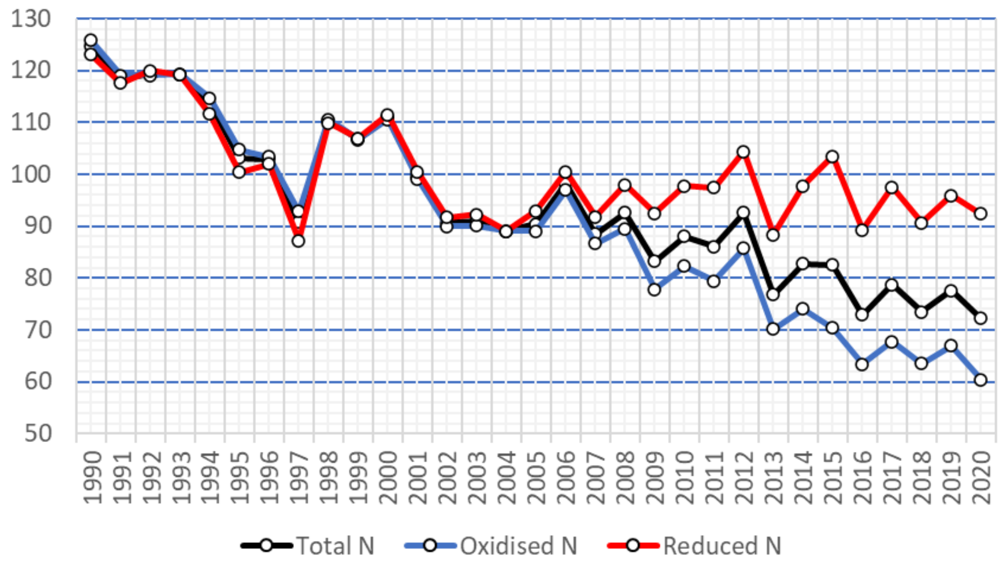

Figure 1. Atmospheric deposition of oxidised, reduced and total nitrogen to the entire Baltic Sea basin for the period 1990-2020, given as percentage of the average values for the 1997 – 2003 reference period.

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 oxidised and total nitrogen in 2020, by 40% and 28%, respectively, as compared to the reference period 1997 - 2003. However, annual deposition of *reduced* nitrogen was only 8% lower in 2020 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 significantly from year to year. Therefore, it has been common practice to 'weather-normalize' depositions in order 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 thus calculate the depositions for all other meteorological years by using *transfer coefficients*[1] for these years. Currently we have data on transfer coefficients for 26 years (1995-2020). In this way we can calculate 26 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 they are often referred to as 'actual deposition'.

An inspection of Figure 2 indicates a downward tendency in normalised 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. Normalised depositions of oxidised, reduced, and total nitrogen in 2020 were 43%, 13% and 32% lower than in the reference period 1997 – 2003.

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 2020.

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 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 nitrogen depositions to the nine sub-basins of the Baltic Sea in the period 1990 – 2020 are presented in Figure 4, while Table 2 lists trends that are statistically significant at the 5% level (Mann-Kendall test). Slopes of the linear regression line are calculated for the whole 31-year period, for the 1990s and for the most recent decade. Trends in oxidized nitrogen are of clearly larger magnitude than those in reduced nitrogen, when the whole period is considered. It is interesting to note that the changes in reduced nitrogen depositions (if any) are smaller than the corresponding changes in reduced nitrogen emissions from HELCOM countries. During the period 2010-2020 there are no significant trends in the deposition of reduced nitrogen.

Compared to the reference period 1997 – 2003, actual depositions of oxidised nitrogen were clearly lower in 2020 (by 32 to 49%) in all sub-basins. The change is particularly large in WEB (49%), KAT (45%) and SOU (44%). Also, the deposition of total nitrogen was lower in 2020 compared to the reference period 1997 – 2003, with reductions ranging from 20% (GUR) to 32% (KAT). Annual deposition of reduced nitrogen was higher in 2020 than in the reference period 1997 – 2003 in one of the nine sub-basins (GUR, 5%), while it was lower in the other eight sub-basins, with reductions ranging from 1% (GUF) to 14% (KAT). There is 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.

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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.

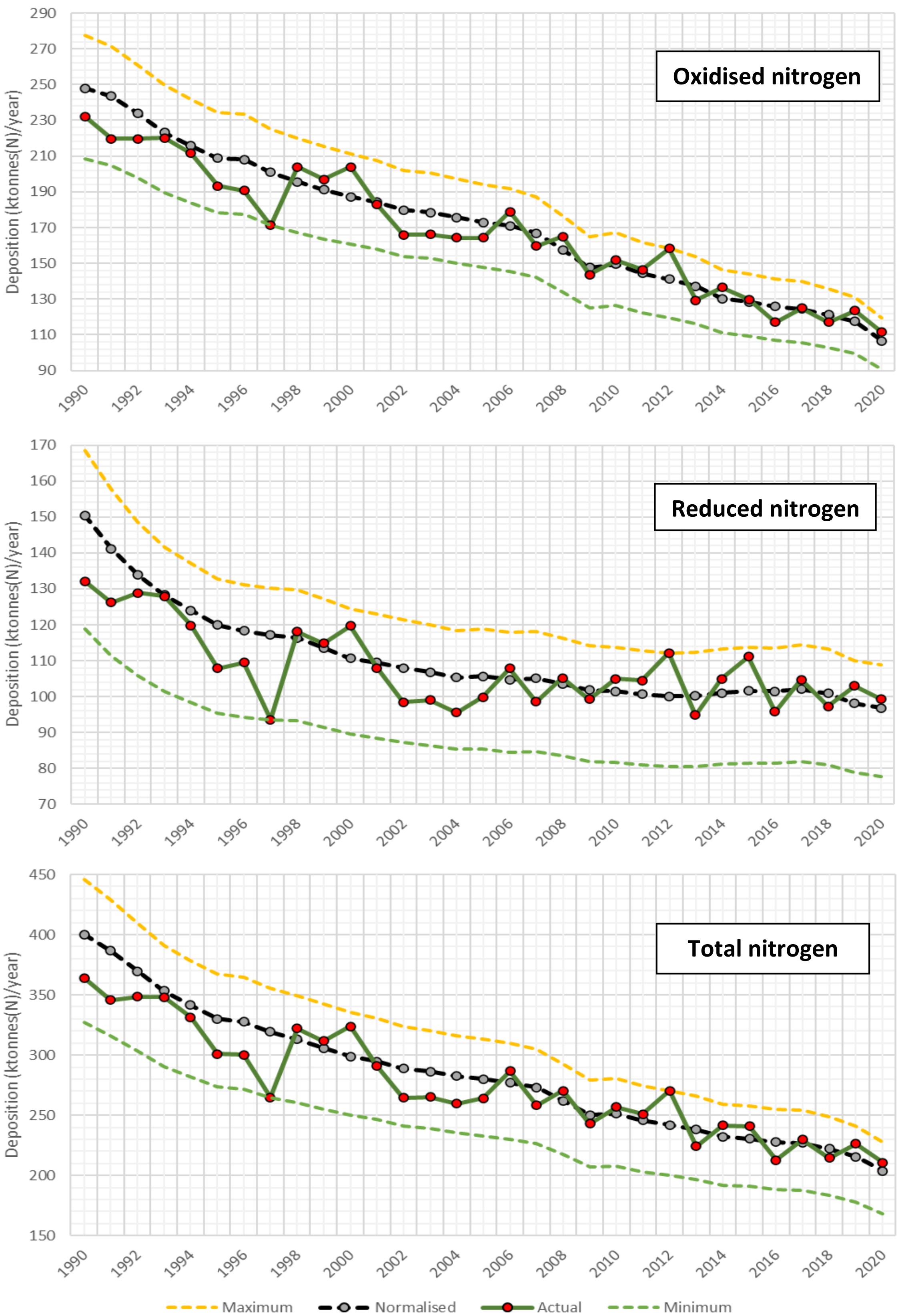


Figure 2. Normalised depositions of oxidised (top), reduced (middle) and total (bottom) nitrogen for the period 1990-2020, depicted by the black dashed line/grey dots. Unit: ktonnes(N)/year. Minimum, maximum and actual values of the depositions are also shown. The actual values correspond to the values listed in Tables 3, 4 and 5, while the normalized values are listed in Table 6. Note that the vertical scale does not start at zero, to make the variability more visible.

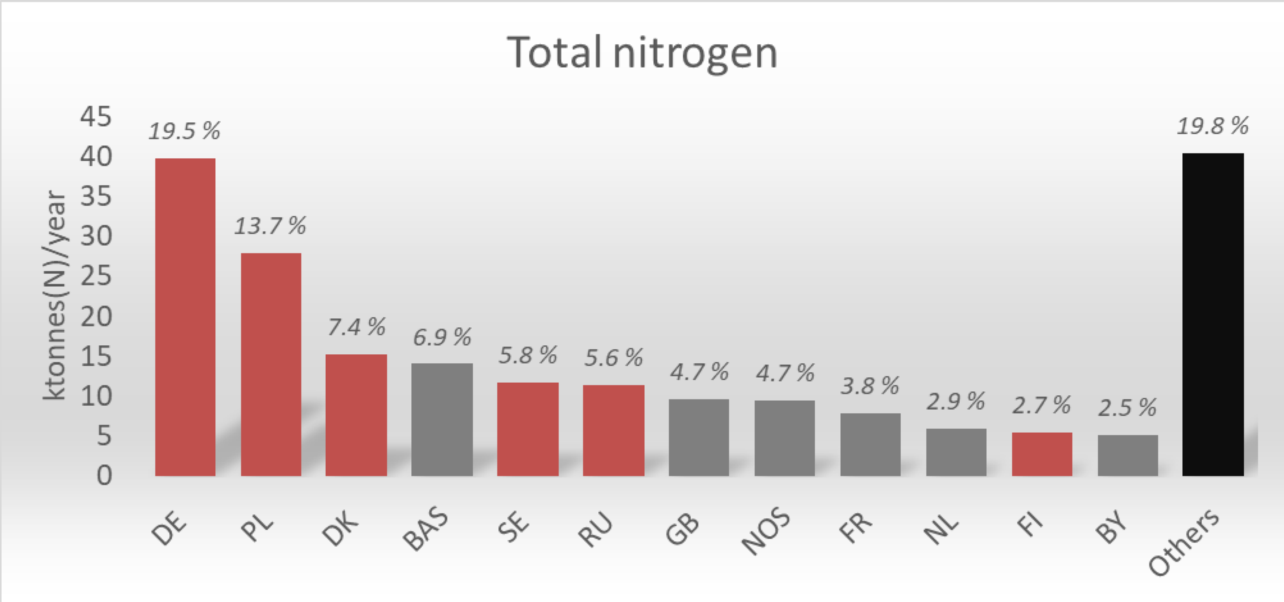
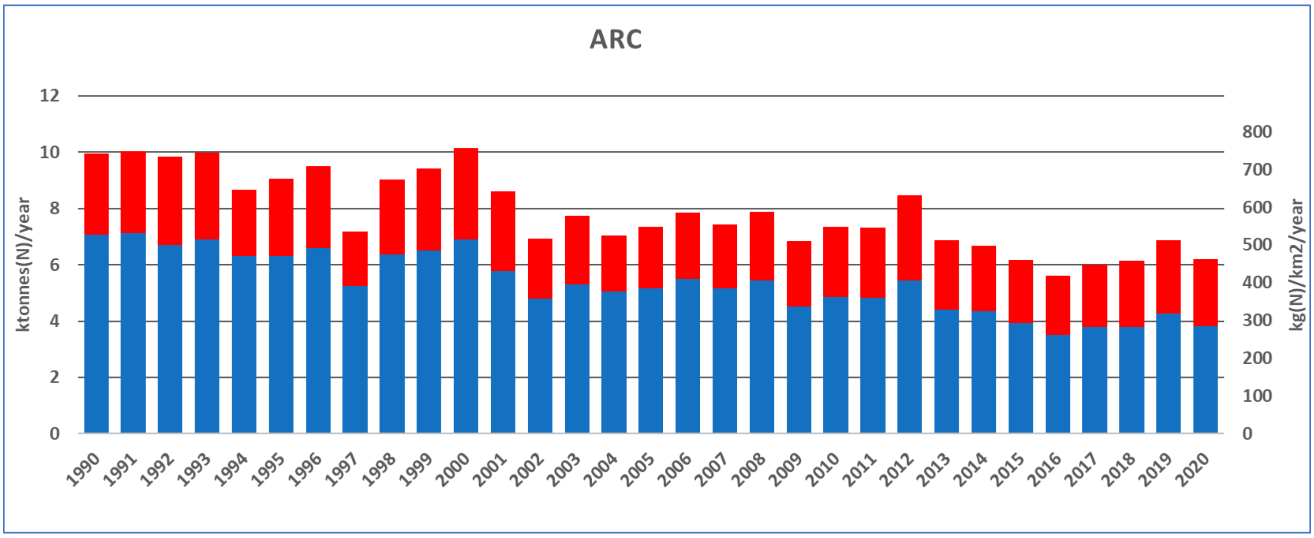
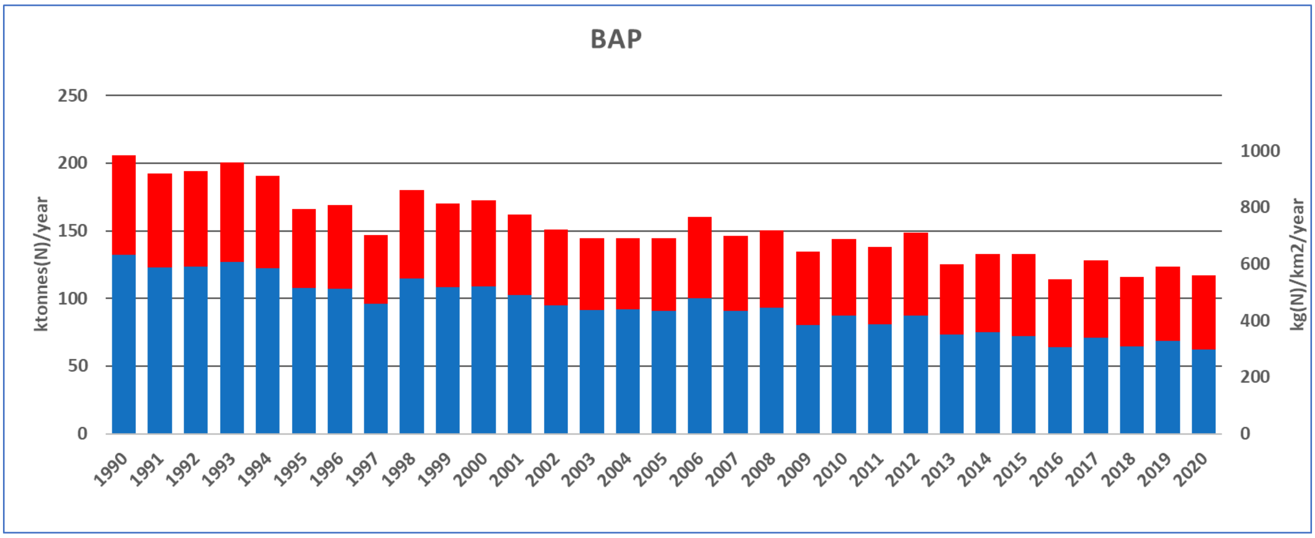


Figure 3. Bar chart showing the top-12 contributions to deposition of total airborne nitrogen to the Baltic Sea (NOS: North Sea Shipping; BAS: Baltic Sea shipping; GB: United Kingdom). "Others": all countries and regions not among the indicated top-12 contributions. Red colour is used for HELCOM contracting parties. The numbers on top of each bar show the percentage share of each contribution to the total. Example: Denmark stands for 7.4% of 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 oxidised, reduced and total airborne nitrogen separately. Example: 9% of Estonia's annual emission of oxidised nitrogen (NOx) is deposited to the Baltic Sea. All calculations are normalized and based on emissions of 2020.

	DK	**EE**	**FI**	**DE**	**LV**	**LT**	**PL**	**RU**	**SE**	**BAS**	**NOS**	**FR**	**GB**
Ox-N	11 %	9 %	7 %	5 %	9 %	9 %	6 %	0.8 %	10 %	13 %	4 %	1.5 %	2.4 %
Re-N	19 %	14 %	11 %	5 %	10 %	10 %	6 %	0.3 %	17 %			0.9 %	1.4 %
Tot-N	17 %	12 %	9 %	5 %	9 %	9 %	6 %	0.6 %	14 %	13 %	4 %	1.1 %	2.0 %





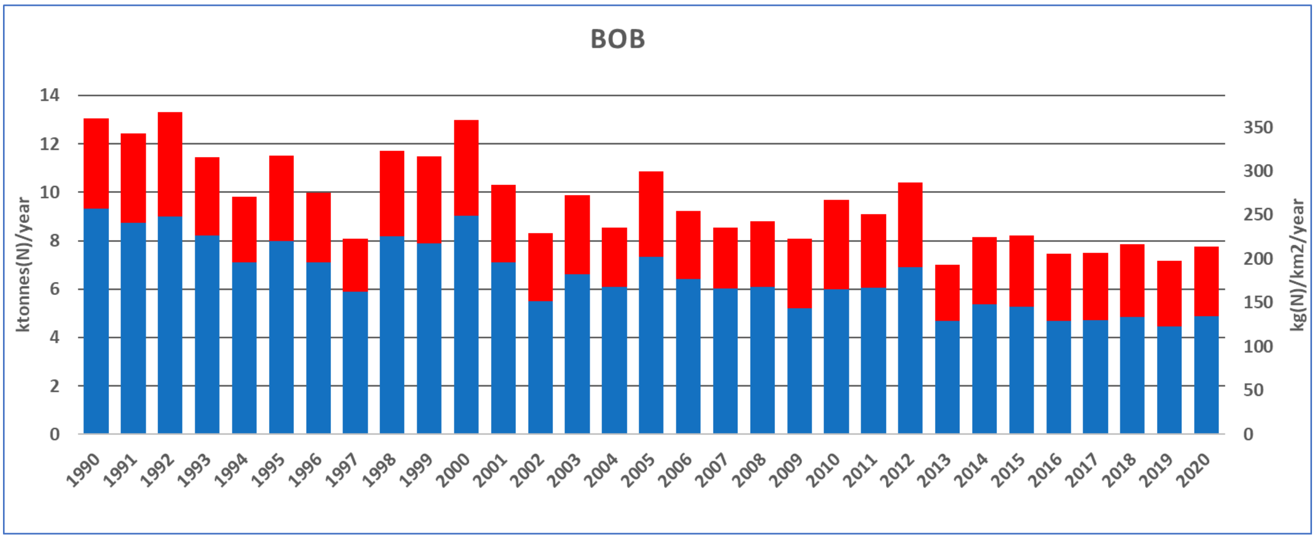


Figure 4. Atmospheric deposition of oxidised nitrogen (blue) and reduced nitrogen (red) to the nine sub-basins of the Baltic Sea in the period 1990 - 2020. Unit: ktonnes(N)/year. Note that the vertical scales in the plots are different. The figure continues on the next two pages. For definitions of sub-basins see Figure 5.

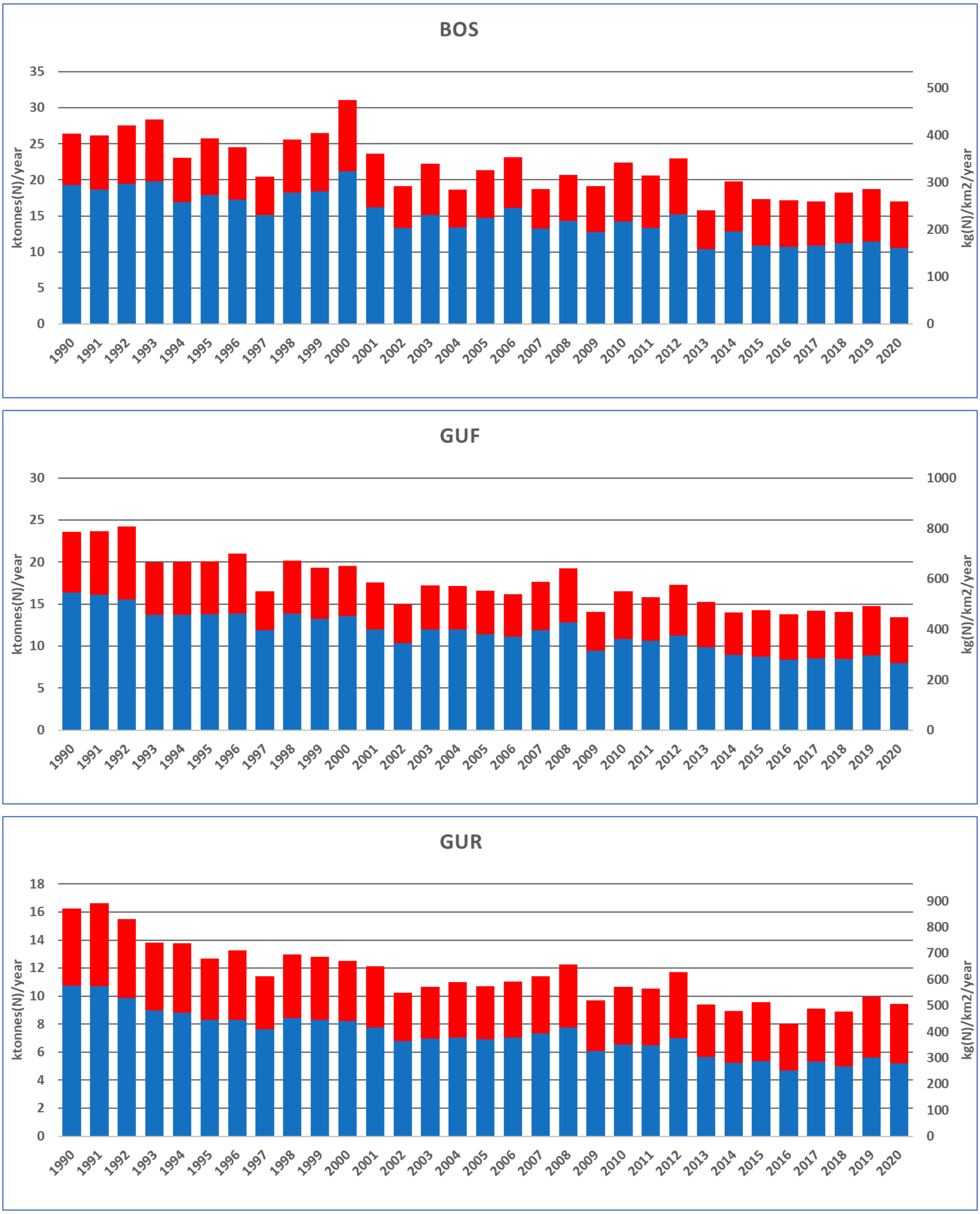
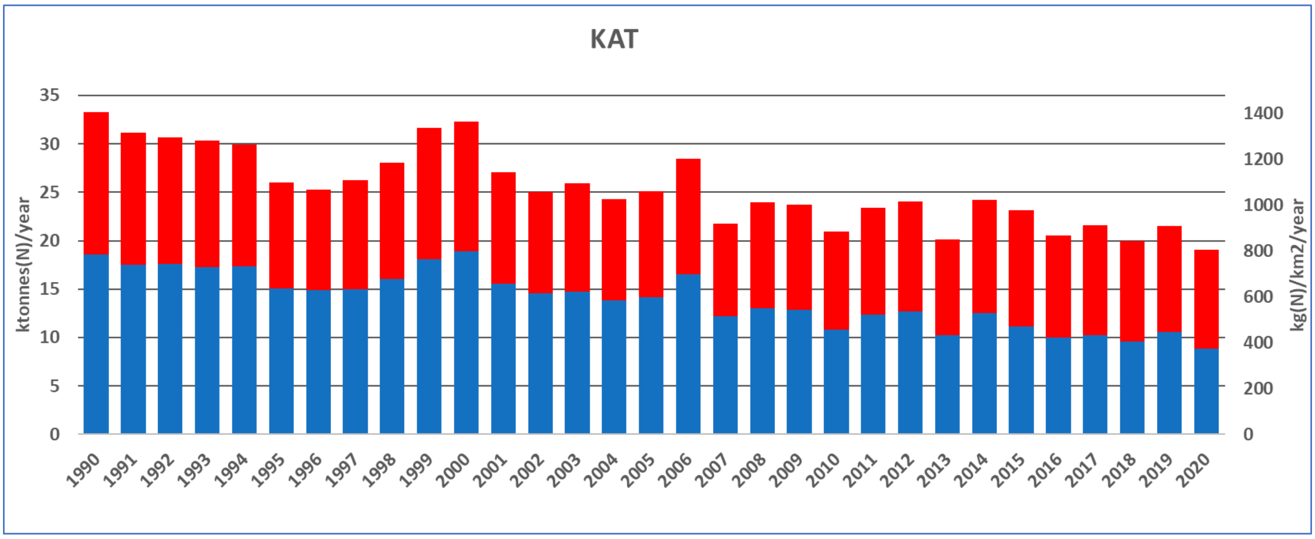
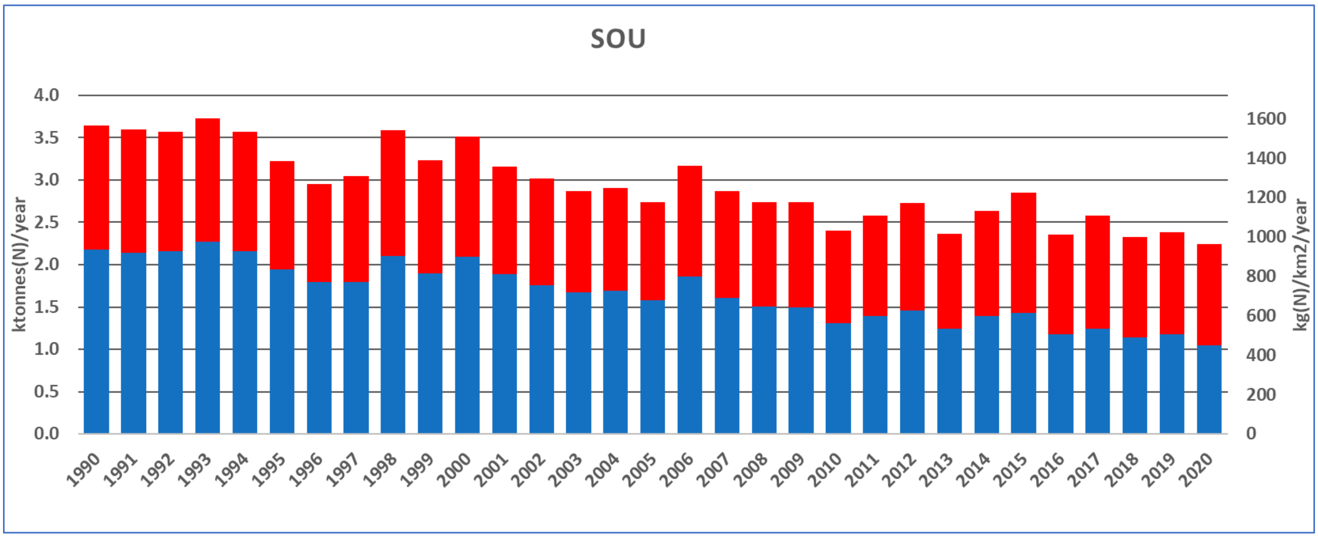


Figure 4. Continued.





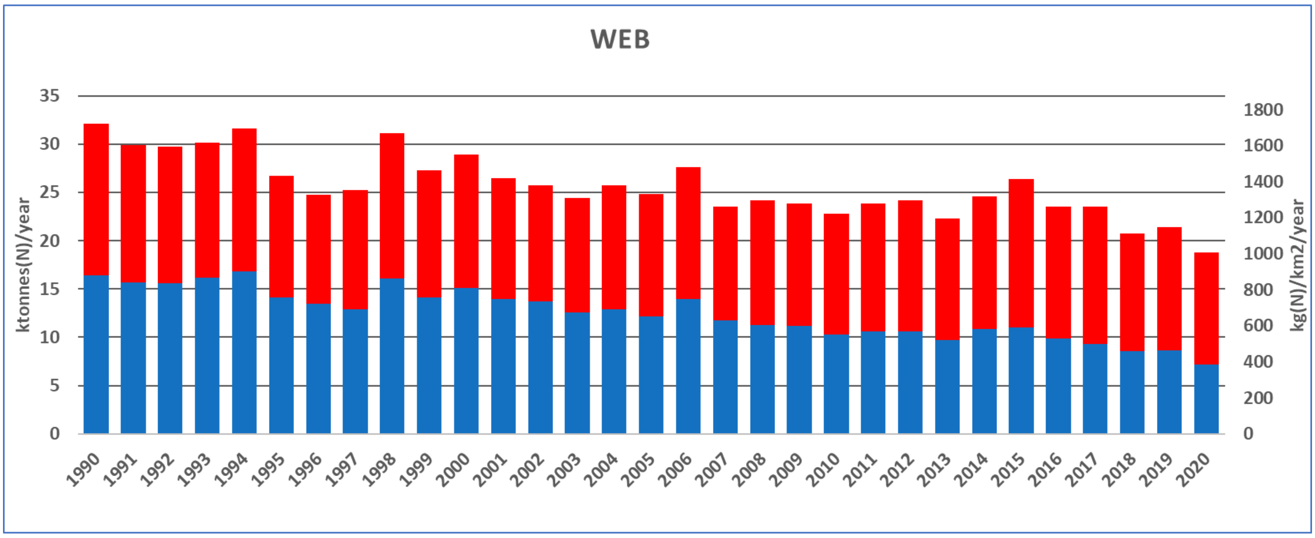
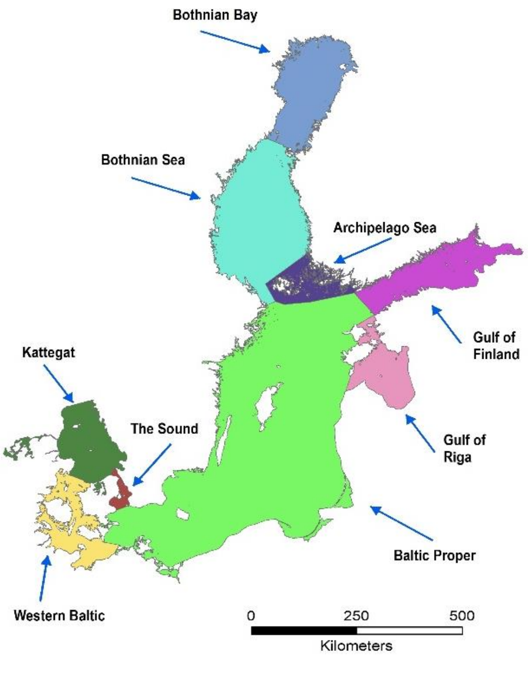


Figure 4. Continued.

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 tonnes(N)/year, calculated for the whole 31-year period (1990 – 2020), for the 1990s and for the most recent decade. Missing values mean that there is no trend that is significant at the 5% confidence level (i.e. the Mann-Kendall test yields a p-value larger than 0.05).

Area	Oxidized Nitrogen			Reduced Nitrogen			Total Nitrogen		
	1990-2020	1990-2000	2010-2020	1990-2020	1990-2000	2010-2020	1990-2020	1990-2000	2010-2020
ARC	-112	-	-132	-20	-	-	-136	-	-159
BAP	-2169	-2408	-2302	-491	-1255	-	-2647	-3548	-2450
BOB	-144	-	-	-25	-	-	-169	-	-
BOS	-294	-	-	-	-	-	-323	-	-
GUF	-245	-311	-287	-43	-177	-	-288	-	-270
GUR	-162	-267	-146	-43	-171	-	-204	-389	-
KAT	-291	-	-286	-82	-	-	-388	-	-
SOU	-37	-	-27	-8	-	-	-46	-	-
WEB	-272	-	-282	-	-	-	-311	-	-



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/

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JRC/PBL: Emission Database for Global Atmospheric Research (EDGAR), Global Emissions EDGAR v4.3.1, European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL), URL http://edgar.jrc.ec.europa.eu, 2016.

Data

Table 3. Actual depositions of oxidised nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2020. 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	7.1	132	9.3	19.3	16.4	10.7	18.5	2.2	16.4	232
1991	7.1	123	8.7	18.7	16.1	10.7	17.5	2.1	15.7	220
1992	6.7	124	9.0	19.5	15.5	9.9	17.6	2.2	15.6	220
1993	6.9	127	8.2	19.7	13.7	9.0	17.3	2.3	16.2	220
1994	6.3	122	7.1	17.0	13.7	8.8	17.3	2.2	16.9	212
1995	6.3	108	8.0	17.9	13.8	8.3	15.1	1.9	14.1	193
1996	6.6	107	7.1	17.2	13.9	8.3	14.9	1.8	13.5	191
1997	5.2	95.8	5.9	15.1	11.9	7.6	15.0	1.8	12.9	171
1998	6.4	115	8.2	18.2	13.8	8.4	16.0	2.1	16.1	204
1999	6.5	109	7.9	18.4	13.2	8.3	18.1	1.9	14.1	197
2000	6.9	109	9.0	21.1	13.6	8.2	18.9	2.1	15.1	204
2001	5.8	103	7.1	16.2	11.9	7.8	15.6	1.9	13.9	183
2002	4.8	95.1	5.5	13.4	10.4	6.8	14.5	1.8	13.7	166
2003	5.3	91.2	6.6	15.1	12.0	7.0	14.7	1.7	12.6	166
2004	5.0	92.2	6.1	13.4	12.0	7.0	13.8	1.7	12.9	164
2005	5.2	90.8	7.3	14.7	11.4	6.9	14.2	1.6	12.2	164
2006	5.5	100	6.4	16.1	11.1	7.1	16.6	1.9	14.0	179
2007	5.2	90.5	6.0	13.2	11.9	7.3	12.2	1.6	11.7	160
2008	5.4	92.9	6.1	14.3	12.8	7.8	13.0	1.5	11.3	165
2009	4.5	80.1	5.2	12.7	9.5	6.1	12.8	1.5	11.2	144
2010	4.9	87.0	6.0	14.2	10.8	6.5	10.8	1.3	10.3	152
2011	4.8	80.9	6.0	13.4	10.6	6.5	12.3	1.4	10.6	147
2012	5.5	87.6	6.9	15.2	11.3	7.0	12.7	1.5	10.6	158
2013	4.4	73.1	4.7	10.4	9.9	5.7	10.3	1.2	9.7	129
2014	4.4	74.9	5.4	12.9	9.0	5.2	12.5	1.4	10.9	137
2015	3.9	72.1	5.3	10.9	8.7	5.4	11.2	1.4	11.0	130
2016	3.5	64.0	4.7	10.7	8.4	4.7	10.0	1.2	9.9	117
2017	3.8	70.9	4.7	10.9	8.6	5.3	10.3	1.2	9.3	125
2018	3.8	64.5	4.8	11.2	8.5	5.0	9.6	1.1	8.6	117
2019	4.3	68.5	4.4	11.4	8.9	5.6	10.5	1.2	8.7	123
2020	3.8	62.0	4.9	10.6	8.0	5.2	8.8	1.0	7.2	111
Ref	**5.8**	**102**	**7.2**	**16.8**	**12.4**	**7.7**	**16.1**	**1.9**	**14.1**	**184**

Table 4. Actual depositions of reduced nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2020. 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	2.9	73.8	3.7	7.1	7.2	5.5	14.7	1.5	15.7	132
1991	2.9	69.3	3.7	7.5	7.6	5.9	13.6	1.5	14.3	126
1992	3.1	70.4	4.3	8.1	8.7	5.6	13.0	1.4	14.1	129
1993	3.1	73.5	3.2	8.6	6.3	4.8	13.1	1.5	13.9	128
1994	2.4	68.5	2.7	6.1	6.4	4.9	12.6	1.4	14.8	120
1995	2.7	58.2	3.5	7.9	6.3	4.4	11.0	1.3	12.6	108
1996	2.9	61.7	2.9	7.3	7.1	5.0	10.3	1.2	11.3	110
1997	2.0	50.9	2.2	5.3	4.7	3.8	11.3	1.2	12.3	93.6
1998	2.7	65.1	3.5	7.4	6.4	4.5	12.0	1.5	15.0	118
1999	2.9	61.6	3.6	8.1	6.1	4.5	13.6	1.3	13.1	115
2000	3.3	63.8	4.0	9.9	5.9	4.3	13.4	1.4	13.8	120
2001	2.8	59.3	3.2	7.5	5.6	4.4	11.5	1.3	12.5	108
2002	2.1	56.0	2.8	5.8	4.6	3.4	10.5	1.3	12.0	98.5
2003	2.4	53.1	3.3	7.1	5.2	3.7	11.2	1.2	11.9	99.0
2004	2.0	52.3	2.5	5.2	5.2	3.9	10.5	1.2	12.8	95.6
2005	2.2	53.8	3.5	6.7	5.2	3.8	10.9	1.2	12.7	99.8
2006	2.4	59.9	2.8	7.0	5.1	4.0	11.9	1.3	13.7	108
2007	2.3	56.0	2.5	5.5	5.7	4.1	9.5	1.3	11.8	98.6
2008	2.4	57.6	2.7	6.4	6.4	4.5	11.0	1.2	12.9	105
2009	2.3	54.7	2.9	6.4	4.6	3.6	10.9	1.2	12.6	99.3
2010	2.5	57.1	3.7	8.2	5.7	4.1	10.1	1.1	12.5	105
2011	2.5	57.1	3.1	7.2	5.2	4.0	11.0	1.2	13.3	105
2012	3.0	61.0	3.5	7.7	6.0	4.7	11.4	1.3	13.6	112
2013	2.5	52.1	2.3	5.4	5.4	3.7	9.9	1.1	12.5	94.9
2014	2.3	57.6	2.8	6.9	5.1	3.7	11.7	1.2	13.7	105
2015	2.2	61.0	3.0	6.4	5.5	4.2	12.0	1.4	15.4	111
2016	2.1	50.4	2.8	6.4	5.4	3.3	10.6	1.2	13.6	95.8
2017	2.2	57.2	2.7	6.1	5.6	3.8	11.4	1.3	14.3	105
2018	2.3	51.7	3.0	7.0	5.6	3.9	10.4	1.2	12.2	97.4
2019	2.6	55.2	2.7	7.3	5.9	4.3	10.9	1.2	12.7	103
2020	2.4	54.9	2.9	6.5	5.4	4.3	10.2	1.2	11.6	99.2
Ref	**2.6**	**58.5**	**3.2**	**7.3**	**5.5**	**4.1**	**11.9**	**1.3**	**13.0**	**107**

Table 5. Actual depositions of total nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2020. 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	10.0	206	13.1	26.4	23.6	16.3	33.3	3.6	32.1	364
1991	10.0	192	12.4	26.2	23.7	16.6	31.1	3.6	29.9	346
1992	9.8	194	13.3	27.6	24.2	15.5	30.6	3.6	29.7	349
1993	10.0	200	11.4	28.4	20.0	13.8	30.4	3.7	30.1	348
1994	8.7	191	9.8	23.1	20.0	13.7	29.9	3.6	31.6	331
1995	9.0	166	11.5	25.7	20.1	12.7	26.0	3.2	26.7	301
1996	9.5	169	10.0	24.5	21.0	13.3	25.2	3.0	24.8	300
1997	7.2	147	8.1	20.4	16.5	11.4	26.3	3.0	25.2	265
1998	9.0	180	11.7	25.6	20.2	13.0	28.1	3.6	31.1	322
1999	9.4	170	11.5	26.4	19.3	12.8	31.6	3.2	27.3	312
2000	10.1	173	13.0	31.0	19.5	12.5	32.3	3.5	28.9	324
2001	8.6	162	10.3	23.7	17.5	12.1	27.1	3.2	26.5	291
2002	6.9	151	8.3	19.1	15.0	10.2	25.0	3.0	25.7	264
2003	7.7	144	9.9	22.2	17.2	10.6	25.9	2.9	24.4	265
2004	7.0	144	8.6	18.6	17.2	11.0	24.3	2.9	25.8	260
2005	7.3	145	10.9	21.4	16.6	10.7	25.1	2.7	24.8	264
2006	7.8	160	9.2	23.1	16.2	11.0	28.5	3.2	27.6	287
2007	7.4	147	8.6	18.8	17.6	11.4	21.7	2.9	23.5	258
2008	7.9	151	8.8	20.7	19.2	12.2	24.0	2.7	24.2	270
2009	6.8	135	8.1	19.1	14.0	9.7	23.7	2.7	23.8	243
2010	7.4	144	9.7	22.4	16.5	10.7	20.9	2.4	22.8	257
2011	7.3	138	9.1	20.6	15.8	10.5	23.4	2.6	23.9	251
2012	8.5	149	10.4	23.0	17.3	11.7	24.1	2.7	24.2	270
2013	6.9	125	7.0	15.7	15.3	9.4	20.1	2.4	22.3	224
2014	6.7	133	8.2	19.8	14.0	8.9	24.2	2.6	24.5	242
2015	6.2	133	8.2	17.3	14.3	9.6	23.1	2.9	26.4	241
2016	5.6	114	7.5	17.2	13.8	8.0	20.5	2.4	23.5	213
2017	6.0	128	7.5	17.0	14.2	9.1	21.6	2.6	23.6	230
2018	6.1	116	7.9	18.3	14.1	8.9	19.9	2.3	20.8	214
2019	6.9	124	7.2	18.7	14.8	10.0	21.5	2.4	21.4	226
2020	6.2	117	7.7	17.0	13.4	9.4	19.0	2.2	18.8	211
Ref	**8.4**	**161**	**10.4**	**24.1**	**17.9**	**11.8**	**28.0**	**3.2**	**27.0**	**292**

Table 6. Normalized depositions of oxidised, reduced and total nitrogen to the Baltic Sea basin in the period 1990 – 2020. 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 oxidised and reduced nitrogen; this is due to the use of medians during normalization.)

Year	Oxidised Nitrogen	Reduced Nitrogen	Total Nitrogen
1990	248.1	150.5	400.2
1991	243.6	141.2	386.8
1992	233.8	133.9	369.5
1993	223.2	128.3	353.2
1994	215.8	124.0	341.4
1995	208.7	120.0	330.1
1996	208.1	118.3	327.5
1997	201.0	117.2	319.2
1998	195.6	116.4	313.0
1999	191.2	113.6	305.8
2000	187.2	110.7	299.0
2001	184.2	109.4	294.7
2002	179.7	108.0	288.9
2003	178.4	106.8	286.5
2004	175.7	105.3	282.4
2005	172.9	105.6	280.0
2006	171.0	104.7	277.1
2007	166.8	105.1	273.1
2008	157.7	103.6	262.2
2009	147.6	101.8	250.2
2010	149.5	101.5	251.3
2011	144.4	100.7	245.6
2012	141.1	100.1	241.8
2013	137.1	100.2	238.0
2014	130.3	101.0	232.1
2015	128.3	101.6	230.6
2016	125.8	101.4	227.8
2017	124.5	102.0	227.0
2018	121.3	100.9	222.2
2019	117.5	98.2	215.5
2020	106.7	96.9	203.8
Ref	**188.2**	**112.7**	**301.0**

Metadata

Technical information

1. Source: EMEP MSC-W.

2. Description of data: The atmospheric depositions of oxidised and reduced nitrogen were calculated with the EMEP MSC-W model, version rv4.45. Emission data based on official data submissions from the HELCOM countries received by June 2022 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 oxidised 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 – 2020.

5. Methodology and frequency of data collection:

Atmospheric input and source allocation budgets of nitrogen (oxidised, reduced and total) to the Baltic Sea basins and catchments were computed using the EMEP MSC-W model, version rv4.45. 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 oxidised 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:

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