Estimation of Exceedance of Critical Atmospheric Nitrogen Inputs (CAI) to the Baltic Sea

Markus Geupel, Bo Gustafsson, Wera Leujak, Thomas Scheuschner, Gudrun Schütze

ECE/EB.AIR/2020/3, Annex 1: Question 2.8. What are the expected impacts of new scientific findings on environmental and health effects assessments?

According to Annex 1, Question 2.8 the Working Group on Effects is assigned to deliver information on the risk of eutrophication of marine ecosystems by atmospheric nitrogen deposition. By cooperation of an Ad-hoc Expert Group on Marine Protection (AMP) under CLRTAP with experts of the Reduction Scheme Core Drafting Group (RedCore DG) under HELCOM, EMEP MSC-West and the Coordination Center for Effects (CCE) of the ICP Modelling and Mapping a method has been developed to provide first, preliminary answers.

Methods and data

Critical Atmospheric Inputs (CAI) of nitrogen for different regions of the Baltic Sea (Baltic sub-basins) have been provided by RedCore DG. The CAI are based on the Maximum Allowable Inputs (MAI) derived by HELCOM (2013) for each Baltic sub-basin (figure 1, table 1). MAI are effect-based quantitative estimates of maximum total inputs, including atmospheric deposition, nutrients from rivers and from direct inputs into the sea which would still allow gradual recovery of the sub-basins from eutrophication. MAI only apply for the open Sea, not for coastal waters (the 1 nautical mile zone).

Figure 1: Sub-basins of the Baltic Sea under consideration.

MAI aim at a good ecological status, which is defined by clearness of the water, natural levels of nutrient and oxygen concentrations, natural occurrence of plants, including algae, and animals. MAI are available for phosphorus and nitrogen, but only MAI for nitrogen have been used as basis for CAI, since atmospheric phosphorus deposition is not relevant for Baltic eutrophication. However, interactions between phosphorus and nitrogen in sea water are considered in the models used to derive MAI. Details on the methods to derive MAI including the specific indicators used are provided in HELCOM (2013).

By dividing the MAI (in tonnes or kilogramme per sub-basin) by the area of the sub-basin the MAI for nitrogen can be expressed in mass per hectare and year, so that they can be compared to critical loads for terrestrial ecosystems, although the differences in the methodology have to be kept in mind.

CAI are calculated as a part of MAI considering the share of atmospheric deposition of the total load in the selected reference time period 2017-2019. For that, data on wet and dry nitrogen deposition from EMEP MSC-West were used (see figure 2). Two CAI calculation options have been tested (Gustafsson et al. 2021):

a) only one CAI value per Baltic sub-basin,
b) CAI values for single EMEP grids, taking the atmospheric deposition pattern over the Baltic Sea into account.

Only results of option a) are presented here since they seemed more plausible and were therefore recommended for further use in the Gothenburg Protocol review.

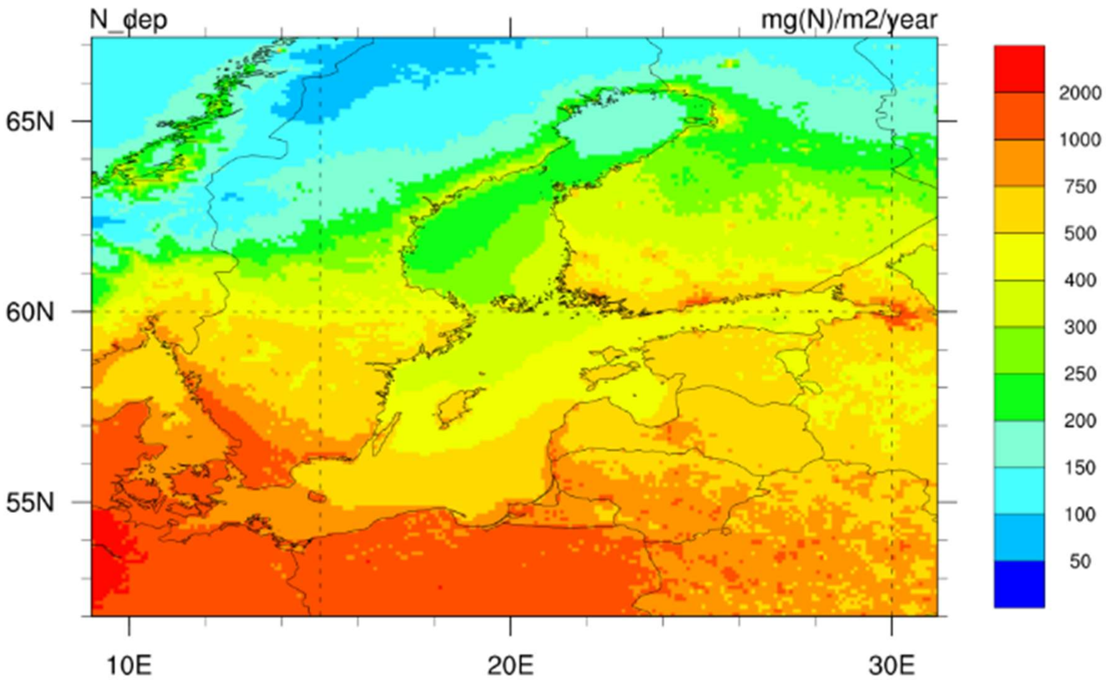

Figure 2: Map of the annual deposition of total (oxidised + reduced) nitrogen for the reference period 2017-2019. Units: mg N m^{-2} yr^{-1} = kg N km^{-2} yr^{-1}.

The CCE calculated the exceedance of CAI expressed as the Average Accumulated Exceedance (AAE) of the Baltic sub-basins using the most recent deposition data from EMEP MSC-West (2019, data as delivered in May 2021, described in Fagerli et al. (2021) based on the EMEP model version rv4.42 and emission data reported by CEIP in 2021. More details on the development of the method and preliminary results are provided in in Gustafsson et al (2021) and in the CCE Status Report 2022 (CCE 2022, in prep.).

Furthermore, the AAE was calculated for the sub-basins using modelled deposition for the year 2030 based on emission scenarios “Baseline” and “Maximum Feasible Reduction” (MFR). This data was produced and provided by EMEP/MSC-W (in July 2022) and the underlying emission estimations are the same as used in the GAINS-model for the Gothenburg Protocol Review (more detailed information is published in Fagerli et al. (2022).

Results

An overview of data on the area of the seven Baltic sub-basins, the deposition, the MAI and CAI, the ratio of CAI to MAI as well as the results of AAE calculations using calculation option a) is provided in table 1. Due to the chosen method to calculate CAI (and its relation to the atmospheric deposition), the sensitivity to nitrogen deposition expressed by CAI does not show the same pattern as the sensitivity values expressed by MAI. The ratio of CAI/MAI shows values between 11% and 43%.

The overall AAE on basin level in general seems not very high compared to the AAE of the terrestrial ecosystems. The exceedance might be higher in selected regions within the sub-basins. Figure 3 shows the results for AAE. The highest exceedance is indicated for the south-western part of the Baltic Proper. There are also tendencies to have higher AAE in (deposition) grids close to the coastlines. Since only one single CAI value is used per sub-basin, the shown gradients within a sub-basin reflect the gradient of deposition.

Table 1: Overview of Basin area, MAI, CAI and AAE (2019), all values are given in relation to the area of [1 ha a^{-1}]. The reference period for deposition in order to calculate CAI from MAI is 2017 - 2019.

	Area [Mio. ha]	**Depo 2019 [kg ha^{-1} yr^{-1}]**	**MAI [kg ha^{-1} yr^{-1}]**	**CAI [kg ha^{-1} yr^{-1}]**	**CAI / MAI**	**AAE 2019 [kg ha^{-1} yr^{-1}]**
Baltic Proper	20.926	6.0	15.5	4.20	27%	1.78
Bothnian Bay	3.625	1.9	15.9	2.31	15%	0.02
Bothnian Sea (including the Archipelago Sea)	7.880	3.6	12.1	3.99	33%	0.06
Gulf of Finland	3.000	4.8	33.9	5.41	16%	0.08
Gulf of Riga	1.865	5.2	47.4	5.34	11%	0.13
Kattegat	2.366	9.3	31.3	9.64	31%	0.25
Danish Straits (comprising The Sound and Western Baltic)	2.097	10.4	31.5	13.48	43%	0.09
Total/Avg	41.759	5.9				0.94

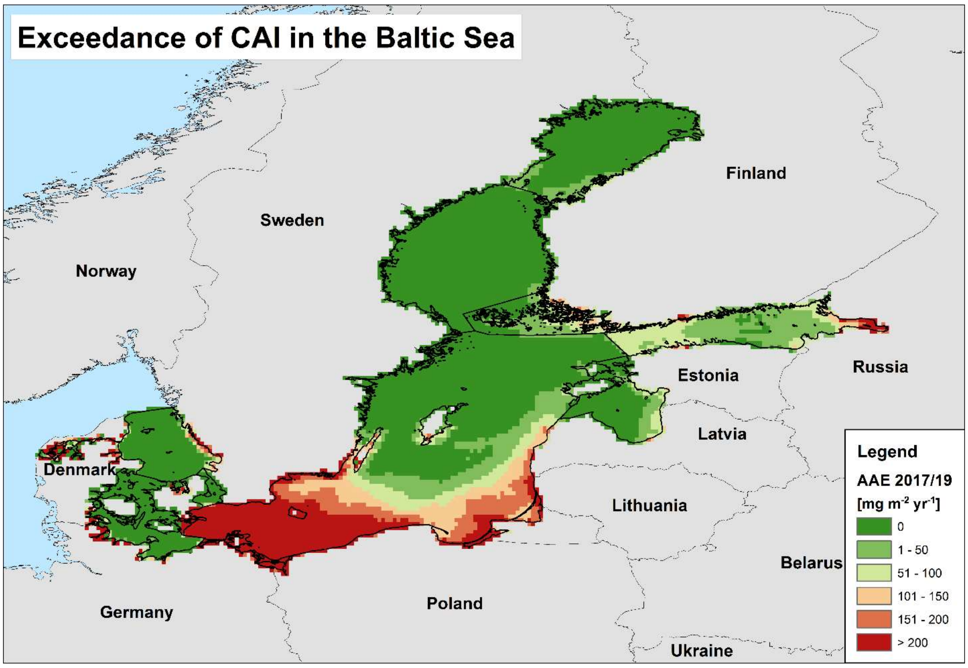

Figure 3: CAI exceedance for the deposition year 2019 using sub-basin specific CAI [mg m^{-2} yr^{-1}][1].

Table 2: Overview of nitrogen deposition and AAE (2030) [kg ha^{-1} yr^{-1}] per Baltic sub-basin using scenarios "Baseline" and "Maximum Feasible Reduction" (MFR,) based on CAI calculations for reference period for deposition in 2017 - 2019.

	Depo 2030 Baseline	Depo 2030 MFR	AAE 2030 Baseline	AAE 2030 MFR
Baltic Proper	4.6	3.9	0.71	0.38
Bothnian Bay	1.5	1.3	0.00	0.00
Bothnian Sea (including the Archipelago Sea)	2.2	1.9	0.00	0.00
Gulf of Finland	3.2	2.8	0.00	0.00
Gulf of Riga	3.6	3.2	0.00	0.00
Kattegat	7.3	6.4	0.03	0.01
Danish Straits (comprising The Sound and Western Baltic)	9.1	7.9	0.02	0.00
Total/Avg	4.5	3.9	0.11	0.06

The deposition in 2030 using the Baseline scenario, which in short means the implementation of currently existing legislation, will lead to less than halve the AAE in the sub-basins compared to 2019, while MFR will leave some AAE only in Baltic Proper and very small AAE in Kattegat. Still, it has to be stressed that the exceedance in some parts of the basins is higher, in particular along the coast lines.

[1] 200 mg m^{-2} yr^{-1} equals 2 kg ha^{-1} yr^{-1}

Discussion and conclusion

The calculation of CAI as used here implies some assumptions, which have to be considered in the interpretation of the results. Using only one CAI value per sub-basin the sensitivity against nitrogen deposition is assumed to be equal within a single sub-basin because of long-term mixing processes of the water body. The resulting CAI exceedance principally follows the gradient of atmospheric nitrogen deposition from west to east. CAI exceedance is, however, low in the Western Baltic Sea due to high MAI assumed for this area, probably as a result of difficulties in modelling water exchange processes with the North Sea. Due to the method used to calculate CAI, with deposition in the reference period having a strong influence, CAI do not fully display nitrogen sensitivity of the water bodies as expressed by the MAI. The method leads to higher CAI for sub-basins where the absolute values and the share of deposition is high (e.g. Danish Straits, see table 1).

The results as presented here should be regarded as a first attempt to evaluate the risk of eutrophication of the Baltic Sea by atmospheric nitrogen deposition. As described in AMP/RedCore (2021), the method represents a simple, pragmatic approach to get a first impression of the geographical area and extent of CAI exceedances. The estimates of exceedances of CAI give a reasonable impression of the general extent of risk for the different Baltic sub-basins.

A more sophisticated method is needed to overcome the uncertainties of the simple approach. As part of future work Integrated Assessment Modelling should be used aiming at cost-optimised reduction targets taking all sources of nitrogen inputs into account. To this end, "scenario development… including cost-effectiveness analysis of specific measures and assessment of the implication of improved modelling, among others, inclusion of … marine deposition targets", is fixed in the CLRTAP workplan for 2022/2023 (see task 1.1.3.2, ECE/EB.AIR/2021/2). When revising the MAIs for the Baltic Sea in the future by HELCOM working groups, efforts should be undertaken to derive grid-based MAIs as a basis for a more precise calculation of CAI that adequately considers ecosystem sensitivity to nitrogen inputs.

Coastal waters are the most sensitive zones of the Baltic Sea with respect to eutrophication. At the same time, they often receive higher atmospheric nitrogen deposition than the open sea due to sources on land. The coastal waters have not been considered in the MAI and CAI calculation, because they fall under the EU Water Framework Directive (WFD 2000/60/EC). Therefore, co-operation beyond CLRTAP and HELCOM including EU WFD experts would be needed to include these sensitive ecosystems in future projects.

References:

AMP/RedCore (2021): Options to consider marine eutrophication in the review of the Gothenburg Protocol. A joint report of the Ad-hoc group on Marine Protection (AMP) under the CLRTAP and the Working Group RedCore under HELCOM to the 7. Joint Meeting of EMEP SB and the WGE, 13 – 16 September 2021. Informal document. https://unece.org/environment/documents/2021/09/informal-documents/agenda-item-7-options-consider-marine

CCE 2022: CCE Status Report 2022. in preparation. Downloadable from October 2022 onwards at https://www.umweltbundesamt.de/en/Coordination_Centre_for_Effects

ECE/EB.AIR/2020/3: Preparations for the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone as amended in 2012, Gothenburg Protocol review group, Executive Body for the

Convention on Long-range Transboundary Air Pollution, Fifty-eighth session, Geneva, 14–15 and 17 December 2020, Item 5. ECE_EB.AIR_2020_3-2012770E.pdf (unece.org)

ECE/EB.AIR/2021/2: Draft 2022–2023 workplan for the implementation of the Convention, Executive Body for the Convention on Long-range Transboundary Air Pollution, Forty-first session, Geneva, 6–8 December 2021, Item 8. https://unece.org/sites/default/files/2021-10/ECE_EB.AIR_2021_2-2113539E.pdf

Fagerli H, Tsyro S, Simpson D et al. (2021): Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components, EMEP Status Report 2021; September 3, 2021, https://emep.int/publ/reports/2021/EMEP_Status_Report_1_2021.pdf .

Fagerli H, Benedictow A, Denby B R et al. (2022): Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components, EMEP Status Report 2022; August 25, 2022, http://emep.int/publ/emep2022_publications.html .

Gustafsson B, Sokolov A, Gauss M (2021): Estimation of Critical Atmospheric nitrogen Inputs (CAI), In: Progress in accounting for marine eutrophication in the review of the Gothenburg, 15th Meeting of the Working Group on Reduction of Pressures from the Baltic Sea Catchment Area, Online, 2-4 November 2021, Document code 7-9 (PRESSURE 15, 7-9 (2021), Annex 2. https://portal.helcom.fi/meetings/PRESSURE%2015-2021-944/MeetingDocuments/Forms/AllItems.aspx

HELCOM (2013): Summary report on the development of revised Maximum Allowable Inputs (MAI) and updated Country Allocated Reduction Targets (CART) of the Baltic Sea Action Plan, prepared for the 2013 HELCOM Ministerial Conference, Baltic Marine Environment Protection Commission, https://helcom.fi/wp-content/uploads/2019/08/Summary-report-on-MAI-CART-1.pdf