TEXTE
135/2022

CCE Status Report 2022

Coordination Centre for Effects (CCE)

by:

Markus Geupel, Christin Loran, Thomas Scheuschner, Lena Wohlgemuth

Coordination Centre for Effects
German Environment Agency, Dessau, Germany

publisher:

German Environment Agency

Umwelt Bundesamt

TEXTE 135/2022

CCE Status Report 2022

November 2022

by

Markus Geupel, Christin Loran, Thomas Scheuschner,
Lena Wohlgemuth
Coordination Centre for Effects
German Environment Agency, Dessau, Germany

On behalf of the German Environment Agency

Imprint

Publisher
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
buergerservice@uba.de
Internet: www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt

Report performed by:
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Germany

Report completed in:
September 2022 // The tables and figures on pages 38-53 were revised in July 2023.

Edited by:
Section Section II 4.3 “Air Pollution and Terrestrial Ecosystems”
Markus Geupel, Christin Loran, Thomas Scheuschner, Lena Wohlgemuth

Publication as pdf:
https://www.umweltbundesamt.de/en/publications

ISSN 1862-4804

Dessau-Roßlau, December 2022

Abstract: CCE Status Report 2022

The Coordination Centre for Effects (CCE) is the programme centre for the International Cooperative Programme on Modelling and Mapping (ICP M&M) under the Working Group on Effects of the Convention of Long-range Transboundary Air Pollution (CLRTAP). The mandate of the CCE is to develop and update methodologies for assessing critical loads (CL), to compile data on CL and to generate maps of CL and their exceedances. Following these goals, this report describes main CCE activities since the CCE was transferred to the German Environment Agency (UBA) from the Dutch National Institute for Public Health (RIVM) in 2018. These activities include the following major projects: i) Coordination of a revision process of empirical CL for nitrogen ($CL_{emp}N$) in Europe resulting in scientifically adjusted $CL_{emp}N$ ranges based on the last $CL_{emp}N$ update in 2011; ii) Call for national data on CL which yielded updated national CL maps representing a respective spatial coverage of 40% for eutrophication and 45% for acidification of the model domain; iii) Updating the European background database for CL calculation, which was necessary in order to ensure a frictionless transfer of data and knowledge from RIVM to UBA. A comparison of CL data between old and new database revealed only minor quantitative differences related to changes in input parameters to the simple mass balance (SMB) model for calculating CL; iv) Assessing CL exceedances, which were calculated from CL values of national data, the updated European CL background database and modelled historic and projected deposition values provided by the EMEP Meteorological Synthesizing Center (MSC) West depending on past emissions and emission scenarios for 2030 - 2050 respectively. Calculated exceedances of CL in the investigated years 2000 - 2020 occurred in a relatively large area of around 74% - 61% (decreasing trend from 2000 - 2020) of the model domain for eutrophication and a smaller area of 14% - 4% for acidification. Projections of CL exceedances for the years 2030 to 2050 as a function of multiple emission scenarios highlighted ecosystem risks for eutrophication even under low emission scenarios; v) Estimation of exceedance of critical atmospheric nitrogen inputs to the Baltic sea as a first attempt to evaluate the risk of open sea eutrophication.

Kurzbeschreibung: CCE Status Report 2022

Das Coordination Centre for Effects (CCE) ist das Programmzentrum für das International Coordinative Programme on Modelling and Mapping (ICP M&M) der Working Group on Effects des Übereinkommens über weiträumige grenzüberschreitende Luftverunreinigung (CLRTAP). Das Mandat des CCE besteht in der Entwicklung und Aktualisierung von Methoden zur Ermittlung von Critical Loads (CL), in der Zusammenstellung von CL Daten und in der Erstellung von Karten zu CL und deren Überschreitungen. Von diesem Mandat ausgehend, beschreibt dieser Bericht die wichtigsten CCE Aktivitäten seit das CCE 2018 vom Dutch National Institute for Public Health (RIVM) auf das Umweltbundesamt (UBA) übertragen wurde. Diese Aktivitäten umfassen die folgenden Projekte: i) Koordinierung eines Überarbeitungsprozesses der empirischen CL für Stickstoff (CLempN) in Europa, was zu wissenschaftlich angepassten CLempN-Bereichen führe bezogen auf die letzte CLempN-Aktualisierung im Jahr 2011; ii) Call for Data zu nationalen CL, welcher zu aktualisierten nationalen CL-Karten führte mit einer räumlichen Abdeckung im Modellgebiet von 40% für Eutrophierung und 45% für Versauerung; iii) Aktualisierung der europäischen Hintergrunddatenbank für CL-Berechnungen, die notwendig war, um einen reibungslosen Transfer von Daten und Wissen vom RIVM zum UBA zu gewährleisten. Ein Vergleich der CL-Daten in der alten und der neuen Datenbank ergab nur geringfügige quantitative Unterschiede, die mit Änderungen der Eingabeparameter für das einfache Massenbilanzmodell (SMB) zur Berechnung der CL zusammenhängen; iv) Bewertung der CL-Überschreitungen berechnet aus CL-Werten nationaler Daten, der aktualisierten europäischen CL-Hintergrunddatenbank und modellierten historischen und prognostizierten Depositionswerten des EMEP Meteorological Synthesizing

Center (MSC) West in Abhängigkeit von früheren Emissionen bzw. Emissionsszenarien für die Jahre 2030 - 2050. Ergebnisse der Überschreitungsrechnung zeigen CL-Überschreitungen in den untersuchten Jahren 2000 - 2020 für einen relativ großen Bereich von etwa 74% - 61% (abnehmender Trend für 2000 – 2020) des Modellgebiets für Eutrophierung und einen kleineren Bereich von 14% -4% für Versauerung. Projektionen der CL-Überschreitungen für die Jahre 2030 bis 2050 in Abhängigkeit von mehreren Emissionsszenarien zeigen die Risiken für die Eutrophierung von Ökosystemen auf, selbst bei Szenarien mit niedrigen Emissionen; v) Abschätzung der Überschreitung kritischer atmosphärischer Stickstoffeinträge in die Ostsee als erster Versuch, das Risiko der Eutrophierung der offenen See zu bewerten.

Table of content

List of figures

List of tables

List of abbreviations

AAE	Average Accumulated Exceedance
AMP	Ad-hoc Expert Group on Marine Protection
CAI	Critical Atmospheric Inputs
CCE	Coordination Centre for Effects
CDF	Cumulative Distribution Function
CEIP	Centre for Emission Inventories and Projections
CfD	Call for Data
CIAM	Centre for Integrated Assessment Modelling
CLE	current legislation (scenario)
CLempN	Empirical Critical Loads of nitrogen
CLmaxN	Maximum Critical Load for nitrogen
CLmaxS	Maximum Critical Load for sulphur
CLminN	Minimum Critical Load for nitrogen
CLnutN	Critical Load for nutrient nitrogen
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CL	Critical Loads
EEA	European Environment Agency
Efiscen	European Forest Information SCENario Model
EMEP	European Monitoring and Evaluation Programme
EU	European Union
EUDB	European Background Database
EUNIS	European Nature Information System
HELCOM	Helsinki Commission
HM	Heavy metals
ICP	International Cooperative Programme
LOW	low emission scenario
MFR	most feasible reduction (scenario)
MSC-W	Meteorological Synthesizing Centre West
NEC	National Emissions reduction Commitments
NFC	National Focal Centre
RedCore DG	Reduction Scheme Core Drafting Group
RIVM	Dutch for National Institute for Public Health and the Environment
SMB	Simple Mass Balance
UBA	German for Federal Environment Agency
UNECE	United Nations Economic Commission for Europe
WEG	Working Group of Effects

Summary and introduction

Air pollution causes severe threats on plants, ecosystems and ecosystem integrity. Anthropogenic emissions of air pollutants are a serious risk for biodiversity. The UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) was initiated in 1979 as a result of the observed relationship between anthropogenic air pollution and acidification of soils and waters, and has been instrumental for reducing pollutant emissions. An important implementation of the emission reduction goals of the CLRTAP is the Gothenburg Protocol on the reduction of specific air pollutants to abate acidification, eutrophication and ground-level ozone. In the context of integrated assessments performed by the CLRTAP under the Gothenburg Protocol, ecosystem-specific critical loads (CL) of acidity and of nutrient nitrogen and respective CL exceedances are deployed to assess cost-effective solutions for emission abatement.

Critical loads are quantitative estimates used to assess and map harmful levels of deposition of different air pollutants on ecosystems, hereby informing policy decisions under the CLRTAP. Besides the costs of emission abatement, the spatially resolved ecosystem vulnerability (expressed by critical loads) is decisive for the composition and development of (European) air pollution policies. In correspondence to their use in the framework of the CLRTAP, CL are also taken into consideration at EU level in the context of the NEC-Directive 2016/2284, which sets emission reduction targets for air pollutants to reduce the levels and deposition of acidifying, eutrophying and ozone air pollution below critical loads and levels as set out by the CLRTAP. Furthermore, exceedances of CL for eutrophication are also used as an indicator in other frameworks of nature protection such as the EU biodiversity strategy (EEA headline indicator). Finally, besides those broad-scale applications of CL, there exist specific regional and local applications in several countries to inform decisions on new and existing emission sources near protected habitats. In nature protection assessments, CL can be used for the reporting on the conservation status of ecosystems and habitats.

Under the CLRTAP, air pollution effects and risks for ecosystems and vegetation are regularly assessed by the Working Group on Effects (WGE) and its International Cooperative Programmes (ICPs). Direct effects of air pollutants on vegetation have been documented for pollutants such as nitrogen oxides (NOx), ammonia (NH_3), sulphur dioxide (SO_2) or ozone (O_3). Additionally, heavy metals (HMs), which spread in the environment via atmospheric dispersion can affect sensitive elements of the vegetation. Risks of eutrophication and acidification, caused by the emission and deposition of nitrogenous and sulfuric gases are quantified on the one hand with modelled area-wide maps by the ICP Modelling & Mapping (ICP M&M) and on the other hand with monitoring data of selected sites of ICP Forests (ICP F) and ICP Integrated Monitoring (ICP IM). This report focuses on model-based area-wide risk assessment of eutrophication and acidification performed by the Coordination Centre for Effects (CCE), one of the two Programme Centres to the ICP M&M.

The tasks of the CCE are documented in the mandate of the ICP and Programme Centres under the Working Group on Effects (ECE/EB.AIR/2019/9). In this respect, CCE is responsible for the coordination of the technical work regarding CL reporting and corresponding methodological developments under ICP M&M. To this, CCE develops and implements databases for the calculation of CL, their exceedances and their mapping at the spatial scale of the convention parties in close cooperation with National Focal Centres. In this report, the setup of the current CLRTAP Critical Load (CL) databases consisting of reported national CL data, modelled gap-filling data and Empirical Critical Loads ($CL_{emp}N$) is documented.

Chapter 1 summarizes the cooperative, international process to review and revise knowledge and values of $CL_{emp}N$. The review and revision of the 2010 $CL_{emp}N$ database was coordinated by the CCE from 2020 until 2022. The updated list of $CL_{emp}N$ contains CL values for 51 different receptors. There was enough evidence to take up 9 new ecosystems in the list of sensitive receptors and adapt the values for 36 receptors. Most of the revised values have been lowered considering latest scientific findings.

The policy relevant Critical Load database which was used for the review of the Gothenburg Protocol is presented in chapter 2 and 3. The national CL data was collected from National Focal Centres to the ICP Modelling & Mapping through a Call for Data announced in the framework of the ICP M&M Task Force in 2019. The country reports and national data are documented in Chapter 2 of the report and in Appendix A (p. 62).

For countries that did not calculate and deliver national data, the CCE fills the gaps with CL data from the so-called background database. The background database facilitates the modelling of CL for European countries under the CLRTAP and has recently been reviewed and updated by the CCE. The documentation of the reworked database is summarized in this report under chapter 3.

Furthermore, to support the current cooperative review of the Gothenburg Protocol under the CLRTAP, risks of acidification and eutrophication of ecosystems have been calculated by the CCE for the European parties to the convention. This work was completed in close cooperation with other bodies of the convention under the EMEP Programme, namely the Centre for Emission Inventories and Projections (CEIP), the Centre for Integrated Assessment Modelling (CIAM) and the Meteorological Synthesizing Centre West (MSC-W). Resulting time series of CL exceedances are documented in chapter 4.

In chapter 5 first steps to include marine ecosystems into the effects-based approaches of the CLRTAP are documented. The CCE contributed to the work of the Ad-hoc Expert Group on Marine Protection (AMP) which was installed 2021 in the framework of the review of the Gothenburg Protocol to assess the potential to include air pollution effects on the Baltic Sea into the integrated assessments schemes of the CLRTAP. Chapter 5 describes first results, which have been achieved by cooperation of the AMP with experts of the Reduction Scheme Core Drafting Group (RedCore DG) under HELCOM, EMEP MSC-West, ICP Waters, the Task Force on Integrated Assessment Modelling and the Coordination Centre for Effects (CCE) of the ICP Modelling and Mapping.

With this report, the CCE team fulfils its responsibility to publish information on methods and results for assessing air pollution impacts on ecosystems at UNECE-wide scale, hereby continuing the long tradition of CCE status reports. This status report is the first CCE report since 2017, before the programme centre was transferred from the Netherlands (RIVM) to Germany (UBA) in 2018. Between 2019 and 2021 the current CCE implemented standard procedures in its new IT and administrative structures, reviewed data, built up and fostered the necessary expert networks, and launched new projects. The new CCE-team at UBA would like to thank its predecessors at RIVM for their help during this transition phase. This 2022 CCE Status Report publishes, for the first time, results of the technical and coordinative work of the first three years of work by the new CCE team. Previous CCE reports (published by RIVM) are still electronically available at the CCE homepage[1].

[1] https://www.umweltbundesamt.de/en/cce-status-reports?parent=68093

Zusammenfassung

Luftschadstoffe stellen eine ernsthafte Bedrohung für die biologische Vielfalt und Integrität von Ökosystemen dar. Das UNECE-Übereinkommen über weiträumige grenzüberschreitende Luftverschmutzung (CLRTAP) wurde 1979 aufgrund des Zusammenhangs zwischen anthropogener Luftverschmutzung und der Versauerung von Böden und Gewässern ins Leben gerufen und hat seitdem maßgeblich zur Verringerung der Schadstoffemissionen beigetragen. Eine wichtige Umsetzung der Emissionsminderungsziele des CLRTAP ist das Göteborg-Protokoll über die Verringerung spezifischer Luftschadstoffe zur Bekämpfung von Versauerung, Eutrophierung und bodennahem Ozon. Im Rahmen des Göteborg-Protokolls werden ökosystemspezifische Critical Loads (CL) für Versauerung und Stickstoffeinträge sowie entsprechende CL-Überschreitungen zur Bewertung kosteneffizienter Lösungen für die Emissionsverringerung herangezogen. Critical Loads sind quantitative Schätzungen, die zur Bewertung und Kartierung schädlicher Ablagerungen verschiedener Luftschadstoffe auf Ökosysteme verwendet werden und somit als Grundlage für politische Entscheidungen im Rahmen des CLRTAP dienen. Neben den Kosten der Emissionsminderung ist die räumlich aufgelöste Anfälligkeit von Ökosystemen (ausgedrückt durch Critical Loads) entscheidend für die Gestaltung und Entwicklung von (europäischer) Politik zu Luftschadstoffe. Entsprechend ihrer Verwendung in der CLRTAP werden CL auch auf EU-Ebene im Rahmen der NEC-Richtlinie 2016/2284 berücksichtigt, die Emissionsminderungsziele für Luftschadstoffe festlegt, um die Konzentration und Deposition von versauernden, eutrophierenden und ozonbildenden Luftschadstoffen unter die im CLRTAP festgelegten kritischen Belastungen und Werte zu senken. Darüber hinaus werden Überschreitungen der CL für Eutrophierung auch als Indikator in anderen Rahmenwerken des Naturschutzes wie der EU-Strategie zur Erhaltung der biologischen Vielfalt (EEA headline indicator) verwendet. Neben diesen breit angelegten Anwendungen der CL gibt es in mehreren Ländern auch spezifische regionale und lokale Anwendungen, um Entscheidungen über neue und bestehende Emissionsquellen in der Nähe geschützter Lebensräume zu treffen. Bei der Bewertung des Naturschutzes können die CL für die Berichterstattung über den Erhaltungszustand von Ökosystemen und Lebensräumen verwendet werden.

Im Rahmen der CLRTAP werden die Auswirkungen der Luftverschmutzung und die Risiken für Ökosysteme und Vegetation regelmäßig von der Working Group on Effects (WGE) und ihren internationalen Kooperationsprogrammen (ICP) bewertet. Direkte Auswirkungen von Luftschadstoffen auf die Vegetation wurden für Schadstoffe wie Stickoxide (NOx), Ammoniak (NH_3), Schwefeldioxid (SO_2) oder Ozon (O_3) dokumentiert. Außerdem können Schwermetalle (HM), die sich in der Umwelt durch atmosphärische Dispersion verbreiten, empfindliche Elemente der Vegetation beeinträchtigen. Die Risiken für Eutrophierung und Versauerung, die durch die Emission und Deposition von stickstoff- und schwefelhaltigen Gasen verursacht werden, werden einerseits mit modellierten flächendeckenden Karten des ICP Modelling & Mapping (ICP M&M) und andererseits mit Monitoringdaten ausgewählter Standorte des ICP Forests (ICP F) und des ICP Integrated Monitoring (ICP IM) quantifiziert. Dieser Bericht befasst sich mit der modellgestützten flächendeckenden Risikobewertung von Eutrophierung und Versauerung, die vom Coordination Centre for Effects (CCE), einem der beiden Programmzentren des ICP M&M, durchgeführt wurde. Die Aufgaben des CCE sind im Mandat des ICP und der Programmzentren der Arbeitsgruppe Working Group on Effects (ECE/EB.AIR/2019/9) dokumentiert. In diesem Zusammenhang ist das CCE für die Koordinierung der technischen Arbeiten bezüglich der CL-Berichterstattung und der entsprechenden methodischen Entwicklungen im Rahmen von ICP M&M verantwortlich. Dazu entwickelt und implementiert das CCE in enger Zusammenarbeit mit den National Focal Centres Datenbanken zur Berechnung der CL, ihrer Überschreitungen und ihrer Kartierung auf der räumlichen Ebene der Konvention. In diesem Bericht wird der Aufbau der

aktuellen CLRTAP-Datenbanken für Critical Loads (CL) dokumentiert, die aus gemeldeten nationalen CL-Daten, modellierten Daten und empirischen Critical Loads ($CL_{emp}N$) bestehen.

Kapitel 1 fasst den kooperativen, internationalen Prozess zur Überprüfung und Überarbeitung der Kenntnisse und Werte von $CL_{emp}N$ zusammen. Die Überprüfung und Überarbeitung der $CL_{emp}N$-Datenbank von 2010 wurde vom CCE von 2020 bis 2022 koordiniert. Die aktualisierte Liste der $CL_{emp}N$ enthält CL-Werte für 51 verschiedene Rezeptoren. Die wissenschaftliche Datenlage war groß genug, um 9 neue Ökosysteme in die Liste der empfindlichen Rezeptoren aufzunehmen und die Werte für 36 Rezeptoren anzupassen. Die meisten der überarbeiteten Werte wurden unter Berücksichtigung der neuesten wissenschaftlichen Erkenntnisse gesenkt. Die politikrelevante Critical-Load-Datenbank, die für die Überprüfung des Göteborg-Protokolls verwendet wurde, wird in Kapitel 2 und 3 vorgestellt. Nationale Daten zu CL wurden von den National Focal Centres von ICP M&M im Rahmen eines Call for Data gesammelt, der im Rahmen der ICP M&M Task Force 2019 erstmals angekündigt wurde. Die Länderberichte und nationalen Daten sind in Kapitel 2 des Berichts und in Anhang A (S. 15) dokumentiert. Für Länder, die keine nationalen Daten berechnet und geliefert haben, füllt das CCE die Lücken mit CL-Daten aus der sogenannten Hintergrunddatenbank. Die Hintergrunddatenbank erleichtert die Modellierung von CL für europäische Länder im Rahmen der CLRTAP und wurde kürzlich vom CCE überprüft und aktualisiert. Die Dokumentation der überarbeiteten Datenbank ist in diesem Bericht in Kapitel 3 zusammengefasst. Zur Unterstützung der laufenden kooperativen Überprüfung des Göteborger Protokolls im Rahmen der CLRTAP hat das CCE außerdem die Risiken für Versauerung und Eutrophierung von Ökosystemen für die europäischen Vertragsparteien des Übereinkommens berechnet. Diese Arbeit wurde in enger Zusammenarbeit mit anderen Gremien des Übereinkommens im Rahmen des EMEP-Programms durchgeführt, nämlich dem Centre for Emission Inventories and Projections (CEIP), dem Centre for Integrated Assessment Modelling (CIAM) und dem Meteorological Synthesizing Centre West (MSC-W). Die daraus resultierenden Zeitreihen von CL-Überschreitungen sind in Kapitel 4 dokumentiert.

In Kapitel 5 werden erste Schritte zur Einbeziehung mariner Ökosysteme in die wirkungsorientierten Ansätze der CLRTAP dokumentiert. Das CCE beteiligte sich an der Ad-hoc Expert Group on Marine Protection (AMP), die 2021 im Rahmen der Überarbeitung des Göteborg-Protokolls eingesetzt wurde, um das Potenzial für die Einbeziehung der Auswirkungen der Luftverschmutzung auf die Ostsee in die integrierten Bewertungssysteme der CLRTAP zu bewerten. Kapitel 5 beschreibt erste Ergebnisse, die durch die Zusammenarbeit der AMP mit Experten der Reduction Scheme Core Drafting Group (RedCore DG) von HELCOM, EMEP MSC-West, ICP Waters der Task Force on Integrated Assessment Modelling und dem CCE erzielt wurden.

Mit diesem Bericht kommt das CCE-Team seiner Verantwortung nach, Informationen über Methoden und Ergebnisse zur Bewertung der Auswirkungen von Luftverschmutzung auf Ökosysteme auf UNECE-Ebene zu veröffentlichen und setzt damit die lange Tradition der CCE-Statusberichte fort. Dieser Statusbericht ist der erste CCE-Bericht seit 2017, nachdem das Programmzentrum 2018 von den Niederlanden (RIVM) nach Deutschland (UBA) verlegt wurde. Zwischen 2019 und 2021 hat das derzeitige CCE Standardverfahren in seinen neuen IT- und Verwaltungsstrukturen implementiert, Daten überprüft, die notwendigen Expertennetzwerke aufgebaut und gepflegt sowie neue Projekte gestartet. Das neue CCE-Team im UBA möchte sich bei seinen Vorgängern im RIVM für die Unterstützung in dieser Übergangsphase bedanken. Der vorliegende CCE-Statusbericht 2022 veröffentlicht erstmals die Ergebnisse der fachlichen und koordinativen Arbeit der ersten drei Jahre des neuen CCE-Teams. Frühere (vom RIVM veröffentlichte) CCE-Berichte sind weiterhin elektronisch auf der CCE-Homepage verfügbar[2].

[2] https://www.umweltbundesamt.de/en/cce-status-reports?parent=68093

1 Review and revision of empirical Critical Loads of nitrogen for Europe

1.1 Motivation

Empirical critical loads for N ($CL_{emp}N$) are quantitative estimates used to assess and map harmful levels of N deposition on ecosystems, hereby informing policy decisions under the UNECE LRTAP Convention. $CL_{emp}N$ are based on empirically detectable changes of the structure and functioning of ecosystems exposed to various rates of N deposition and represent constant values/value ranges. As such, $CL_{emp}N$ need to be updated regularly to incorporate novel scientific findings and observations. The last update of $CL_{emp}N$ values was agreed upon in an expert workshop in Noordwijkerhout in 2010 (Bobbink et al., 2011). Since this 2010 workshop, new N gradient studies and other relevant scientific literature on ecosystem changes under N deposition had been published making a revision of established $CL_{emp}N$ necessary. Furthermore, the EUNIS (European Nature Information System) classes of most habitats addressed in the 2010 revision had changed, which required establishing $CL_{emp}N$ values for the new EUNIS classes. This EUNIS related task motivated the goal to additionally link the revised $CL_{emp}N$ values to Natura 2000 Annex 1 habitats where possible. Following a recommendation of the ICP M&M Task Force in the year 2019, the review and revision of the 2010 $CL_{emp}N$ database was included by the WGE into the CLRTAP workplan 2020-2021. In spring 2020, the CCE therefore launched a project for reviewing $CL_{emp}N$ for Europe. Project results include tabulated $CL_{emp}N$ values, that are summarized in Bobbink et al., 2022 and Table 21 in Annex C.

1.2 Methods

The technical working procedure of the $CL_{emp}N$ project included the following working steps: kick-off meeting in June 2020; data collection on effects of N deposition to EUNIS habitats from European publications of the past 10 years; first drafting of the project report chapters; internal reviews; external reviews; discussion of preliminary results at a UNECE CCE expert workshop in Berne in October 2021 and finalization of the project report incorporating expert comments of workshop participants. A total of 43 authors contributed to the final project report and the overview table of revised $CL_{emp}N$ values per EUNIS habitat (Bobbink et al., 2022). The following EUNIS classes were considered (EUNIS code in brackets): marine habitats (MA), coastal habitats (N), surface water habitats (C), forbs, mosses and lichens (R), heathland, scrub and tundra (S) and forests (T). In order to review and set values for $CL_{emp}N$ of terrestrial ecosystems, the authors focused on two types of empirical evidence for effects of N deposition: long-term field addition (or manipulation) experiments and studies exploring ecosystem changes observed at an N deposition gradient. Criteria for selecting statistically and biologically significant outcomes of field N addition experiments included independent N treatments and realistic N loads and durations (below 100 kg N ha^{-1} yr^{-1}; 2 years or more, optimally > 5-10 years in low background areas). Regarding N gradient studies, the authors compared four methods to derive CL from observational gradient data: visual inspection of gradient categories, Threshold Indicator Taxa Analysis (TITAN), point at which significance reduction can be observed and linear models with change-point. Three out of the four methods (visual inspection, TITAN and linear model) resulted in CL estimates that were similar when applied to the same input dataset. For details on methods of CL assessment see Bobbink et al., 2022. In comparison to the former $CL_{emp}N$ report from 2011 (Bobbink et al., 2011), the updated $CL_{emp}N$ report contains an additional chapter (see

Chapter 10 in Bobbink et al., 2022) that offers guidance on the use of $CL_{emp}N$ in risk assessment and nature protection.

1.3 Main results

Table 21 of Annex C gives an overview of $CL_{emp}N$ ranges resulting from the reviewing procedure. All $CL_{emp}N$ ranges of Table 21 represent consensus values that were agreed upon at a workshop hosted by the Swiss Federal Office for the Environment (BAFU) in Berne in 2021. For 40% of the assessed EUNIS habitats, the lower value of the range had become lower compared to the former $CL_{emp}N$ revision in 2011. The same applies to the upper value. The upper value increased in only one case. The final report identified multiple habitats, for which more observational data is needed such as all EUNIS habi-tat types that have an 'expert' judgement rating. Further research is needed in (sensitive) fresh-water and shallow marine ecosystems and on N deposition effects under climate change.

1.4 References

Bobbink R, Hettelingh J-P (eds), 2011. Review and revision of empirical critical loads and dose response relationships. Proceedings of an international expert workshop, Noordwijkerhout, 23-25 Juni 2010, RIVM Report 680359002, Coordination Centre for Effects, RIVM, Bilthoven

Bobbink R, Loran C, Tomassen H, 2022. Review and revision of empirical critical loads of nitrogen for Europe. B-WARE Research Centre, German Environment Agency

2 National Critical Load Data

The National Focal Centres (NFC) of ICP Modelling and Mapping (ICP M&M) are regularly invited by the Working Group on Effects (WGE) to update their national Critical Loads (CL) data. This procedure is formalised in a so-called "Call for data" (CfD). These CfD are usually announced when the existing database appears outdated due to any new scientific findings which lead to methodological changes. Besides this more technical function, the CfD also serves as a formal communication tool between WGE/ICP/CCE/ and the member states. The CfD can be used, for example, to identify knowledge gaps, but also to help NFCs focus on tasks relevant to the work of the Convention. One of the main objectives of the ICP M&M in relation to CfD is to collect national data for CL. The use of national data has at least two particularly positive aspects. The first is the potentially higher level of detail of the input data which is used by the NFC for the modelling of national CL data. This better spatial accuracy in national data compared to European-wide maps modelled from the Background Database (see Section 3) is particularly relevant for risk assessment of rare ecosystem types, since scarce ecosystems are usually not well presented in datasets covering relatively large areas (e.g. whole of Europe). The second important advantage is the inclusion of national decisions related to the CL derivation itself. The results of CL modelling exercises are very sensitive to the choice of receptors and also to the choice of chemical limits. In other words, the choice of what to protect and what impacts to avoid is crucial and should, in the best case, be made by the countries themselves.

The collection and integration of the information and data collected in a CfD is coordinated by the Coordination Centre for Effects (CCE). The latest CfD was performed in 2019/21 (see Appendix B) and basically followed the ruleset of the last CfD hosted by the previous CCE in the year 2017. The main objectives of the latest call were:

- to gather information related to national use and application of empirical CL in order to support the recent review process of empirical Critical Loads of nitrogen ($CL_{emp}N$) (see Chapter 1 and Bobbink et al., 2022[3]).
- give NFCs the opportunity to review their national data for CL for acidification and eutrophication with focus on the steady state simple mass balance (SMB) approach

The CfD outlined a two-step time frame for NFCs. In the first step (time period of 2019/20), NFCs answered a number of methodological questions on empirical CL. The results of these answers are summarized in the report on Review and revision of empirical critical loads of nitrogen for Europe (Bobbink et al., 2022[3]). In the second step (time period of 2020/21), NFCs submitted national steady-state CL data. The national reports to the respective data submissions are included in Annex A of this report.

With regard to the update of steady-state Critical Loads, in total 6 countries (Belgium (Flanders), Czech Republic, Ireland, Netherlands, Poland, UK) submitted revised national data in the 2019/2020 call. Please be aware that the national dataset from Belgium consists of 2 data submissions of the regions Flanders and Wallonia (while 8 countries delivered data in the year 2017). In addition, 4 countries (Belgium (Wallonia), Germany, Sweden, Switzerland) actively confirmed the previously submitted CL data. For other countries (Austria, Finland, France, Luxemburg, Norway, Italy), it was decided that CL data would be kept valid when no further notice

[3] Bobbink R, Loran C, Tomassen H, 2022. Review and revision of empirical critical loads of nitrogen for Europe. B-WARE Research Centre, German Environment Agency

was received from NFCs. In total 36 out of 50 parties to the convention did not respond to the Call for data.

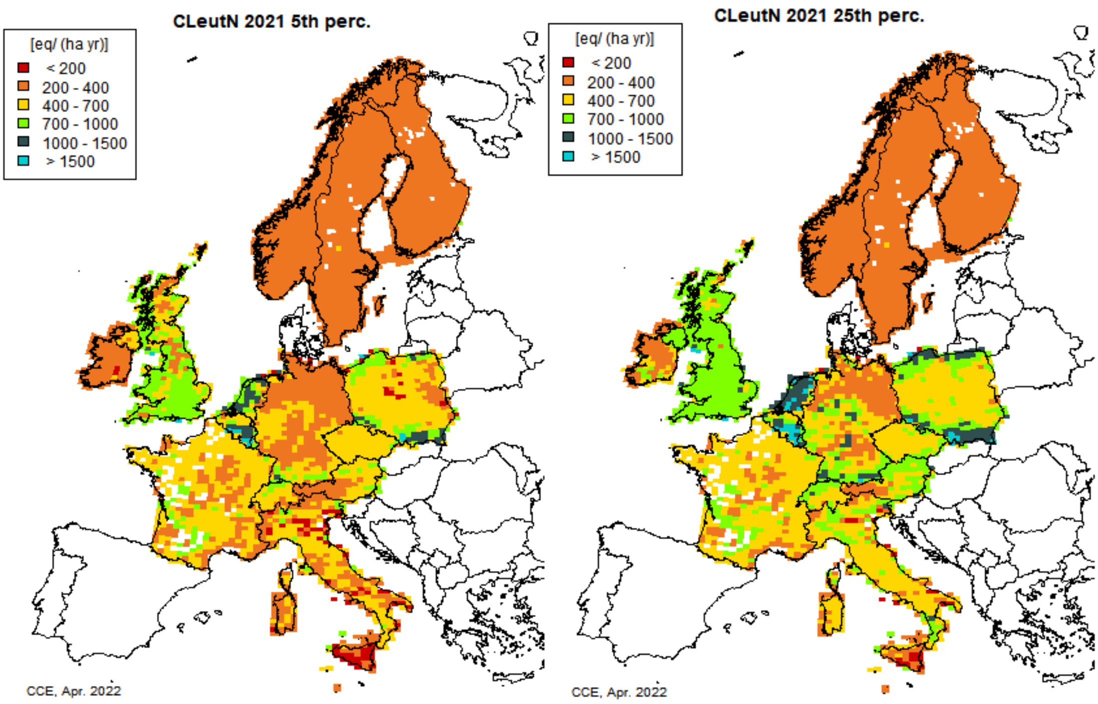
Table 1 includes countries, which have submitted national data and the estimated number of sites and covered area for the CL for Acidification and Eutrophication. The CL data submitted by NFCs covers about 45% of the total area of the whole dataset for Acidification, and about 40% for Eutrophication respectively. Please note that the number of sites (Table 1) were derived after an aggregation of the original data by grouping the sites with the same CL, land use class, coordinates and protection status.

Table 1: Countries with submitted national data following CfD 2017 or 2019/2021

Country	NFC delivery		Acidification		Eutrophication	
	2017	2019/2021	number of sites	EcoArea [km2]	number of sites	EcoArea [km2]
Austria	X		9.643	38.957	14.681	50.588
Belgium		X	14.086	15.482	25.813	15.552
Czech Republic		X	7.574	23.831	6.509	23.831
Finland	X		1.051	286	12.378	41.141
France	X		37.889	177.006	14.982	177.006
Germany	X		895.049	106.947	744.312	106.947
Ireland		X	11.447	16.195	9.480	16.776
Italy	X		11.729	101.030	27.537	105.946
Netherlands		X	125.071	2.827	5.612	3.093
Poland		X	80.675	95.950	74.259	95.950
Sweden	X		16.222	391.745	5.874	58.688
Norway	X		11.527	320.450	68.960	304.028
Switzerland	X		9.978	9.733	7.465	24.248
United Kingdom		X	215.767	75.806	30.766	71.070
All NFC			1.447.708	1.379.754	1.048.628	1.094.892
Total CL database			2.210.288	3.065.290	1.732.399	2.783.937

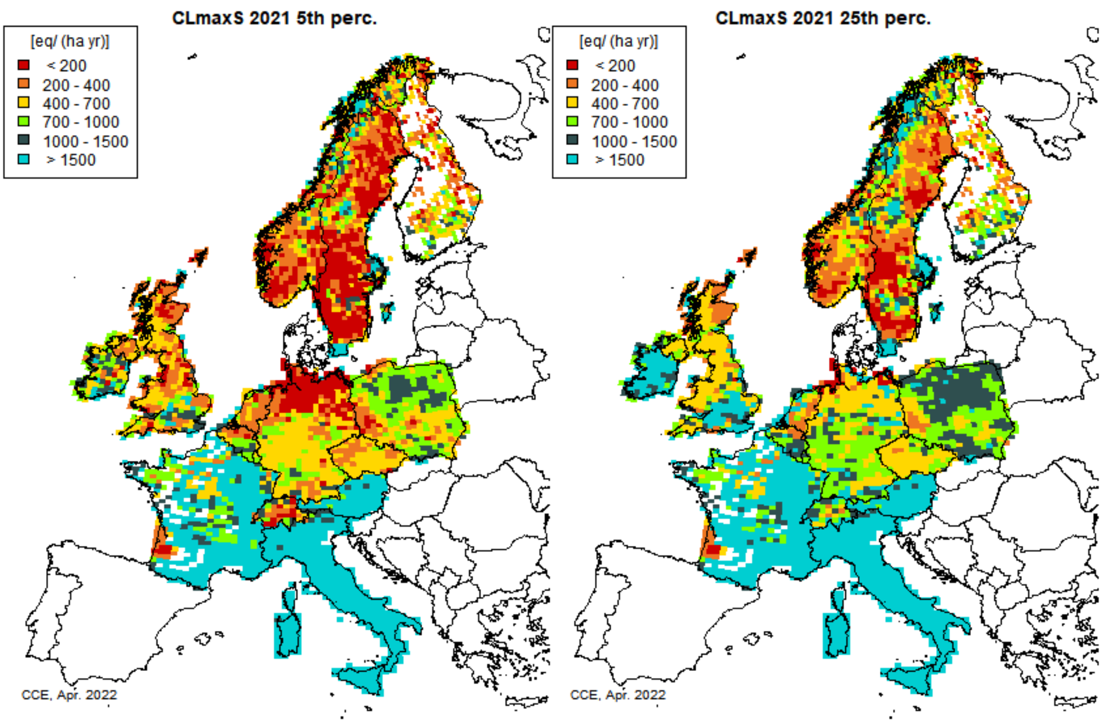
The maps of Figure 1 and Figure 2 display national CL data of countries that provided data in the 2017 or 2019/21 call for data. Figure 1 displays the results of the statistical distribution analysis based on a 0.5° x 0.25° grid of CL for eutrophication and Figure 2 displays the respective results for acidification. The scale ranges from low CL values (ecosystems with a relatively high sensitivity to acidification or eutrophication) in red to high CL values (ecosystems with a relatively low sensitivity to acidification or eutrophication) in blue. The left-hand map of both figures shows the 5th percentile of all critical load values per grid cell, the right-hand map shows the 25th percentile. This means that the left maps display a higher sensitivity compared to the right maps. These maps also show that the differences among NFC data sets vary by region. The Scandinavian countries, for example, have similarly low CL values, which means high sensitivity. On the other hand, the border region between the Netherlands and Germany shows noticeable differences in nationally calculated CL. These differences are the result of different input data and different national decisions on which ecosystems should be protected and which negative impacts of air pollution should be avoided. For further insights, please also consult the NFC reports listed in the Appendix A.

Figure 1: Critical Load for Eutrophication delivered by the NFCs (Cfd 2017 or 2019/21)



Source: Own illustration, Coordination Center for Effects

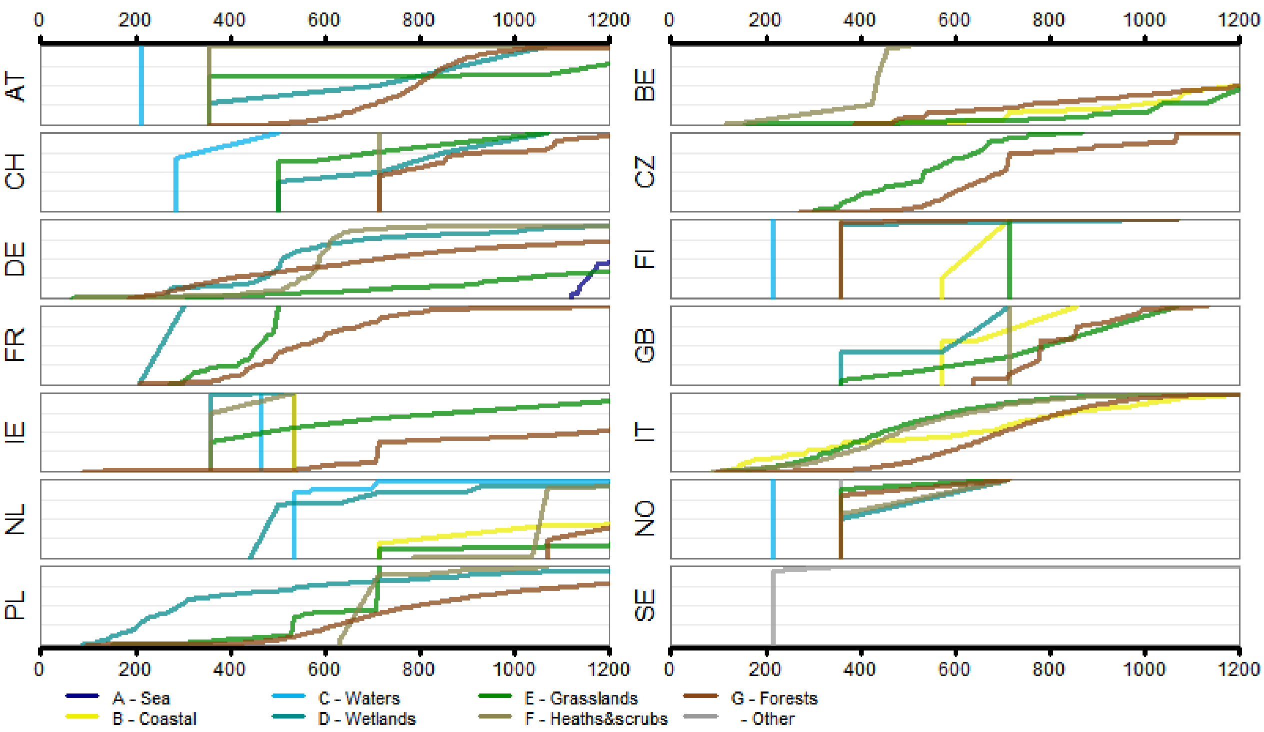
Figure 2: Critical Load for Acidification delivered by the NFCs (Cfd 2017 or 2019/21)



Source: Own illustration, Coordination Center for Effects

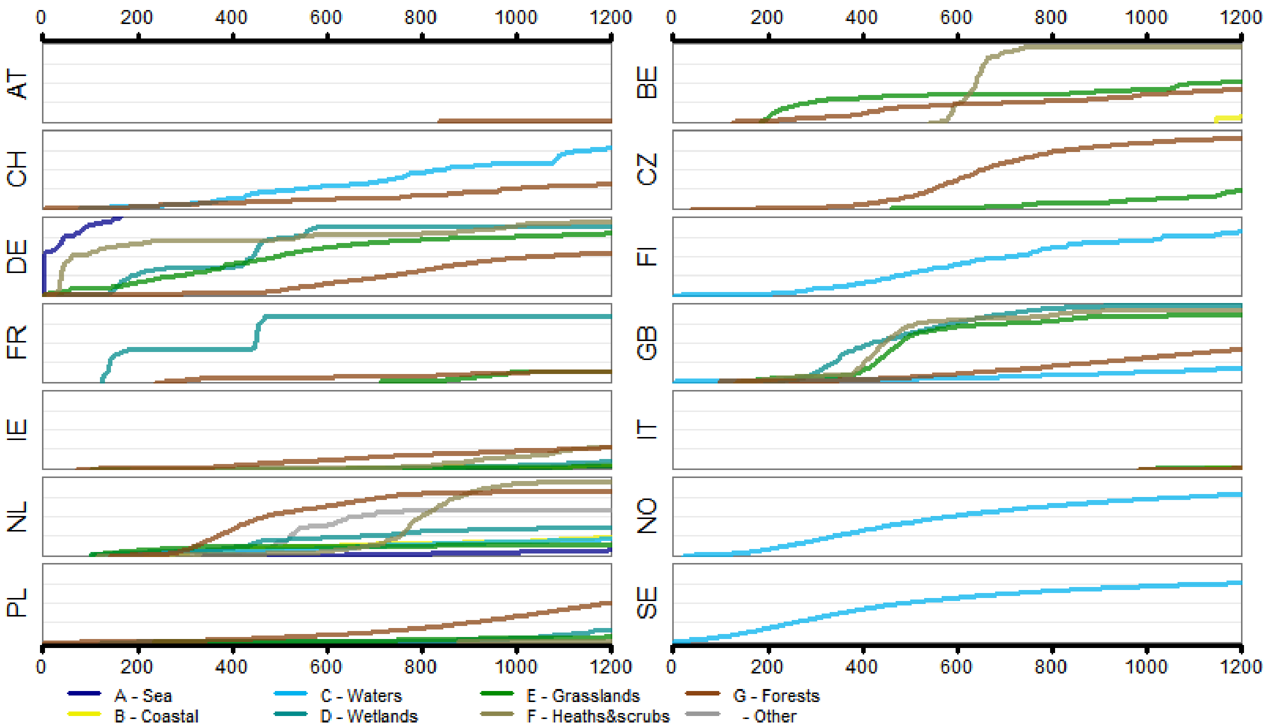
Figure 3 and Figure 4 show output of the cumulative distribution functions (CDFs) of CL, i.e. the proportion of values within respective CL datasets smaller or equal than a given CL value. Figure 3 displays results for Eutrophication and Figure 4 displays results for Acidification, subplots are grouped by countries and EUNIS types. CL values on the X-axis are in units of [eq ha-1yr-1] and the Y-axis shows the proportion of the respective national CL data set smaller or equal than a given CL. Each horizontal grey line marks the quartiles of the respective national CL data. The CDF analysis gives insight into the different distribution of CL data by country and EUNIS class. For a better understanding, here are some examples of how to read the figures. In Figure 3, the top-left subplot shows the distribution of CL for eutrophication for Austria (AT). The brown line represents the distribution of the subset of CL data for forests. This brown line for forests intersects the horizontal grey medium line of the Y-axis at about the CL value 800 [eq ha-1yr-1]. This means that for 50% of the forests in Austria the CL for eutrophication is smaller or equal than 800 [eq ha-1yr-1]. The blue line in the same subplot of Austria represents the EUNIS class "waters" and is comparably simple as there is a constant CL value of 200 [eq ha-1 yr-1] given for waters.

Figure 3: Cumulative distribution function (CDF) for the CL for Eutrophication (x-axis: sensitivity [eq ha^{1} yr^{-1}]; y-axis: share of total area [%])



Source: Own illustration, Coordination Center for Effects

Figure 4: Cumulative distribution function (CDF) for the CL for Acidification (x-axis: sensitivity [eq ha^{-1} yr^{-1}]; y-axis: share of total area [%])



Source: Own illustration, Coordination Center for Effects

3 Updated European background database for the calculation of critical loads

3.1 Motivation for the update of the existing background database

A main task of the CCE is to collect and collate national data on critical loads (CL) for eutrophication and acidification for European terrestrial ecosystems, and to provide European maps and databases to the relevant bodies under the LRTAP Convention. For meaningful applications, a complete European coverage with CL is desirable/required. If a country does not contribute with providing national data, the CCE fills the gaps with CL from a so-called European Background Database (EUDB) of CL.

Because of transfer of the CCE from the National Institute for Public Health and Environment (RIVM) in The Netherlands to the German Environment Agency (UBA) in Germany in 2018, a review of the existing background database and a detailed understanding of the tool was required. Therefore, Wageningen Environmental Research, who also supported the CCE at RIVM with regard to the computation of Critical Loads was commissioned from 2019 till 2021 to provide a detailed documentation of the stored calculations. Also, Alterra was tasked, to transfer the database and computational procedures to compute CL for eutrophication and acidification for terrestrial ecosystems in Europe from the old Fortran software into a R-surrounding.

With regard to the calculations and calculation results the new system was aimed to be in line with the tool, that was used by RIVM prior to the transfer of the CCE to Germany, as closely as possible. However, some smaller changes had to be implemented (Chapter 3.2). This chapter provides a short summary of the publication “Critical loads for eutrophication and acidification for European terrestrial ecosystems” (Reinds et al., 2021), which describes the last updates made to the EUDB in 2019-2021.

3.2 Data and procedures for the update

To compute CL for (semi-)natural ecosystems, information is needed on ecosystem characteristics such as vegetation cover and soil. Therefore, six maps are combined to construct a background data base for CL computations: (1) Land cover, (2) Soil type, (3) Forest growth region, (4) Distance to coast, (5) Natura 2000 delineations, (6) Country borders. CL computations are restricted to (semi) natural habitats, i.e. forests and (semi-)natural vegetation (mires, bogs and fens, natural grasslands and heathland, scrub and tundra).

The maps are gridded in an ArcMap Pro procedure in Python to rasters with a resolution of 0.01° × 0.01° for each country separately. Thereafter, the different layers are combined. There are also two regional datasets used: base cation deposition and meteorological data (temperature and precipitation surplus). Precipitation surpluses are computed using the MetHyd model (meteo-hydrological model), which for the results presented thereafter was run for the period 1999-2018 using daily meteorological data.

CL are computed from South to North through Europe preparing meteorological data, computing hydrology and CL for all receptors in the latitude stripe of 0.5 degrees and between -12 and 42 degrees longitude.

3.3 Comparison of background database results 2017 vs 2020

Results from the R procedure have been mapped and compared to the results from EUDB computed by RIVM-CCE and reported in the CCE Final Report 2017 (Posch & Reinds, 2017). The following CL for N and S were computed with the Simple Mass Balance (SMB) method: the maximum CL for sulphur ($CL_{max}S$), the minimum CL for nitrogen ($CL_{min}N$), the maximum CL for nitrogen ($CL_{max}N$) and the CL for nutrient nitrogen ($CL_{nut}N$). $CL_{max}S$ can be based on critical values for various chemical criteria such as molar [Al]:[Bc] ratio in soil solution, pH or base saturation. A few changes have been made regarding the computation of CL compared to the 2017 results. These are the following:

The software was ported to R

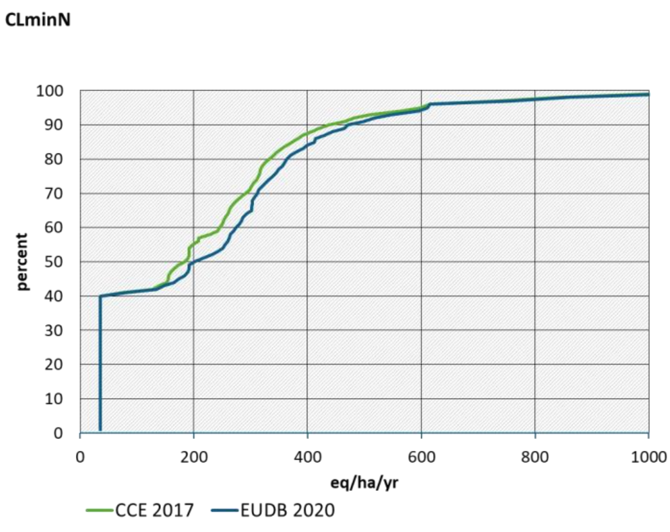
1. The MetHyd model uses daily data for 1999-2018 instead of monthly data 1970-2000
2. The Efiscen forest growth data have been updated to the latest (2016) version (Petz et al., 2016; Prins et al., 2017)

Due to these changes, some minor differences occur in inputs (precipitation surplus) and in CL between the new EUDB 2020 and the former EUDB dated 2017 results, but the patterns over Europe are mostly identical.

3.3.1 Minimum critical loads for nitrogen

The minimum CL of N ($CL_{min}N$), is derived by summarizing the nitrogen uptake of the vegetation (N_{uptake}) and the nitrogen immobilization in the soil (N_{imm}). It is very similar between the EUDB maintained by the former CCE until 2017 and EUDB 2020 (Figure 5). Differences originate from the use of updated Efiscen forest data, because $CL_{min}N$ is mostly determined by the growth-related uptake rates of nitrogen in vegetation (N_{uptake}).

Figure 5: Cumulative distribution function (CDF) of $CL_{min}N$ in eq ha^{-1} yr^{-1} for the EUDB CCE 2017 (green line) and EUDB 2020 (blue line)

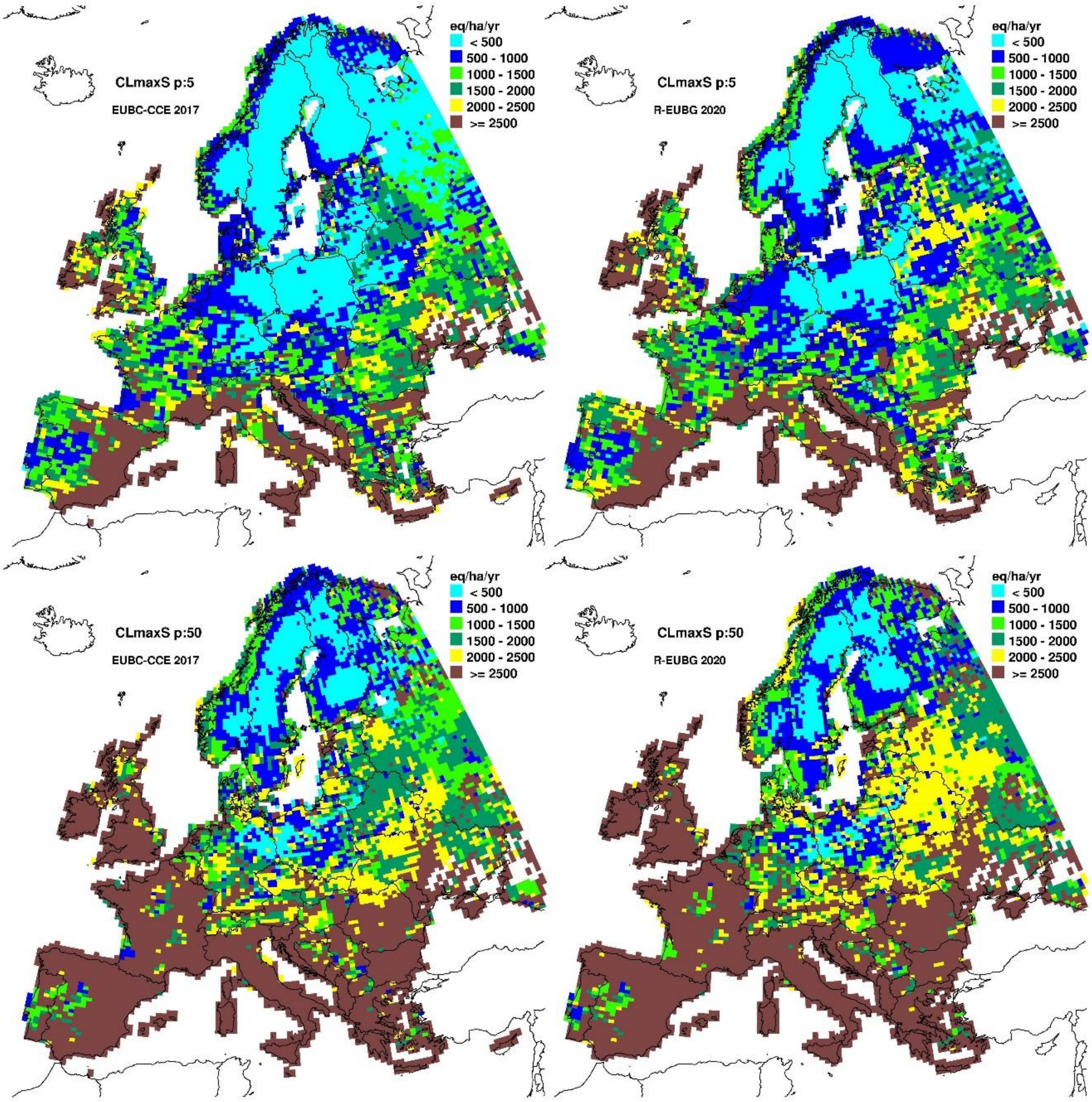


Source: Reinds et al., 2021

3.3.2 Maximum critical loads for sulphur

The geographical patterns for the maximum CL for S, $CL_{max}S$, show strong geographic similarities between the EUDB maintained by the former CCE until 2017 and EUDB 2020 (Figure 6). Some differences occur in Russia due to the change in base cation deposition. Minor differences can occur because of minor changes in the uptake of base cations by ecosystems (due to updated growth data) and/or because leaching of base cations has changed (due to the use of a different meteorological dataset).

Figure 6: 5th percentile (upper row) and median (50th percentile, lower row) $CL_{max}S$ in eq ha^{-1} yr^{-1} for the EUDB CCE 2017 (left) and the EUDB 2020 (right)

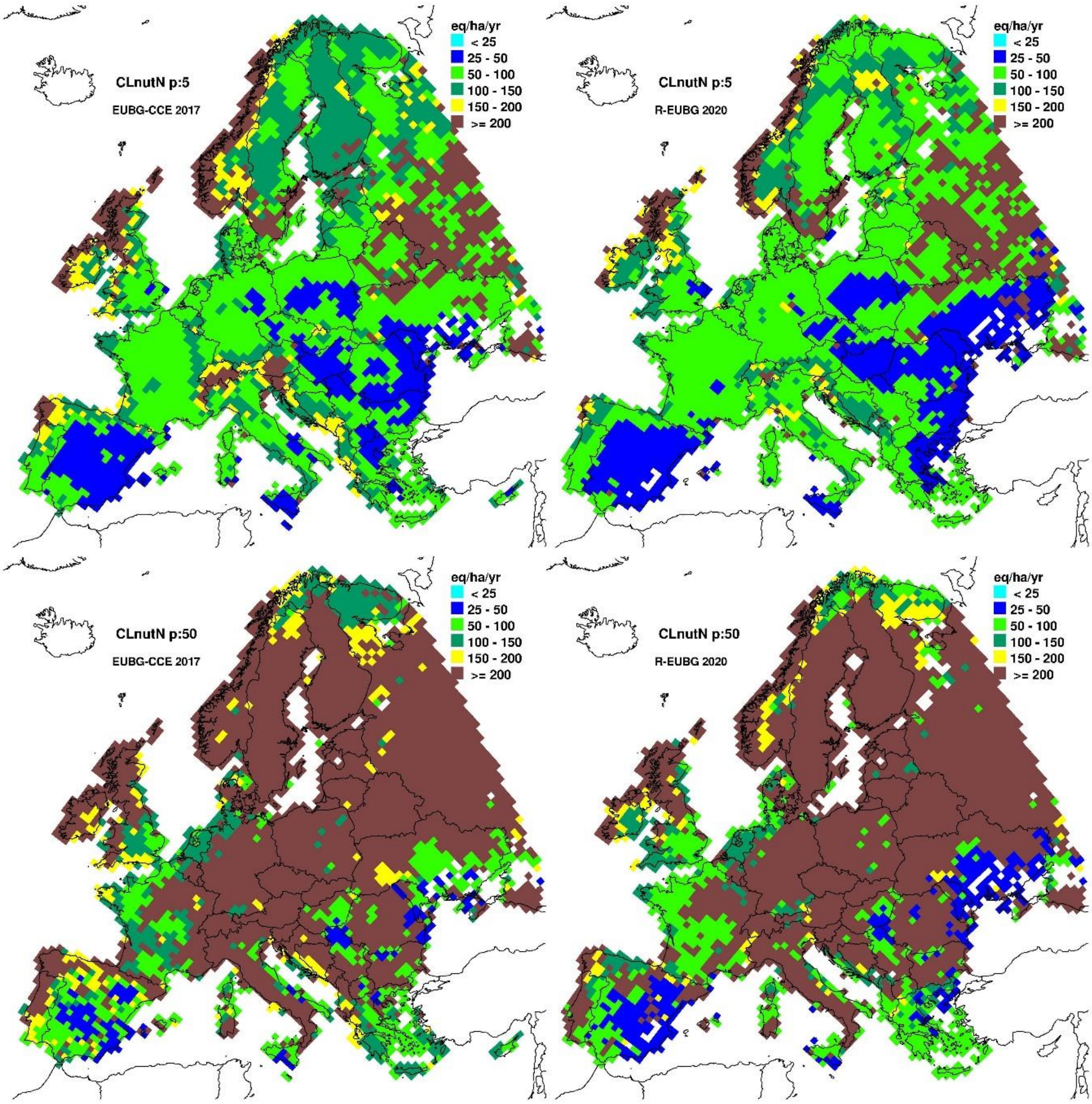


Source: Reinds et al., 2021

3.3.3 Critical loads for eutrophying nitrogen

The geographical patterns for the CL for eutrophying N, $CL_{nut}N$, also show strong similarities between the EUDB maintained by the former CCE until 2017 and EUDB 2020 (Figure 7). The calculation of $CL_{nut}N$ incorporates N immobilisation (set to a constant value of 1 kg N ha^{-1} yr^{-1}), net N uptake by vegetation (zero for non-forests), the N denitrification fraction and N leaching. Lowest values (see the 5th percentile maps) are confined to non-forest ecosystems due to the zero net uptake term. The 5th percentile maps are considered to reflect the patterns in precipitation surplus in Europe as N immobilisation is set to a constant value.

Figure 7: 5th percentile (upper row) and median (50th percentile, lower row) $CL_{nut}N$ in eq ha^{-1} yr^{-1} for the 2017 background DB (left) and the EUDB 2020 (right)



Source: Reinds et al., 2021

In addition to the comparison of EUDB results from 2017 and 2020, the EUDB 2020 results were also compared to national CL data provided in 2017 by the Irish and German NFCs; and to empirical CL for N. Further details are presented in Reinds et al. (2021).

3.4 Conclusion

A software package in R was developed for CCE to update computation of CL of S and N for Europe and build a new EUDB 2020. A comparison of results from this EUDB 2020 with the original Fortran software used in the final RIVM-CCE report dated 2017 (Posch & Reinds, 2017) shows that results are almost identical. Some slight differences occur because of the update of hydrology and forest growth data made for the purpose of EUDB 2020.

The new procedure now uses the most recent meteorological data. Although the R procedures allow for an update of these data, there is no need to do so on the short term unless the quality of the basic data would improve. Furthermore, using updated datasets with more recent years will also hardly change the results as the hydrology is computed and averaged over a twenty-year period.

Finally, it is worth noting that the land use map operated for this work (Cinderby et al., 2007), meanwhile, is almost 15 years old. Due to land use changes that occurred in Europe over the past decades, an update of this land use map is advised. This is one of the current issues CCE will be dealing with in the coming years in the context of the ICP M&M 2022/2023 workplan. (Chapter 6).

3.5 List of references

Cinderby, S., L. Emberson, A. Owen & M. Ashmore, 2007. *LRTAP land cover map of Europe*. In: Slootweg J, P.M., Hettelingh J-P (Ed). Critical loads of nitrogen and dynamic modelling, CCE Progress Report 2007. Bilthoven, the Netherlands, Report 500090001, MNP, pp. 59-70.

Posch, M. & G.J. Reinds, 2017. *The European Background Database of N and S Critical Loads.* In: Hettelingh, J.P., M. Posch & J. Slootweg (Eds). European critical loads: database, biodiversity and ecosystems at risk: CCE Final Report 2017. RIVM Report 2017-0155. Bilthoven, Netherlands, pp. 49-60.

Reinds, G.J., Thomas, D., Posch, M. & J. Slootweg, 2021. *Critical loads for eutrophication and acidification for European terrestrial ecosystems*. Final report. Ressortforschungsplan of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Report No. FB000514/ENG. Dessau, Germany.

4 Assessing eutrophication and acidification status with the most recent European CL database

To support the review process of the Gothenburg Protocol, the CCE compared the latest Critical Load database described in the previous chapters with a time series of deposition of eutrophying and acidifying air pollutants.

The 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol)[4] was amended in 2012 by the Executive Body of the CLRTAP to include national emission reduction commitments to be achieved by 2020 and beyond[5, 6]. The amended Protocol entered into force on 7 October 2019. Following that, in 2020 the CLRTAP Executive Body started the review of the 2012 Protocol. Therefore, the Gothenburg Protocol Review Group formulated guiding questions for the scientific bodies of the Working Group on Effects to work on. ICP Modelling & Mapping was tasked to calculate and display the periodic change in exceedance of Critical Loads for acidification and eutrophication between the years 2000 and 2019 (historic data) and for projected scenarios in the years 2030 and 2050 (scenario data) in terms of percentage ecosystems with exceedances and accumulated excess, based on current Critical Loads[7]. The scenario data used in the Review of the Gothenburg Protocol is displayed in the following chapter. With respect to the historic this report displays an extended timeseries until 2020.

4.1 Methodological approach

Eutrophication and acidification are serious threats to European ecosystems and are caused by the deposition of nitrogen and sulphur. Both processes alter the chemical properties of soils and thus also the availability of nutrients for plants. As a result of altered nutrient availability, species composition may change and ecosystem integrity may be threatened. These changes carry the risk that more resilient ecosystems may prevail, resulting in the loss of ecosystem diversity as an integral part of overall biodiversity. To be able to quantitatively assess the risks for ecosystems from those changes, the concept of Critical Loads was developed to estimate the amount of deposition that does not lead to effects as mentioned above and is therefore considered acceptable. As soon as the estimated deposition exceeds the Critical Loads, ecosystems are considered to be at risk.

The Critical Load database consists of two components (see previous chapters 2 and 3). The first component is the aggregated data from national contributions (see chapter 2). National contributions were submitted as part of the most recent Call for Data for the period 2019-21 (see documentation on the CCE website[8]). It was also possible that data from the previous Call for Data (Hettelingh et al., 2017) was used if the National Focal Centres (NFCs) confirmed the continued validity of the values to the CCE or did not object to their further use.

The second component consists in data from the recently completed Critical Load background database of the Coordination Centre for Effects (CCE) (Reinds et al., 2021[9]) for the areas for which no contributions were provided from the respective NFCs (36 out of 50 countries, see

[4] Protocol to Abate Acidification, Eutrophication and Ground-level Ozone | UNECE

[5] https://unece.org/DAM/env/documents/2013/air/ECE_EB.AIR_111_Add.1__ENG_DECISION_1.pdf

[6] https://unece.org/DAM/env/documents/2013/air/ECE_EB.AIR_111_Add.1__ENG_DECISION_2.pdf

[7] https://unece.org/fileadmin/DAM/env/documents/2020/AIR/EB/ECE_EB.AIR_2020_3-2012770E.pdf

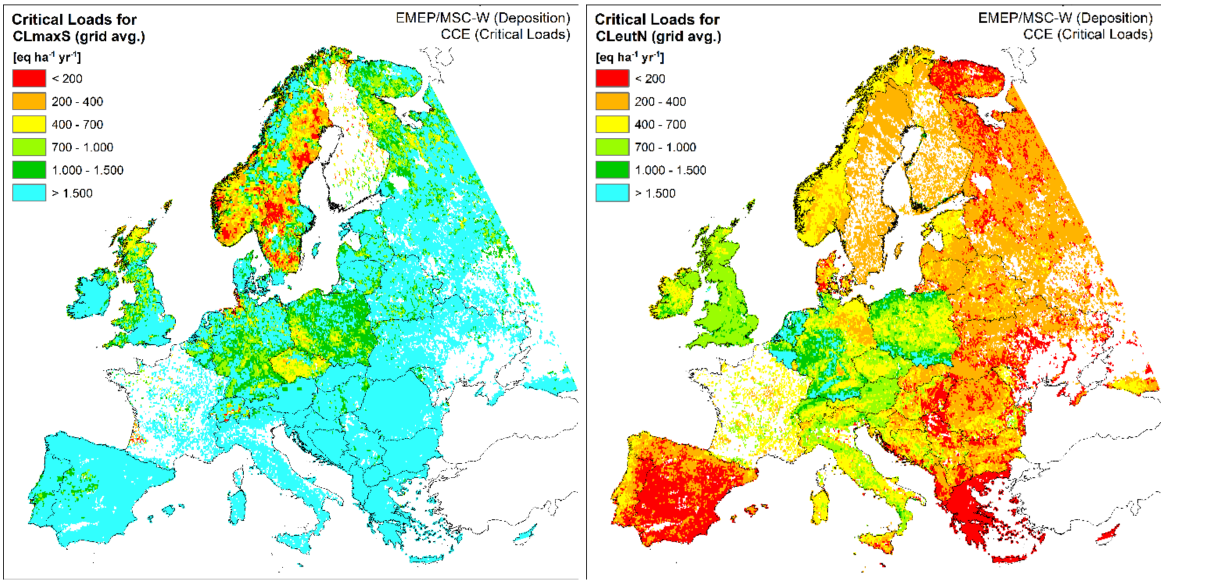
[8] https://www.umweltbundesamt.de/en/call-for-data?parent=69334

[9] https://www.umweltbundesamt.de/publikationen/critical-loads-for-eutrophication-acidification-for

chapter 3). A general description of the methods to calculate these Critical Loads is given in the Mapping Manual of the ICP Modelling and Mapping (CLRTAP, 2017).

Both data components have been merged and made available in a consolidated database. Critical Loads are available for about 4.1 million sites in Europe with an area of about 2.9 million km^2 for acidification impacts (Figure 8a) and about 2.6 million km^2 for the effects of eutrophication[10](Figure 8b). The analysed ecosystems for the CL for acidification are mainly forests (54%) but also freshwater ecosystems (24%) and grasslands (16%). The CL dataset for eutrophication contains also mainly forests (65%) and different types of grasslands (20%).

Figure 8: Critical Loads for Europe for Acidification (left) and Eutrophication (right) expressed as area- weighted grid average of $CL_{max}S$ and $CL_{eut}N$ respectively



Source: Own illustration, Coordination Center for Effects

The exceedances of European Critical Loads (CL) are computed for the total nitrogen (N) and sulphur (S) depositions, which were modelled on the 0.1°x 0.1° longitude-latitude grid (approx. 11 x 5.5 km^2 at 60°N) by the EMEP Meteorological Synthesizing Center (MSC)-West with the EMEP model version EMEP01_rv4.45 (EMEP, 2022).

The historic deposition for the years 2000, 2005, 2010, 2015 and 2020 are based on reported emission data provided by the Center for Emission Inventories and projections (CEIP) in spring 2022.

The projected deposition for the years 2030 and 2050 was calculated by MSC-West based on the same grid and model version as specified above and on the meteorology of the year 2015 to display the effects of altered emissions in comparison to the year 2015. The emission scenarios were provided to MSC-West by the Center for Integrated Assessment Modelling (CIAM) (CLRTAP, 2022). In total there are 5 emission/deposition scenarios: (1) 2030 Baseline/current legislation (CLE); (2) 2030 most feasible reduction (MFR); (3) 2050 Baseline/current legislation (CLE); (4) 2050 most feasible reduction (MFR); (5) 2050 global climate mitigation (LOW). The current legislation scenarios represent air pollutants and methane emissions up to 2050 including up-to-date policies and measures and national implementation progress and plans. For the EU, this CLE scenario comprises energy and agriculture policies following the 55% greenhouse

[10] Note, that due to missing input data the previous background data (Hettelingh, J.-P. et al. 2017) was used for Cyprus and Malta. At the same time no national data for these countries is available.

gas reduction-target for 2030 and net-zero carbon in 2050. The MFR scenarios use the same activity data as the CLE scenarios, but explore the potential for further technical mitigation measures with the lowest attainable emission factors associated with reduction technologies for which experience exists. These technical measures include highly efficient end of pipe technologies in industry, transport sector, residential combustion, measures in agriculture, solvent substitution and control of leaks on oil and gas production. The LOW scenario includes changes in activity data due to global climate mitigation policy, including a significant transformation in the agricultural sector leading to strong reduction of livestock numbers, especially cattle and pigs. The descriptions given here are cited from the CIAM contribution to the report of the Gothenburg Protocol review, where more details can be found (CLRTAP, 2022).

The comparison of deposition and critical load data is computed for a matching longitude-latitude grid. The calculated exceedance in each grid cell is displayed as the so-called "Average Accumulated Exceedance" (AAE), which is calculated as an area-weighted average of the exceedances of the Critical Loads of all ecosystems in a respective grid cell. Critical Loads and their exceedances are given in equivalents (eq) per area and time (ha and year), so as 1 equivalent is the same as 1 mole of charge (H^+, molc). Using equivalents is primarily important for the independent assessment of acidification that is caused by both S- and N-deposition.

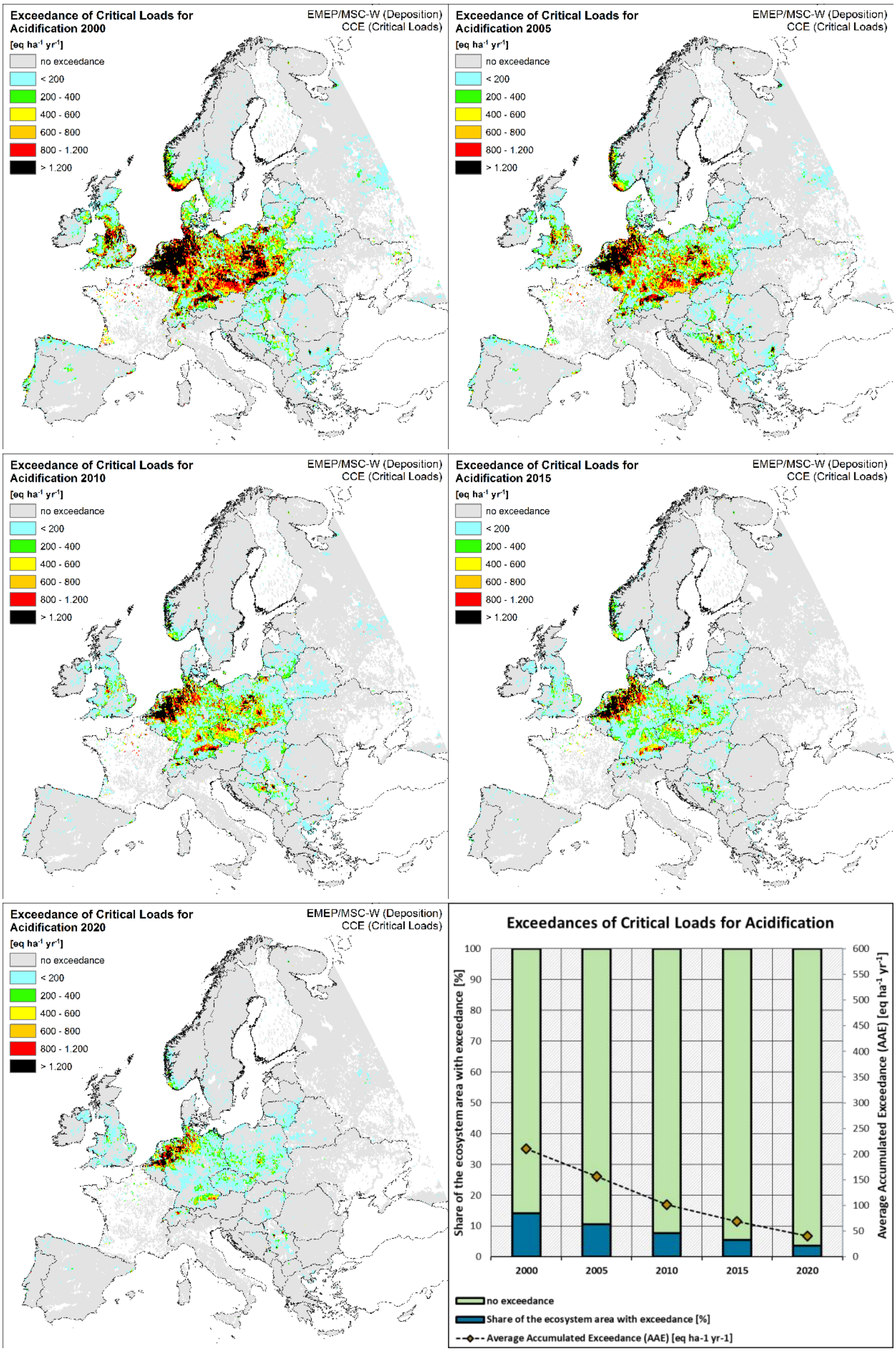
4.2 Summarised results of risk assessment for acidification and eutrophication

4.2.1 Historic risks for acidification and eutrophication for the years 2000 – 2020

The results of the exceedance calculations for acidification and eutrophication are given in Figure 9 and Figure 10. Statistics for the different parties to the convention are shown in Table 2 and Table 3. Figure 9 a-e shows that exceedances of Critical Loads for acidity occur on 14.1% (2000) and 3.6% (2020) of the ecosystem area and the European average AAE is about 211 eq ha^{-1} yr^{-1} (2000) and 40 eq ha^{-1} yr^{-1} (2020). Hot spots of exceedances can be found in the Netherlands and its border areas to Germany and Belgium, and some smaller maxima in southern Germany and Czechia, whereas most of Europe is not exceeded (grey areas). Summarized descriptive statistics for the share of Critical Load exceedance and European average of AAE are shown in Figure 9f.

By contrast to Critical Loads of acidity, it is worth noting that Critical Loads for eutrophication are exceeded in large parts of the model domain and in all years (Figure 10 a-e). The share of ecosystems, where the Critical Loads for eutrophication are exceeded, decreases relatively slowly, starting at 74,0% in 2000 and going down to 61.2% in 2020, with a European average AAE of about 538 eq ha^{-1} yr^{-1} and 284 eq ha^{-1} yr^{-1} in 2000 and 2020, respectively. The highest exceedances of CL are found in the Po Valley in Italy, the Dutch-German and German-Danish border areas and in north-eastern Spain. Summarized descriptive statistics for the share of Critical Load exceedance and European average of AAE are shown in Figure 10 f.

Figure 9: a-e: CL Exceedance for Acidification for the years 2000, 2005, 2010, 2015 and 2020; f: Summarized descriptive statistics for exceedance of CL for acidification for European ecosystems.



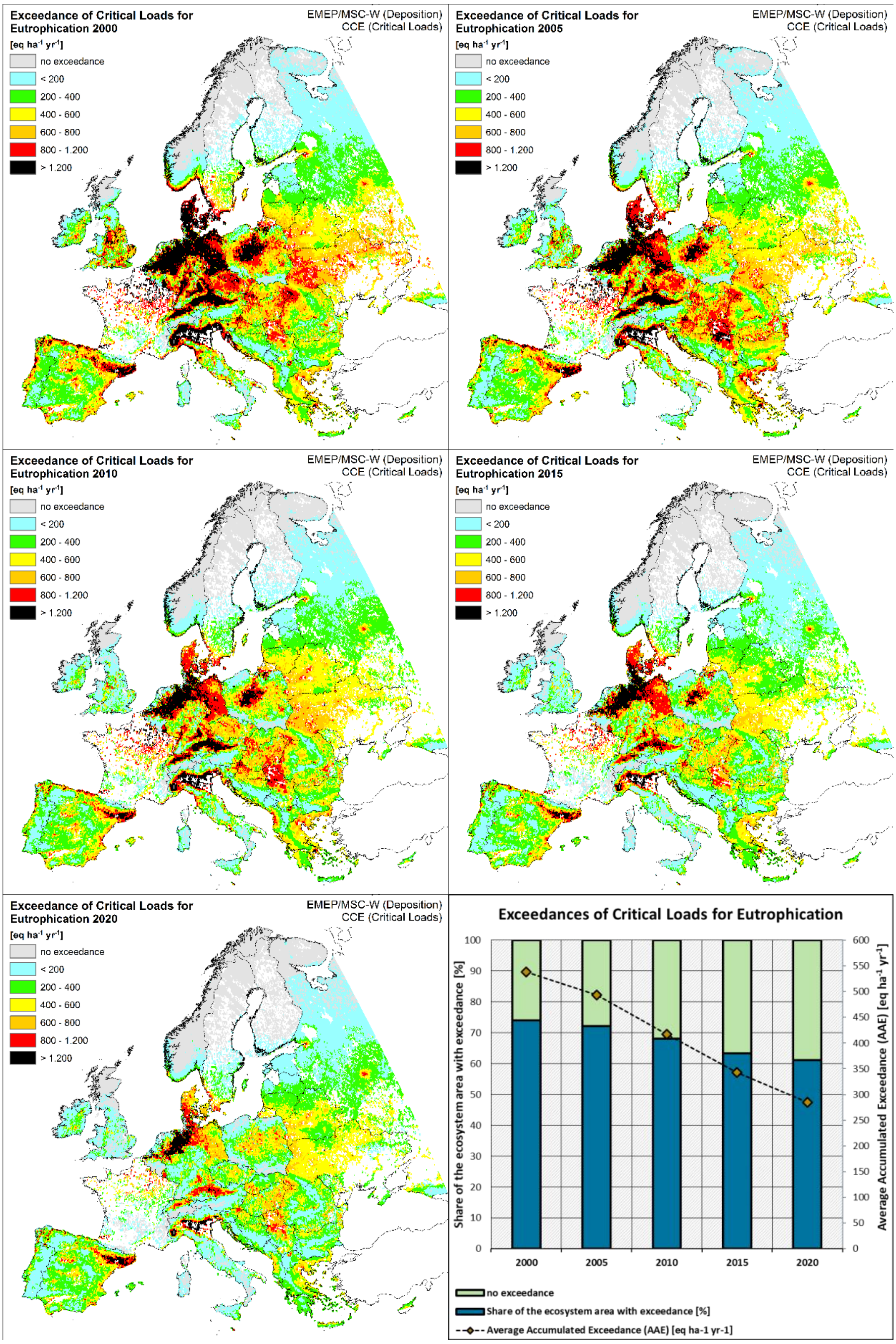
Source: Own illustration, Coordination Center for Effects

Table 2: Exceedance of CL for acidification presented as share of the receptor area and the AAE.

Acidification		Exceedance of CL acid									
Country	Eco area [km²]	Share of the Eco Area in [%]					AAE in [eq ha-1 yr-1]				
		2000	2005	2010	2015	2020	2000	2005	2010	2015	2020
Austria	38.957	2	2	<1	<1	<1	9	7	3	0	0
Belgium	15.482	68	58	45	39	31	1506	1154	713	482	248
Bulgaria	54.470	4	6	<1	<1	<1	70	76	7	2	0
Croatia	36.484	3	4	3	2	<1	15	20	13	3	0
Cyprus	1.701	<1	<1	<1	<1	<1	0	0	0	0	0
Czech Re-public	23.831	91	86	78	65	30	760	584	351	182	46
Denmark	6.741	41	31	10	10	2	261	115	23	23	3
Estonia	30.735	<1	<1	<1	<1	<1	2	1	1	0	0
Finland	286	2	1	1	<1	<1	2	1	1	0	0
France	177.006	12	10	7	4	3	68	42	19	9	4
Germany	106.947	75	67	54	43	26	780	560	379	276	131
Greece	78.016	3	3	1	<1	<1	12	18	3	1	0
Hungary	30.120	25	13	10	5	4	135	59	41	19	11
Ireland	16.195	3	2	<1	<1	<1	11	5	1	1	0
Italy	101.030	3	<1	<1	<1	<1	52	9	6	8	4
Latvia	44.389	11	5	5	2	1	19	7	8	1	1
Lithuania	26.522	31	27	26	23	20	172	96	98	48	34
Luxembourg	1.388	18	16	14	14	12	268	198	124	81	23
Malta	35	<1	<1	<1	<1	<1	0	0	0	0	0
Netherlands	2.827	74	73	72	72	70	2810	2162	1531	1299	936
Poland	95.950	69	50	42	24	18	516	270	196	85	44
Portugal	42.199	8	3	2	1	<1	41	12	5	3	2
Romania	109.564	2	3	<1	<1	<1	10	22	5	1	0
Slovakia	26.875	13	7	6	4	2	78	30	24	9	3
Slovenia	14.104	2	<1	<1	<1	<1	7	1	0	0	0
Spain	252.450	2	1	<1	<1	<1	23	12	2	2	1
Sweden	391.745	14	6	4	2	2	20	5	2	1	0
EU 27	1.726.049	18	13	10	7	5	283	202	132	94	55

Acidification		Exceedance of CL acid									
Country	Eco area [km²]	Share of the Eco Area in [%]					AAE in [eq ha-1 yr-1]				
		2000	2005	2010	2015	2020	2000	2005	2010	2015	2020
Albania	20.018	<1	<1	<1	<1	<1	1	0	0	0	0
Belarus	66.612	14	7	8	2	1	38	12	12	2	1
Bosnia and Herzegovina	37.104	9	12	10	8	<1	32	82	75	42	2
Kosovo	4.712	6	7	5	<1	<1	13	23	7	0	0
Liechtenstein	109	46	46	40	25	6	221	204	133	42	14
Moldova	3.780	4	2	<1	<1	<1	5	3	1	0	0
Montenegro	9.072	1	2	1	1	1	9	17	15	19	16
Norway	320.450	20	16	10	10	6	76	47	17	18	9
Republic of Macedonia	16.922	6	9	2	<1	<1	18	33	8	1	1
Russia	643.887	2	1	<1	<1	<1	4	3	1	1	0
Serbia	33.121	22	28	19	11	8	127	275	151	61	57
Switzerland	9.733	34	26	21	15	9	280	191	138	83	46
Ukraine	97.915	5	2	1	<1	<1	14	3	3	0	0
United King-dom	75.806	29	17	8	5	4	159	74	27	14	8
Total	**3.065.290**	**14**	**11**	**8**	**5**	**4**	**211**	**157**	**101**	**69**	**40**

Figure 10: a-e: CL Exceedance for Eutrophication for the years 2000, 2005,2010, 2015 and 2020; f: Summarized descriptive statistics for exceedance of CL for Eutrophication.



Source: Own illustration, Coordination Center for Effects

Table 3: Exceedance of CL for Eutrophication given as share of the receptor area and the AAE.

Eutrophication		Exceedance of CL eut									
Country	Eco area [km²]	Share of the Eco Area in [%]					AAE in [eq ha-1 yr-1]				
		2000	2005	2010	2015	2020	2000	2005	2010	2015	2020
Austria	50.588	82	75	68	65	50	386	353	294	234	147
Belgium	15.552	88	82	71	59	52	1433	1161	900	671	432
Bulgaria	54.470	92	94	89	83	76	276	389	259	221	170
Croatia	36.484	93	95	89	81	81	510	571	470	318	291
Cyprus	1.701	100	100	100	100	100	366	347	306	320	361
Czech Republic	23.831	99	98	95	91	84	753	639	486	383	257
Denmark	6.741	100	100	100	100	100	1313	1055	825	885	664
Estonia	30.735	65	57	56	46	39	128	93	98	73	58
Finland	41.141	15	9	9	3	2	15	7	6	3	2
France	177.006	85	85	82	69	61	549	497	429	294	195
Germany	106.975	88	85	82	78	70	1080	921	798	707	467
Greece	78.016	100	100	100	100	100	483	552	469	431	337
Hungary	30.120	97	96	92	86	78	602	639	567	452	395
Ireland	16.776	60	51	37	36	48	160	135	81	71	95
Italy	105.946	81	80	73	62	53	572	454	356	250	179
Latvia	44.389	95	94	94	92	88	288	245	272	220	191
Lithuania	26.522	99	99	99	99	98	517	432	477	393	367
Luxembourg	1.388	100	100	100	100	100	1539	1350	1199	1034	798
Malta	35	99	99	99	99	99	877	772	688	602	517
Netherlands	3.093	92	88	81	81	76	1770	1314	941	783	491
Poland	95.950	84	79	76	70	67	589	429	396	280	238
Portugal	42.199	89	85	85	81	76	329	228	221	188	168
Romania	109.564	94	96	92	92	88	419	475	344	292	251
Slovakia	26.875	100	98	97	95	91	622	527	459	386	338
Slovenia	14.104	93	92	84	75	75	615	529	441	334	320
Spain	252.450	97	96	94	92	92	463	426	383	346	338
Sweden	58.688	19	17	16	15	15	100	71	60	54	45
EU 27	**1.451.339**	**85**	**84**	**80**	**75**	**71**	**621**	**541**	**453**	**379**	**300**

Eutrophication		Exceedance of CL eut									
Country	Eco area [km2]	Share of the Eco Area in [%]					AAE in [eq ha-1 yr-1]				
		2000	2005	2010	2015	2020	2000	2005	2010	2015	2020
Albania	20.018	92	94	93	89	89	342	386	401	316	311
Belarus	66.612	100	100	100	100	100	499	427	480	350	388
Bosnia and Herzegovina	37.104	74	78	74	73	74	236	347	254	204	203
Kosovo	4.712	79	82	79	78	80	250	343	244	202	239
Liechtenstein	109	100	100	100	99	98	924	966	907	721	531
Moldova	3.780	100	100	100	95	95	517	561	478	354	340
Montenegro	9.072	69	72	60	57	63	177	191	138	104	138
Norway	304.028	20	19	13	11	9	70	47	23	21	18
Republic of Macedonia	16.922	82	84	81	77	71	267	333	280	221	185
Russia	643.887	70	67	62	54	56	162	142	125	92	104
Serbia	33.121	92	94	92	90	90	496	718	547	433	432
Switzerland	24.248	71	66	62	53	47	524	470	414	306	198
Ukraine	97.915	100	100	100	100	100	681	584	542	466	439
United Kingdom	71.070	36	27	18	14	12	166	108	52	33	25
Total	**2.783.937**	**74**	**72**	**68**	**63**	**61**	**538**	**494**	**417**	**343**	**284**

4.2.2 Projected risks for acidification and eutrophication for the years 2030 and 2050

Identical, as in the previous section, the calculated height of the projected exceedance in a grid cell is displayed as a so-called "average accumulated exceedance" (AAE), which is calculated as an area-weighted average of the exceedances of the Critical Loads of all ecosystems in the respective grid cell. Also, the percentage of the area of ecosystems which is affected by exceedance are calculated.

The projected AAE for acidification and eutrophication was computed on a 0.1°x 0.1° longitude-latitude grid for the 5 different scenarios (see method section) and are displayed in the maps of Figure 11 and Figure 13. The statistics for the projected exceedances of CL for acidification and eutrophication for the overall European domain and the single European Parties are displayed in Figure 12 and Figure 14 and in Table 4 and Table 5.

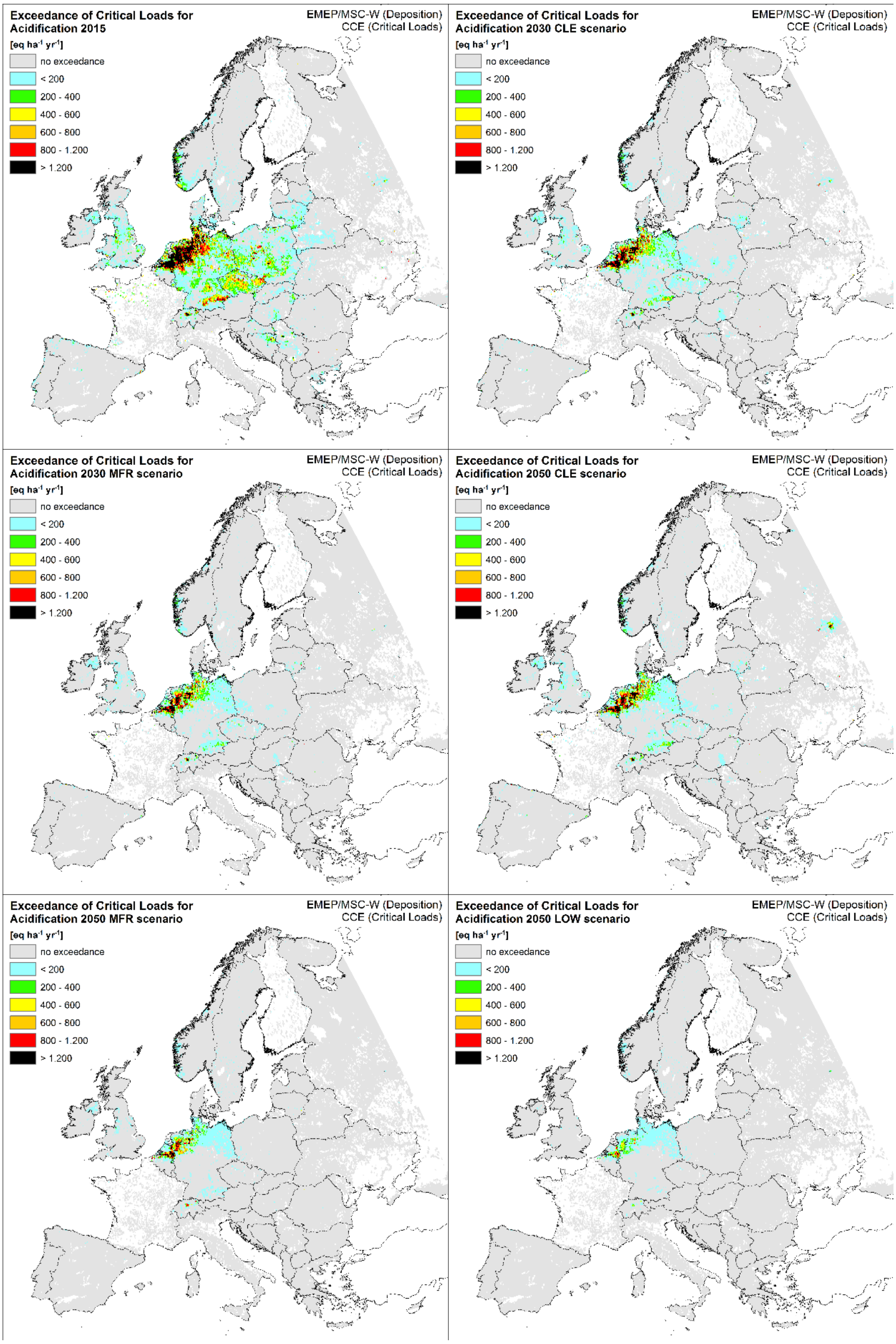
With regard to the projected acidification, the emission reduction of the different scenarios will help to diminish risks for ecosystems substantially. For the European domain the scenarios project a decline from 6% of the affected area (2015) to 2% (2030 CLE), 1% (2030 MFR), 2% (2050 CLE), 1% (2050 MFR) and 1% (2050 LOW). While in the 2015 base year, larger areas in central Europe, in the UK and Ireland or in the south of Scandinavia are still suffering from acidification, with help of emission abatement and projected deposition scenarios the affected area will be diminished to areas in the north of Belgium, the Netherlands and the north of Germany with very low AAE. The AAE for the European domain is projected to decrease from 74 eq ha^{-1} a^{-1} (2015) to 34 eq ha^{-1} a^{-1} (2030 CLE), 27 eq ha^{-1} a^{-1} (2030 MFR), 27 eq ha^{-1} a^{-1} (2050 CLE), 17 eq ha^{-1} a^{-1} (2050 MFR) and 6 eq ha^{-1} a^{-1} (2050 LOW). Only in the Netherlands, Germany, Belgium and Switzerland the AAE results still exhibit relatively high AAE-values even under the 5 different scenarios. In the Netherlands, AAE-values are not projected to fall below 200 eq ha^{-1} a^{-1} (comparable to 3 kg of nitrogen) even under the most ambitious 2050 LOW scenario.

With regard to eutrophication, the projected emission reduction of the different scenarios diminishes risks for ecosystems. However, the trend is projected to be less distinct than for acidification. For the European domain the scenarios predict a decline of the affected total area from 63% (2015) to 53% (2030 CLE), 44% (2030 MFR), 49% (2050 CLE), 31% (2050 MFR) and 22% (2050 LOW). While in the 2015 base year, large areas in the whole of Europe, such as in the UK and Ireland or in the south of Scandinavia are suffering from severe eutrophication, the affected total area is outlined to decline due to emission abatement under the deposition scenarios.

The AAE for the European domain is projected to decline from 343 eq ha^{-1} a^{-1} (2015) to 226 eq ha^{-1} a^{-1} (2030 CLE), 170 eq ha^{-1} a^{-1} (2030 MFR), 197 eq ha^{-1} a^{-1} (2050 CLE), 100 eq ha^{-1} a^{-1} (2050 MFR) and 50 eq ha^{-1} a^{-1} (2050 LOW).

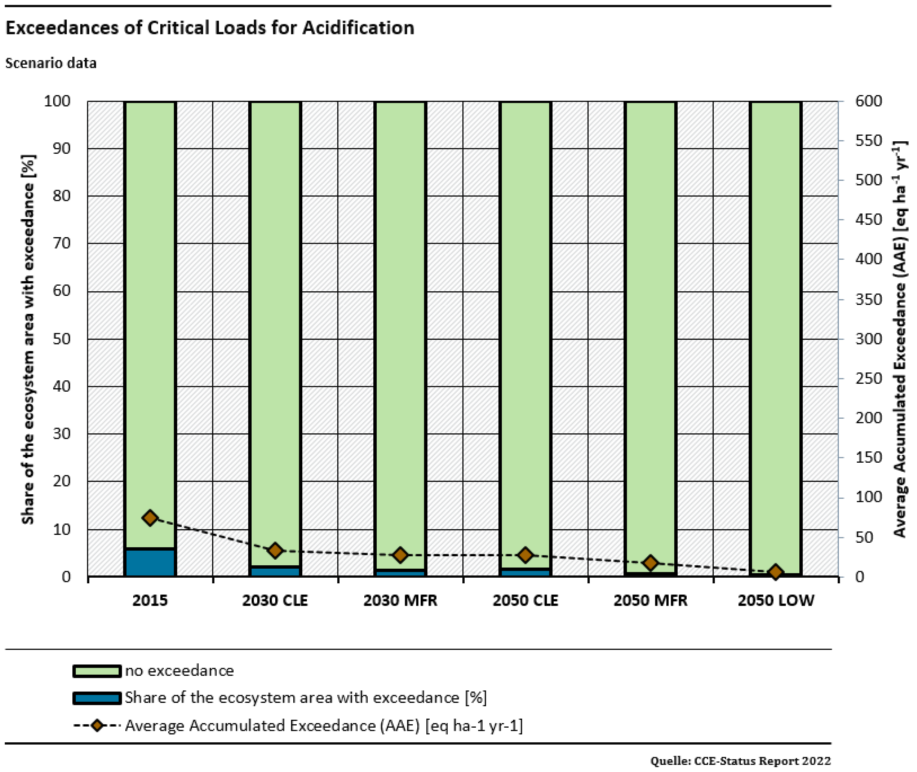
However, even under the most ambitious scenario 2050 LOW 22% of European ecosystems would still be exposed to nitrogen deposition beyond Critical Loads.

Figure 11: Critical Load Exceedance for Acidification for the year 2015 and 2 scenarios for 2030 and 3 scenarios for 2050



Source: Own illustration, Coordination Center for Effects

Figure 12: Total exceedance of Critical Load for acidification as share of receptor area and AAE for the year 2015 and the 5 scenarios



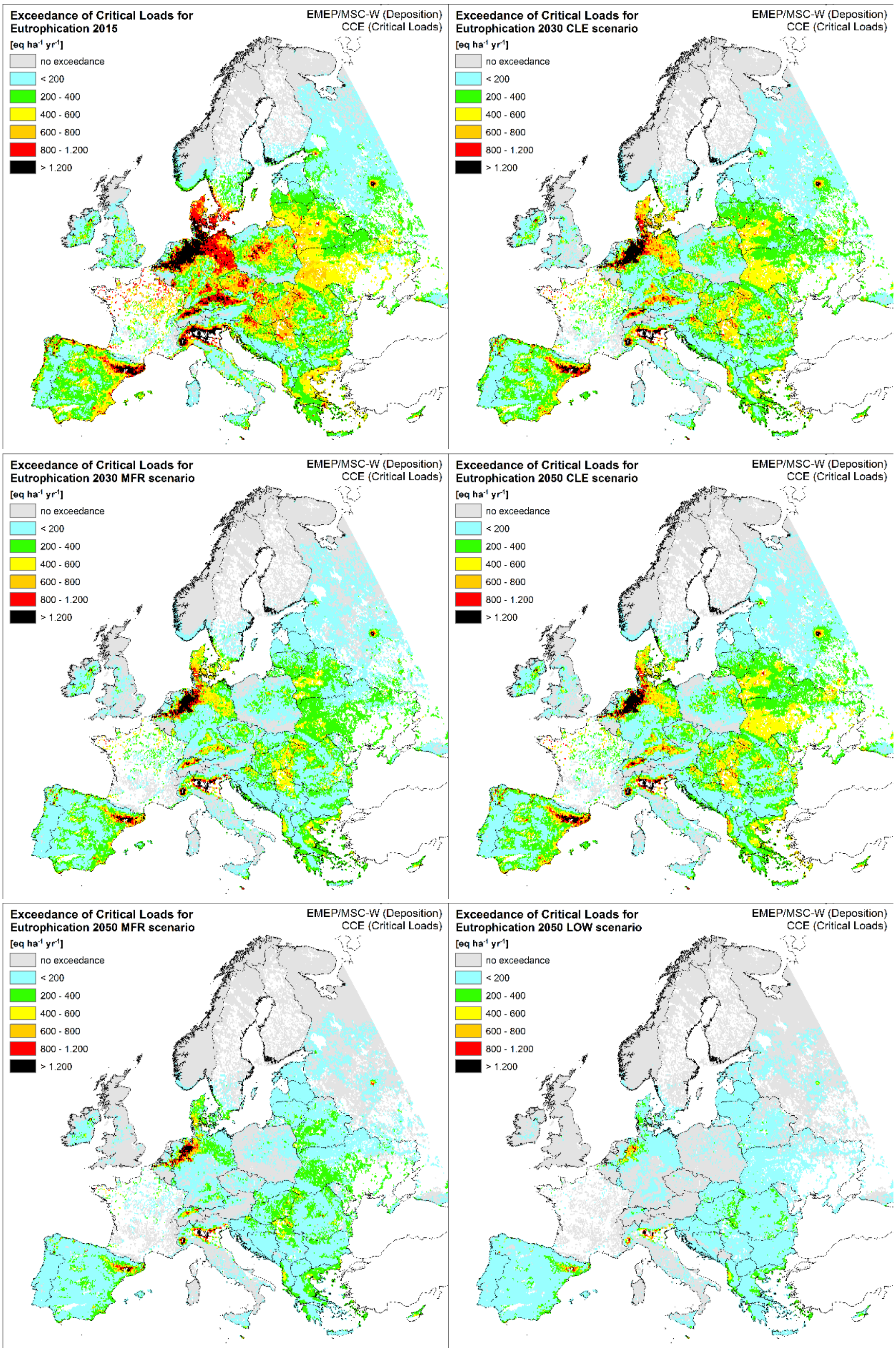
Source: Own illustration, Coordination Center for Effects

Table 4: Projected exceedance of Critical Loads for acidification presented as the share of the receptor area and the AAE.

Acidification		Projected exceedance of CL acid											
Country	Eco area [km²]	Share of the Eco Area in [%]						AAE in [eq ha^{-1} yr^{-1}]					
		2015	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**	**2015**	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**
Austria	38.957	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Belgium	15.482	39	29	26	25	18	9	489	232	185	168	85	20
Bulgaria	54.470	<1	<1	<1	<1	<1	<1	1	0	0	0	0	0
Croatia	36.484	2	<1	<1	<1	<1	<1	3	0	0	0	0	0
Cyprus	1.701	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Czech Republic	23.831	73	9	2	2	<1	<1	265	10	2	2	0	0
Denmark	6.741	10	<1	<1	<1	<1	<1	23	2	1	1	0	0
Estonia	30.735	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Finland	286	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
France	177.006	3	<1	<1	<1	<1	<1	7	1	0	0	0	0
Germany	106.947	42	19	14	16	6	4	280	104	63	74	24	8
Greece	78.016	<1	<1	<1	<1	<1	<1	1	0	0	0	0	0
Hungary	30.120	5	2	<1	2	<1	<1	21	4	1	2	0	0
Ireland	16.195	<1	<1	<1	<1	<1	<1	1	0	0	0	0	0
Italy	101.030	<1	<1	<1	<1	<1	<1	8	7	7	7	7	7
Latvia	44.389	2	<1	<1	<1	<1	<1	2	0	0	0	0	0
Lithuania	26.522	24	9	2	5	<1	<1	63	12	5	7	2	0
Luxembourg	1.388	14	4	<1	<1	<1	<1	83	4	1	1	0	0
Malta	35	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Netherlands	2.827	72	69	69	68	66	48	1399	914	796	774	562	211
Poland	95.950	26	3	1	1	<1	<1	87	4	1	1	0	0
Portugal	42.199	1	<1	<1	<1	<1	<1	3	1	0	0	0	0
Romania	109.564	<1	<1	<1	<1	<1	<1	2	1	0	1	0	0
Slovakia	26.875	4	<1	<1	<1	<1	<1	11	0	0	0	0	0
Slovenia	14.104	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Spain	252.450	<1	<1	<1	<1	<1	<1	2	1	0	1	0	0
Sweden	391.745	3	1	<1	<1	<1	<1	1	0	0	0	0	0
EU 27	**1.726.049**	**7**	**2**	**2**	**2**	**<1**	**<1**	**102**	**48**	**39**	**38**	**25**	**9**

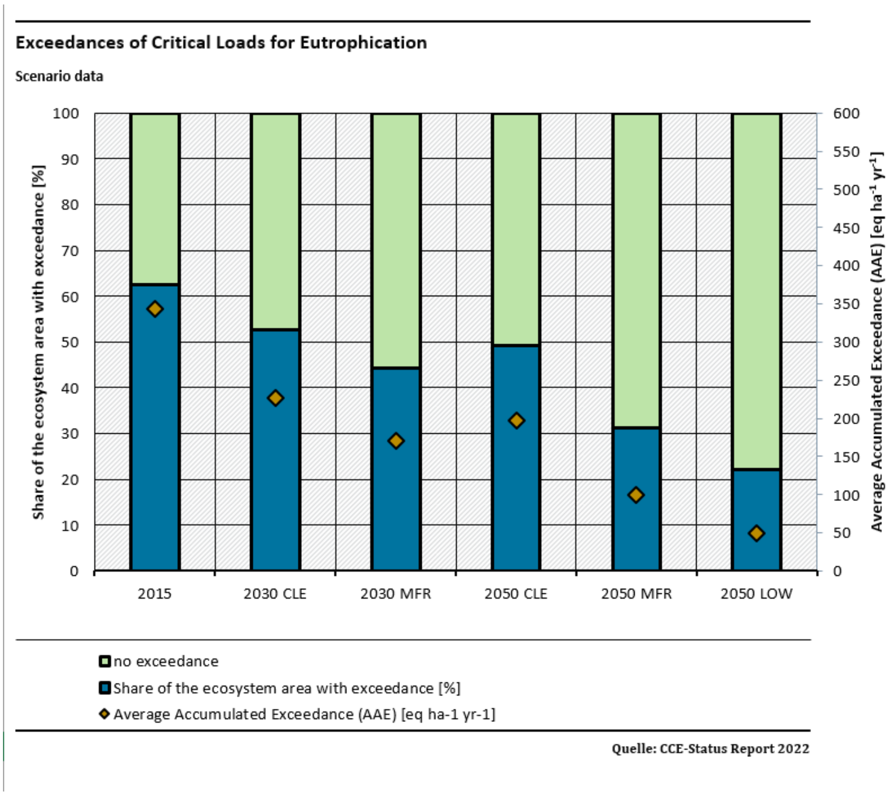
Acidification		**Projected exceedance of CL acid**											
Country	Eco area [km^2]	Share of the Eco Area in [%]						AAE in [eq ha^{-1} yr^{-1}]					
		2015	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**	**2015**	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**
Albania	20.018	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Belarus	66.612	4	<1	<1	<1	<1	<1	4	1	0	1	0	0
Bosnia and Herzegovina	37.104	8	<1	<1	<1	<1	<1	37	1	0	0	0	0
Kosovo	4.712	4	<1	<1	<1	<1	<1	26	0	0	0	0	0
Liechtenstein	109	6	6	5	6	<1	<1	26	11	2	6	0	0
Moldova	3.780	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Montenegro	9.072	<1	<1	<1	<1	<1	<1	1	0	0	0	0	0
Norway	320.450	10	5	4	5	3	2	16	6	5	5	2	2
Republic of Macedonia	16.922	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
Russia	643.887	<1	<1	<1	<1	<1	<1	1	1	0	3	0	0
Serbia	33.121	8	<1	<1	<1	<1	<1	32	1	0	0	0	0
Switzerland	9.733	16	11	9	9	7	3	104	64	49	55	32	8
Ukraine	97.915	<1	<1	<1	<1	<1	<1	2	0	0	0	0	0
United King-dom	75.806	5	2	1	1	<1	<1	15	4	2	2	0	0
Total	**3.065.290**	**6**	**2**	**1**	**2**	**1**	**1**	74	34	27	27	17	6

Figure 13: Critical Load Exceedance for Eutrophication for the year 2015 and 2 scenarios for the year 2030 and 3 scenarios for the year2050



Source: Own illustration, Coordination Center for Effects

Figure 14: Total exceedance of Critical Load for eutrophication as share of receptor area and AAE for the year 2015 and the 5 scenarios



Source: Own illustration, Coordination Center for Effects

Table 5: Projected exceedance of Critical Loads for eutrophication presented as the share of the receptor area and the AAE.

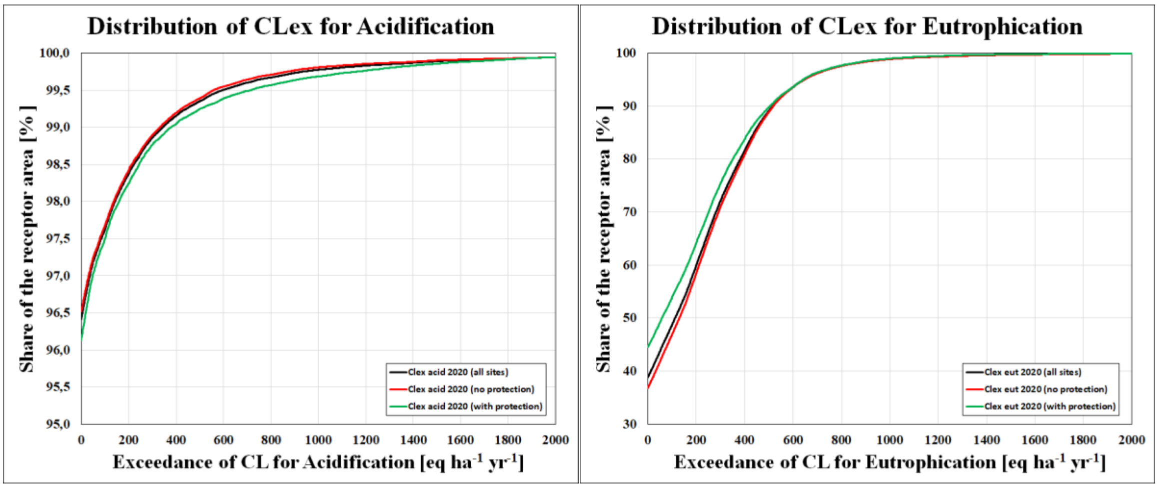
Eutrophication		Projected exceedance of CL eut											
Country	Eco area [km²]	Share of the Eco Area in [%]						AAE in [eq ha^{-1} yr^{-1}]					
		2015	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**	**2015**	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**
Austria	50.588	63	37	24	30	8	<1	224	91	45	68	9	0
Belgium	15.552	57	46	44	41	35	20	682	365	315	278	178	45
Bulgaria	54.470	84	65	48	59	35	33	211	143	101	129	71	48
Croatia	36.484	82	70	61	65	48	43	344	220	160	191	94	59
Cyprus	1.701	100	100	100	100	100	100	346	333	280	378	247	191
Czech Republic	23.831	94	72	56	59	20	1	493	196	105	118	17	1
Denmark	6.741	100	99	99	99	92	53	871	582	470	459	258	105
Estonia	30.735	48	33	28	28	17	11	78	39	28	27	12	5
Finland	41.141	3	<1	<1	<1	<1	<1	3	0	0	0	0	0
France	177.006	75	55	44	49	24	4	304	150	98	116	32	3
Germany	106.975	77	65	59	59	43	24	702	399	287	314	134	42
Greece	78.016	100	100	100	100	99	96	401	301	247	293	178	127
Hungary	30.120	87	71	68	69	58	46	463	337	260	293	167	87
Ireland	16.776	34	34	27	31	19	1	70	67	44	58	22	1
Italy	105.946	62	40	32	34	19	10	289	153	114	122	60	23
Latvia	44.389	93	72	58	59	42	38	234	130	96	102	56	29
Lithuania	26.522	99	97	92	92	64	34	431	288	212	230	102	40
Luxembourg	1.388	100	98	96	96	85	39	961	591	457	476	224	78
Malta	35	99	99	99	99	93	93	565	497	412	492	275	228
Netherlands	3.093	80	72	66	62	44	12	889	487	392	371	229	37
Poland	95.950	72	49	32	38	10	2	295	111	52	73	10	2
Portugal	42.199	81	66	60	63	49	46	190	130	90	112	43	33
Romania	109.564	92	85	74	80	54	39	306	241	183	208	118	68
Slovakia	26.875	96	86	80	83	55	28	422	242	165	194	77	35
Slovenia	14.104	77	55	48	50	34	23	364	199	142	160	73	32
Spain	252.450	93	87	81	85	71	66	365	288	214	267	127	90
Sweden	58.688	15	13	12	12	8	4	56	30	23	21	9	4
EU 27	**1.451.339**	**76**	**64**	**56**	**59**	**41**	**31**	**391**	**245**	**185**	**206**	**104**	**52**

Eutrophication		**Projected exceedance of CL eut**											
Country	Eco area [km²]	Share of the Eco Area in [%]						AAE in [eq ha^{-1} yr^{-1}]					
		2015	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**	**2015**	**2030 CLE**	**2030 MFR**	**2050 CLE**	**2050 MFR**	**2050 LOW**
Albania	20.018	88	83	78	82	71	69	306	274	222	272	171	157
Belarus	66.612	100	99	95	99	79	30	383	309	217	293	112	26
Bosnia and Herzegovina	37.104	72	67	62	66	50	38	208	156	105	143	52	35
Kosovo	4.712	69	52	42	49	34	17	148	96	65	91	43	12
Liechtenstein	109	98	97	97	97	96	50	637	468	377	411	257	103
Moldova	3.780	95	90	76	90	58	52	310	273	196	273	137	84
Montenegro	9.072	51	43	38	42	30	21	80	58	42	53	26	14
Norway	304.028	11	5	3	3	<1	<1	18	5	3	3	0	0
Republic of Macedonia	16.922	78	62	57	60	53	51	193	137	110	132	84	48
Russia	643.887	49	40	26	38	8	4	68	47	22	45	6	2
Serbia	33.121	86	76	67	72	56	40	339	262	199	240	138	60
Switzerland	24.248	55	46	40	42	30	10	336	225	173	193	106	17
Ukraine	97.915	100	100	100	100	92	61	432	346	244	349	141	61
United Kingdom	71.070	15	7	4	5	1	<1	36	13	6	9	2	0
Total	**2.783.937**	**63**	**53**	**44**	**49**	**31**	**22**	**343**	**226**	**170**	**197**	**100**	**50**

4.3 Link between CL exceedances and the protection status of an ecosystem

The following section presents the difference in CL exceedances in the European CL database of sensitive ecosystem that are categorized either as protected or as not protected by national conservation laws or within the Natura2000 (N2K) framework. The protection status was derived by analysing the data submitted by NFCs and the data contained in the background database. Figure 15 displays the 2020 distribution of CL exceedance for the entire CL dataset (black lines) and the distinguished groups of CL with (green lines) and without (red lines) protection status. For both acidification and eutrophication, the cumulated share of receptor area is relatively similar between protection status and non-protection status (Figure 15). Both figures indicate that the protection status of a recorded sensitive receptor area does not strongly influence the exceedance of CL. This is in line with model expectation, since the protection status does not alter the modelling approach and thus the sensitivity of the CL. It also shows that the regional pattern of the deposition is evenly distributed over receptors with and without national or international natural protection status.

Figure 15: Cumulative distribution functions (CDF) for CL exceedance for acidification (left) and eutrophication (right) for 2020.



Source: Own illustration, Coordination Center for Effects

4.4 Influence of nitrogen species nature in deposition data on the CL exceedance

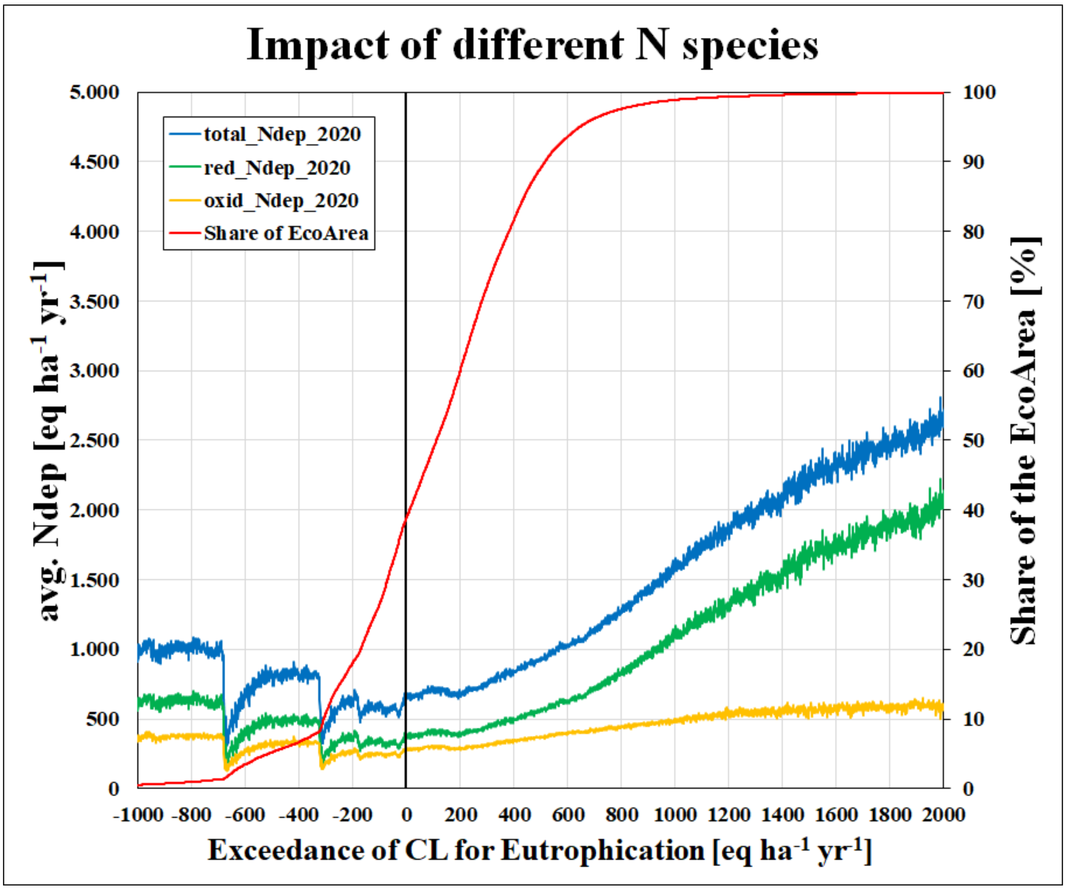
This section illustrates how different Nitrogen species (oxidized and reduced) may affect the CL exceedance for eutrophication according to the analysis of the results available. Similar to the previous section, this analysis focuses on the deposition and CL exceedance for the year 2020.

In this analysis, the areas with exceedance of the CL for eutrophication were evaluated for the amount of total nitrogen deposition and the contribution of the different nitrogen species to the total deposition (Figure 16).

It appears that the deposition of reduced nitrogen (green line) on CL relevant receptor areas is always higher than the deposition of oxidized nitrogen (yellow line). This pattern is less pronounced in areas of no CL exceedance (negative values on the x-axis), while the share of reduced nitrogen to the total nitrogen deposition increases with rising CL exceedances. Especially in areas with high CL exceedances (> 800 eq ha^{-1} yr^{-1}), the deposition of reduced nitrogen accounts for more than 2/3 of the total deposition. However, as the cumulative distribution graph of share of area (red line in Figure 16) reveals, areas of such high exceedances account for only about 3% of the total receptor area.

In summary, the deposition of reduced nitrogen to the areas at risk for eutrophication dominates the eutrophying deposition, however oxidized nitrogen contributes to eutrophying deposition in the order of 30% to roughly 50% depending on the exceedance. Therefore, in order to effectively reduce the share of sensitive areas affected by eutrophication, a combined reduction of oxidized and reduced nitrogen deposition is urgently required.

Figure 16: Exceedance of CL for Eutrophication and different species of Nitrogen deposition (2020)



Source: Own illustration, Coordination Center for Effects

4.5 List of references

CLRTAP, 2022. Review of the Gothenburg Protocol - Annex II Policy background (draft). August 2022 [3.9.2022]. https://unece.org/sites/default/files/2022-08/Item%207%20%28a%29%20Annex%20II_rm_Draft%2022%20Aug_0.pdf

EMEP, 2022. EMEP Status Report 1/2022. "Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components". Joint MSC-W & CCC & CEIP & CIAM Report. https://emep.int/publ/reports/2022/EMEP_Status_Report_1_2022.pdf

Hettelingh, J.P., M. Posch & J. Slootweg (Eds), 2017. European critical loads: database, biodiversity and ecosystems at risk: CCE Final Report 2017. RIVM Report 2017-0155. Bilthoven, Netherlands, pp. 49-60.

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

5.1 Introduction

In the cooperative work related to the review of the Gothenburg Protocol the Working Group on Effects was assigned to deliver information on the risk of eutrophication of marine ecosystems by atmospheric nitrogen deposition for the first time (ECE/EB.AIR/2020/3, Annex 1). This chapter[11] describes first results, which have been achieved by cooperation of the 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, ICP Waters the Task Force on Integrated Assessment Modelling and the Coordination Center for Effects (CCE) of the ICP Modelling and Mapping.

Critical Atmospheric Inputs (CAI) of nitrogen for different regions of the Baltic Sea (Baltic Basins) have been provided by RedCore DG. The CAI are based on the Maximum Allowable Inputs (MAI) derived for each Baltic sub-basin in HELCOM (Figure 17, Table 6). MAI are effect-based quantitative estimates of maximum total inputs, including atmospheric deposition, nitrogen from rivers and from direct inputs into the sea which would still allow gradual recovery of the Basins from eutrophication. MAI only apply for the open Sea, not for coastal waters representing the 1 nautical mile zone. CAI are calculated as a part of MAI considering the share of atmospheric deposition of the total load in a selected reference time period. The method is documented in more detail in Gustafsson et al (2021).

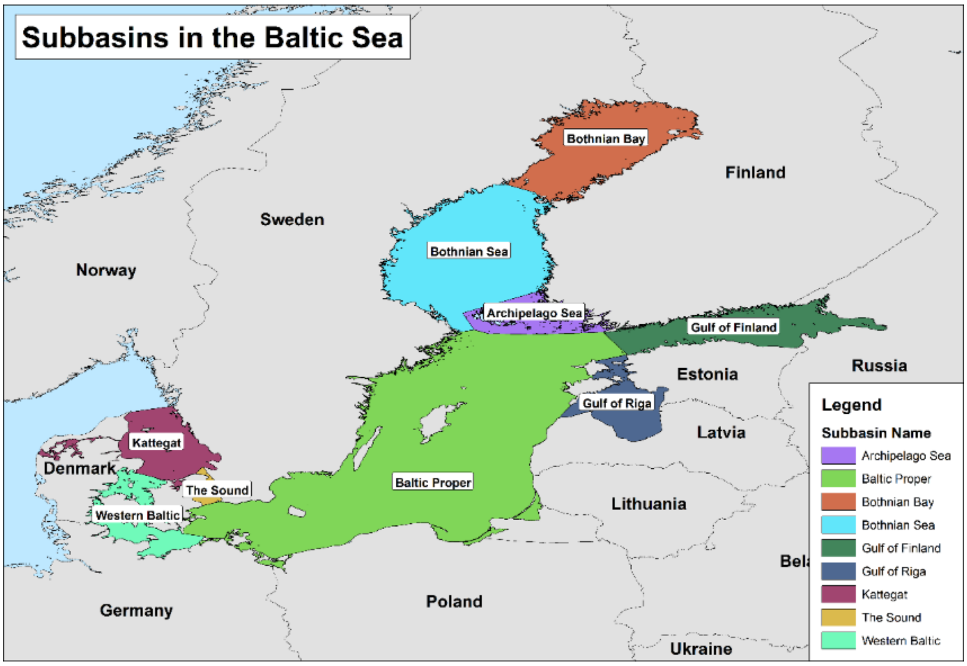
5.2 Method and data

Based on the following datasets from the RedCore DG under HELCOM the exceedance of CAI in relation to atmospheric nitrogen deposition was calculated

- an ESRI shapefile containing the spatial extent of the Baltic Sea sub-basins under consideration (Figure 17).
- a NetCDF file with information of covered area within each deposition cell of the different sub-basins (the depositions are based on EMEP model version rv4.42 and CEIP-Emission data reported in 2021).
- basin-wise CAI for the averages of the years 2015-19 and 2017-19 (Table 6) and gridded CAI values for these two reference periods as ASCII raster file (Figure 18).

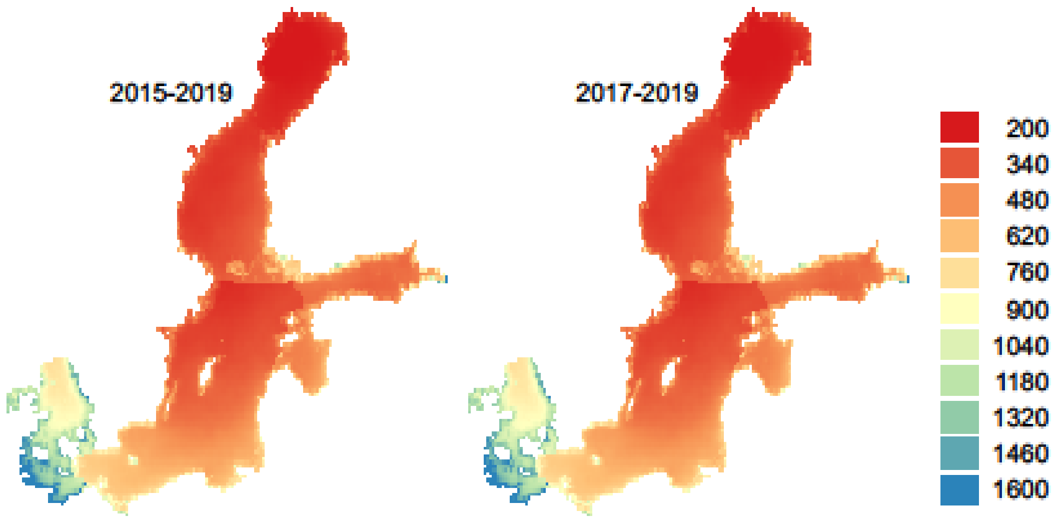
[11] The chapter builds on a report prepared by Thomas Scheuschner, Gudrun Schütze, Markus Geupel, and Wera Leujak from the German Environment Agency and Bo Gustafsson from Stockholm University Baltic Sea Centre.

Figure 17: Sub-basins of the Baltic Sea under consideration.



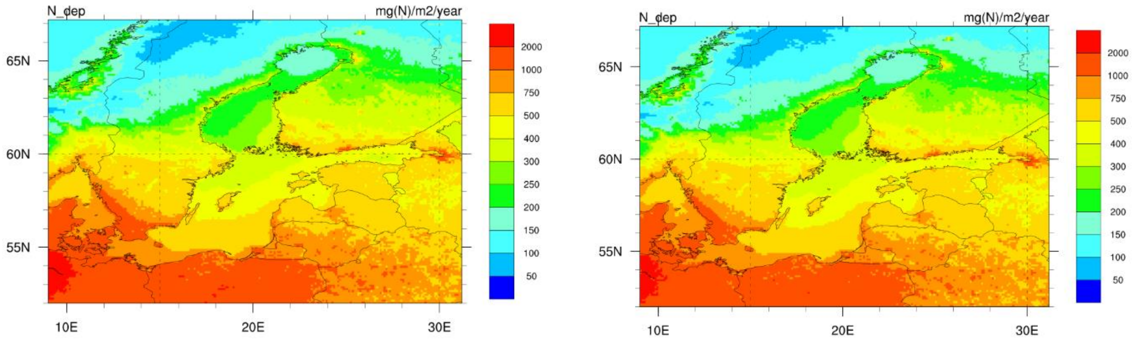
Source: AMP/RedCore, 2021

Figure 18: Spatially distributed CAI in kg km^{-2} y^{-1} for reference period 2015-19 (left) and 2017-19 (right) as used in calculation option b). The two different time periods were selected to explore the impact of different lengths of the reference period.



Source: AMP/RedCore, 2021

Figure 19: Map of annual deposition of total (oxidised + reduced) nitrogen 2015-2019 (left) and 2017-2019 (right). Units: kg N km^{-2} yr^{-1}.



Source: AMP/RedCore, 2021

First the deposition data was extracted from the MSC-West NetCDF file using R scripts. The deposition delivery of MSC-West is usually split in wet and dry deposition and in the two different nitrogen species oxidized and reduced nitrogen. To get the total nitrogen deposition the wet and dry (for the land use class "Water") component were aggregated and later the results for the two nitrogen species were combined.

It seemed to be preferable to use high spatial resolution data not only for deposition but also CAI. Besides having a more differentiated picture this would also reduce artificial abrupt changes of AAE values along the borders of the sub-basins. Therefore, AMP asked RedCore DG to provide gridded CAI data, if possible. This was done as described in Gustafsson et al. (2021).

The CCE calculated the exceedance of the CAI for the Baltic sub-basins using the most recent deposition data from EMEP MSC-West (2019) and two types of CAI data:

- Only one CAI value per Baltic sub-basin, in the following indicated as "option a)".
- CAI values for single EMEP grids, taking the atmospheric deposition pattern over the Baltic Sea into account, in the following "option b)".

The exceedance was calculated and weighted with respect to the share of the total sub-basin area for each deposition cell. In the final step the exceedance data was aggregated in order to get the Average Accumulated Exceedance (AAE) for the CAI 2015-19 and 2017-19 for the deposition year 2019.

5.3 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) and b) is provided in Table 6, where all values are provided in hectare or per hectare and year, respectively.

Table 6 reveals that 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 comparison of calculations and maps using CAI of two different reference periods do only show very minor differences.

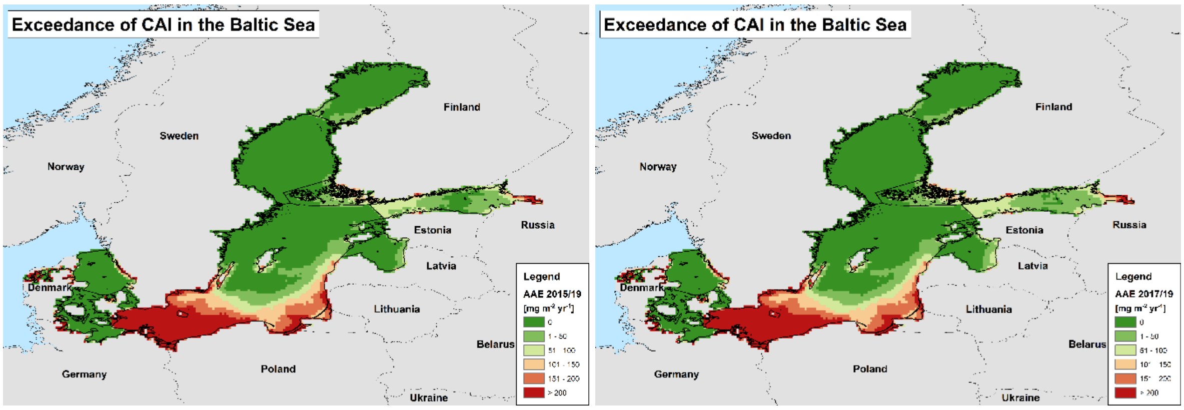
The overall AAE on basin level in general seems not very high compared to the AAE of the terrestrial ecosystems. The exceedance might be higher in selected regions. Figure 20 shows the results for AAE using calculation option a) for the two selected reference periods. The highest exceedance is indicated for the south-western part of the Baltic Proper. There are also tendencies to have the higher AAE in 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.

AAE results of option b) are shown in Figure 21. It is striking that here the spatial pattern of AAE is different to option a). The high exceedances (in red) are more scattered across the Baltic Proper, having their maximum in the eastern part. Further, there are tendencies that exceedance is particularly low along the coastlines, which is often in line with higher CAI in the related grids.

Table 6: Overview of Basin area, MAI, CAI and AAE (2019), all values are given in relation to the area of [1 ha a^{-1}].

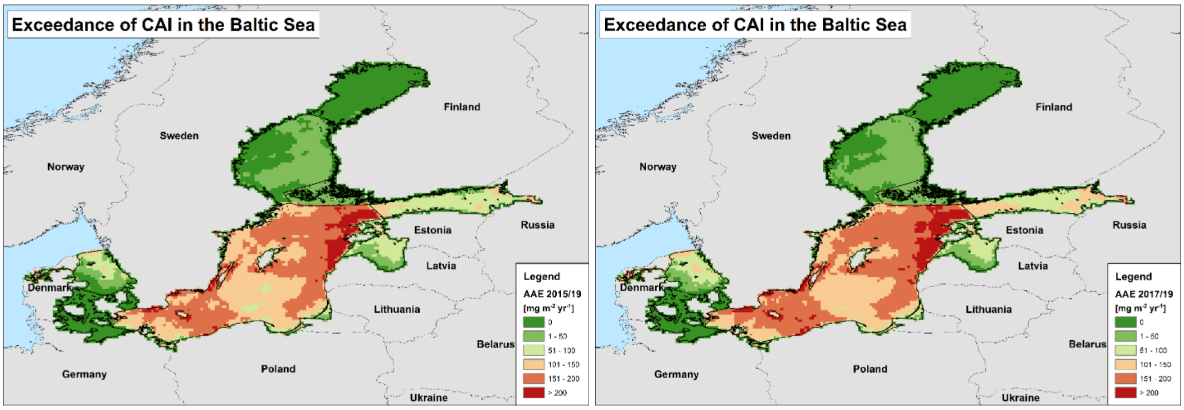
	Area [Mio. ha]	Deposition	MAI	CAI		Ratio $CAI_{17/19}$ / MAI	AAE option a)		AAE option b)	
		values given in [kg ha^{-1} yr^{-1}]					values given in [kg ha^{-1} yr^{-1}]			
Year(s)		2019		15/19	17/19		15/19	17/19	15/19	17/19
Baltic Proper	20.926	6.0	15.5	4.27	4.20	27%	1,72	1,78	1,48	1,55
Bothnian Bay	3.625	1.9	15.9	2.29	2.31	15%	0,02	0,02	0	0
Bothnian Sea (including the Archipelago Sea)	7.880	3.6	12.1	4,04	3.99	33%	0,05	0,06	0,05	0,07
Gulf of Finland	3.000	4.8	33.9	5.72	5.41	16%	0,06	0,08	0,65	0,84
Gulf of Riga	1.865	5.2	47.4	5.32	5.34	11%	0,14	0,13	0,48	0,47
Kattegat	2.366	9.3	31.3	9.89	9.64	31%	0,21	0,25	0,36	0,53
Danish Straits (comprising The Sound and Western Baltic)	2.097	10.4	31.5	13.88	13.48	43%	0,08	0,09	0	0
Total/Average	**41.759**	**5.9**					**0,90**	**0,94**	**0,43**	**0,49**

Figure 20: Results of calculation option a): CAI exceedance for the Baltic Sea sub-basins for the deposition year 2019 and the CAI 2015/19 (left) and the CAI 2017/19 (right).



Source: AMP/RedCore, 2021

Figure 21: Results of calculation option b): CAI exceedance for the Baltic Sea sub-basins for the deposition year 2019 and the CAI 2015/19 (left) and the CAI 2017/19 (right).



Source: AMP/RedCore, 2021

5.4 Discussion

The calculation of CAI as used here implies some assumptions, which have to be considered in the interpretation of the results. In calculation option a) the sensitivity against nitrogen deposition is assumed to be equal within each of the single sub-basins 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, but CAI exceedance is 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. Depending on the methods 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. Our chosen 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 6).

If calculation option b) is used, there are additional gradients of CAI within the basins, i.e. again grids with high deposition loads appear with higher CAI. The reason is that in order to calculate CAI for each single grid the ratio of the deposition in this grid to the area-weighted average of the deposition in the basin has been used as a factor and has been multiplied with the average CAI of the basin. This once more leads to higher CAI in such grids within a basin where deposition is high, applying in particular to areas near the coasts. Other than for the CAI calculation for basins, it is not possible, yet, to consider the inputs from other sources than atmospheric deposition (waterborne and direct nitrogen inputs) to each of the grids. In consequence, the areas close to the coasts appear to be least sensitive to eutrophication (high CAI), which seems not very plausible.

5.5 Conclusion

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), we regard this method as a simple approach to get a first impression of 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. However, the geographical distribution of CAI exceedance within the basins has to be interpreted with care, in particular close to the coastal waters. Because of the uncertainties implied with the use of gridded CAI data, we recommend to use calculation option a) for including the Baltic Sea in the European AAE mapping with respect to risks of eutrophication for the Review of the Gothenburg Protocol.

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, but cannot be considered in our CAI exceedance calculation, because they are subject of work of the EU Water Framework Directive (2000/60/EC). Co-operation beyond CLRTAP and HELCOM would be needed to include these sensitive ecosystems in future projects

5.6 References

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

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

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). [3.9.2022] https://portal.helcom.fi/meetings/PRESSURE%2015-2021-944/MeetingDocuments/Forms/AllItems.aspx

6 Outlook

In this chapter a brief outlook is given on current and upcoming activities of the CCE to further develop Critical Load modelling and future assessments of air pollution effects on sensitive ecosystems across CLRTAP. The topics below were also discussed at the 38th ICP M&M Meeting in May 2022 (ICP M&M, 2022).

Harmonized CLRTAP receptor map

CCE currently coordinates a research and development project at the German Environment Agency, executed by Earth Observation Solutions and Services (EOSS) GmbH, to update the CLRTAP receptor map. Such a receptor map is needed for the calculation of critical loads and for the modelling of air quality. The product of the project is jointly used by different bodies of the Convention and therefore a harmonized up-to date database plays a central role for the adherence of the scientific quality of convention wide assessment results. The descriptions of the current receptor map are more than 10 years old and underlying datasets are even older (Cinderby et al., 2007; Slootweg et al., 2009). The land cover maps are currently based on data from the 1990s and 2000s, i.e. it is based on information that is 20 to 30 years old. The update of the receptor map is therefore urgently needed and part of the current 2022-2023 workplan of the convention (CLRTAP, 2021). In this project, the receptor map will be updated based on the latest available land cover, ecosystem and vegetation data. In addition, the map is planned to be extended to the region of the EECCA countries. The project started in December 2021 and will run until summer 2023.

Evaluation of climate change impact to CL calculated from the simple mass balance (SMB) model

The main goal of this ongoing project at the German Environment Agency is to assess the impact that a climate change induced shift in climate-related input values to the SMB model might have on CL calculation. Furthermore, possible additional relevant CL climate dependences to be implemented in the SMB model are investigated. To this, the variation of climate-related input variables with climate change is evaluated. Working steps in this project include an analysis of CL calculated by the SMB method after altering climate-related variables using data from the German NFC dataset and ICP Forests Level II plots and a literature search on climate impacts to eutrophication and acidification. The project started in October 2021 and is planned to be finalized in summer 2023.

Updating critical limits used in the simple mass balance (SMB) model

Critical Limits are the basis for calculating critical loads in the SMB model because they represent a chemical criterion (e.g. N leaching, acid neutralizing capacity) that is mathematically linked to a deposition threshold (the critical load) above which significant ecosystem damage is expected. The choice of the critical limit is therefore essential for calculating a critical load. CCE coordinates an ongoing project at the Environment Agency Austria, to analyze the current scientific knowledge on critical limits for acidification and eutrophication in order to derive recommendations on possible updates of critical limits and decrease the uncertainty in critical loads. To this, an NFC survey on the application of critical limits by NFCs was prepared along with a literature review and a sensitivity analysis of critical loads calculated from varied critical limits using the SMB model and the latest background database. An expert workshop on this topic is planned for later in the project.

Future/planned updates of the CCE CL background database (BGDB)

The CL background database is now integrated in to the CCE CL exceedance framework. National subsets of this data can be obtained by the respected NFC via the CCE cloud. This new opportunity was presented by Thomas Scheuschner at the 38th ICP M&M Meeting in May 2022 and some NFC expressed their interest in this “on-demand” service. The option of publishing an GIS-WebMap-Service (WMS) was also discussed but no currently running applications were identified. An exchange of data allows for comparison of national and BGDB input data and modelling results.

With the above-mentioned update of the CLRTAP receptor map a spatial extension of the BGDB to EECCA countries is planned.

Future call for data and joint activities with national focal centers

The recent achievements described here in this report are also a basis for future joint activities with National Focal Centers of the ICP Modelling & Mapping. Given the finalized update of $CL_{emp}N$ (Chapter 1) and the above-mentioned ongoing update of the receptor map, the ICP M&M community at its 38th meeting in May 2022 informed that a new Call for data is planned for 2023 to be part of the future Workplan of the Convention in the years 2024-2025. In this regard, it is considered, that National Focal Centers should apply the updated empirical CL to national receptor maps. Also, a closer interaction between CCE and National Focal Centers on the CL data produced with the Background Database for comparison and evaluation with national data is foreseen.

Manual updates

Lastly, a number of updates of the Mapping Manual are foreseen following the work achieved on the update of empirical Critical Loads for Nitrogen and review of new scientific findings regarding ammonia. The new findings on Empirical Critical Loads are described in Chapter 1. The latest scientific findings on ammonia were discussed at a CCE workshop in March 2022[12]. The results are not being presented in this CCE Status report in detail but are documented in a workshop proceedings report, standing on its own (Franzaring & Kösler, 2022). For both topics, new text referring to the workshop reports will be presented in the 39th ICP M&M meeting in 2023 for adoption and uptake into the manual. For this purpose, CCE will coordinate two drafting groups corresponding to both topics and with participation of the involved experts.

References:

Cinderby S, Emberson L, Owen A, Ashmore M (2007) LRTAP land cover map of Europe. pp 59-70 in Slootweg J, Posch M, Hettelingh J-P (eds) Critical Loads of Nitrogen and Dynamic Modelling, CCE Progress Report 2007, Bilthoven

CLRTAP 2021: 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

Franzaring J. & Kösler, J. (eds), 2022. Review of internationally proposed critical levels for ammonia - Proceedings of an Expert Workshop held in Dessau and online on 28/29 March 2022. German Environment Agency, Dessau-Roßlau 2022. https://www.umweltbundesamt.de/dokument/expert-workshop-on-ammonia-proceedings-final-draft

ICP M&M, 2022. Annual report of the International Cooperative Programme on Modelling & Mapping of Critical Levels and Loads and air pollution effects, risks and trends https://www.umweltbundesamt.de/dokument/annual-report-of-the-icp-mm-2022

[12] https://www.umweltbundesamt.de/dokument/expert-workshop-on-ammonia-proceedings-final-draft

Slootweg J, Posch M, Warrink A (2009) Status of the harmonized European land cover map. pp 31-34 in Hettelingh JP, Posch M, Slootweg J (eds.) Progress in the modelling of critical thresholds, impacts to plant species diversity and ecosystem services in Europe: CCE Status Report 2009, Bilthoven

A NFC reports of the ICP Modelling and Mapping

NFC-Reports, which have been submitted to CCE with the CfD to be added after bilateral and editorial exchange and finalization in follow-up of the meeting.

A.1 National report of Belgium (Flanders)

National Focal Centre:

Johan Neirynck
Research Institute for Nature and Forest (INBO)
Havenlaan 88 bus 73
BE-1000 Brussel
johan.neirynck@inbo.be

Collaborating institutions:

Jeroen Staelens
Flanders Environment Agency (VMM)
Kronenburgstraat 45
BE-2000 Antwerp
j.staelens@vmm.be

A.1.1 Introduction

Belgium (Flanders) decided to answer the call for data 2021 because the former database was based on an outdated vegetation map and instructions from an old mapping manual (UBA, 1996). A new dataset was also required to corroborate the Flemish air abatement policy plan.

A.1.2 Mapping of ecosystem types

A new vegetation map was produced for mapping CL from 4 EUNIS classes (B, E, F, G). The subdivision into the 4 envisaged classes was based on the INBO Biological Valuation Map (De Saeger et al., 2016). This map is achieved from a uniform field-driven survey of land cover and vegetation in the Flemish Region. The map is drawn at a detailed scale of 1/10.000 and land cover classes along with vegetation types are defined by an extensive list of legend units. The classification for the CL vegetation map was done by combining the relevant units (polygons) into 5 ecosystem types (deciduous and coniferous forest, heathland, grassland and coastal dunes). The total Flemish Eco Area amounted to 2218.6 km^2 (Table 7). By overlaying existing soil profile datasets with this vegetation map, a database of 1890 soil receptors, with vegetation types belonging to 4 EUNIS classes (B, E, F, G), was retained for critical load calculations.

Table 7: Type and area of ecosystems provided by the NFC for critical load calculations in Flanders

Ecosystem type	Area (km^2)	% receptor area of total area Flanders
Deciduous forest	938.9	6.9%
Coniferous forest	586.9	4.3%
Grassland	572.2	4.2%

Ecosystem type	Area (km²)	% receptor area of total area Flanders
Heathland	96.7	0.7%
Coastal dunes	23.9	0.2%
Total	**2218.6**	**16.3%**

A.1.3 Meteo

Meteorological data for soil receptors consisted of 5 by 5 km^2 gridded information of monthly precipitation, temperature and global radiation. The data spanned a period of 30 years (1980-2010) and were provided by the Royal Meteorological Institute of Belgium (KMI). Precipitation surplus (Q) was computed using Methyd (v1.9, Bonten et al., 2016) using monthly precipitation, temperature and global radiation data. Calculations also required measured soil carbon, clay and sand contents and varying albedo values (0.05-0.3), depending on the habitat type. For a small part of the soil database, soil bulk density was available.

A.1.4 Critical Loads of Eutrophication ($CL_{eut}N$)

Calculation critical load of eutrophying nitrogen

The critical load of eutrophying nitrogen (*CLeutN*) was mainly calculated as *CLnut(N)*, which is achieved from simple mass balance calculations (eq.V.5, CLRTAP, 2017). For some coastal Natura 2000 habitats (type 2130, 2160, 2170 and 2190), critical load values for eutrophying nitrogen were adopted from Van Dobben et al. (2012).

Acceptable leaching of inorganic nitrogen ($N_{le}(acc)$)

The acceptable inorganic N leaching for temperate heathland, grassland, coniferous and deciduous forest was based on range values in kg N ha^{-1} yr^{-1} listed on page V.23 of CLRTAP (2017) (Table 8).

Nitrogen immobilization

Long-term sustainable immobilization of N (Ni) was set to 1 kg N ha-1 yr-1 for all soil groups as recommended by the mapping manual (CLRTAP, 2017).

Table 8: Acceptable leaching rate of inorganic nitrogen ($N_{le}(acc)$, in kg N ha^{-1} yr^{-1}) applied to soil receptors from different ecosystem types (n: number of receptors), excluding some dune habitat types for which Clemp were chosen.

Ecosystem type	n	$N_{le(acc)}$
Heathland	99	0.5
Dystric meadows	55	1
Eutrophic fresh grassland	574	3
Deciduous forest (including dune woods)	798	4

Ecosystem type	n	$N_{le(acc)}$
Intensive coniferous plantations	43	3
Managed coniferous forests/woodlands	297	1

Nitrogen uptake

Forests: annual average growth rates for the whole rotation length were calculated by SIM4tree (Borremans et al., 2014), which is mainly based on Dutch production yield tables (Jansen et al., 1996). The computed growth rates varied depending on the soil quality (texture, drainage status, profile), as indicated by the Belgian soil legend. Wood (stem) concentrations for steady-state conditions were retrieved from literature (de Vries et al., 1991; Jacobsen et al., 2002; Staelens et al., 2006; van der Salm and de Vries, 2000). Nitrogen uptake was set to zero for (permanent) forest clearings, scrubland, thickets, transitional woodland-scrubland and young plantations or natural regenerations consisting of unidentified tree or shrub species.

Non forest (semi-)natural ecosystems: net uptake through extensive management for heathland, dystric meadows and eutrophic fresh grasslands (nitrogen and base cation concentrations, yield) were obtained from German CL studies (Posch et al., 2001; Schlutow et al., 2018). Nitrogen uptake was set to zero for rush dominated pastures, dune slacks, shifting coastal dunes, inland dune pioneer grasslands and coastal stable dune grassland.

Denitrification

The denitrification fraction fde was determined based on soil texture and drainage status (de Vries et al., 1993; Reinds et al., 2001; Staelens et al., 2006).

A.1.5 Critical Loads of acidity

Critical load function of acidity (CLacid)

The critical load of acidifying sulphur and nitrogen deposition for the envisaged ecosystem types was calculated using the critical load function (CLF) with deposition-dependent denitrification. The CLF is quantified by CLmax(S) (eq.V.22 of the mapping manual), CLmin(N) (eq.V.25) and CLmax(N) (eq.V.26).

Chemical criteria and the critical leaching of Acid Neutralizing Capacity ($ANC_{le,crit}$)

The critical leaching of acid neutralizing capacity ($ANC_{le,crit}$) was calculated using critical Bc/Al ratios ($(Bc/Al)_{crit}$), related to a 20% growth impact (equation V.31 along with information found in Table V.8 from the mapping manual). For forests, species-specific ratios were used, depending on the dominant tree species, with values ranging from 0.3 to 6 (Sverdrup and Warfvinge, 1993). For grasslands and heathland, the $(Bc/Al)_{crit}$ of 1 and 0.8, respectively, were adopted from the national report of the Netherlands (Posch et al., 2001).

Parent material

The subdivision of soil receptors into parent material classes was based on Table V.15 (CLRTAP, 2017). The Belgian soil legend was converted into the FAO soil classification (1990) using the correlation legend for the Belgian soil map (Langohr et al., 2002).

Weathering depth

The rooting depth in the weathering rate estimation ranged from 0.35 to 0.8 m, depending on the vegetation type (Table V.13 from the manual).

Weathering rate of base cations (WBC)

Non calcareous soils: the approximate weathering rate for a soil depth z (in meter) is computed using equation V.44, using weathering rate classes as function of texture and parent material classes (Table V.16, CLRTAP, 2017).

Calcareous soils: an estimate of the calcite weathering rate was made based on the look-up table from the manual (Table V.10).

$W_{BC,soil}$ was calculated by multiplying $W_{BC,soil}$ with a factor between 0.70 for poor sandy soils and 0.85 for rich (sandy) soils.

Gibbsite equilibrium constant (K_{gibb})

The choice of the K_{gibb} was based on measured C concentrations in the soil profile (Table V.9 from the manual).

Base cation and chloride deposition

The sea-salt corrected total deposition of B_c and Cl were derived from wet-only collector data using the methodology of Downing et al. (1993) and Draaijers et al. (1997). Total sea-salt corrected deposition of B_c varied between 244 and 320 eq ha^{-1} $year^{-1}$.

Base cation uptake

For semi-natural vegetation and forests a similar approach was followed as for nitrogen uptake. Base cation uptake was constrained according to equation V.45 (Bc_{min} in soil solution = 0.01 mol_c m_{-3}). In case of violation of this criterion (when base cation supply by weathering or atmospheric inputs was too low), base cation uptake had to be adjusted. Subsequently, nitrogen uptake rates were adjusted respecting the vegetation-specific ratios.

A.1.6 Results

Coniferous forests and heathlands have the lowest *CLeutN* over the whole range (Table 3). The soils supporting these ecosystems are coarse sandy and have low denitrification values. They occur especially in the northern part of Flanders where large nitrogen depositions occur due to presence of animal husbandry. The median *CLeutN* values from deciduous forests, grasslands and coastal dunes are above 1000 eq ha^{-1} yr^{-1}. Soil receptors from deciduous forests and grasslands are more variable in texture and have also conspicuously higher f_{de} values, resulting in higher *CLeutN* values.

With regard to $CL_{max}(S)$ and $CL_{max}(N)$, the ecosystem types heathland and coniferous forest are most sensitive to acidification. However, also the 5th and first quartiles from (dystric) grasslands and deciduous forests are low, indicating their presence on soils with low buffer capacity. The larger part of deciduous forest and grassland are growing on better buffered soils, with a large clay content and high denitrification fractions, alleviating acidification effects. Soil receptors in coastal dunes are rich in calcite.

Table 9: Percentile distribution of CLeutN, $CL_{max}(S)$, $CL_{min}(N)$ and $CL_{max}(N)$ for the 5 ecosystem types (in eq ha^{-1} yr^{-1}).

Ecosystem type		*CLeutN*	*$CL_{max}(S)$*	*$CL_{min}(N)$*	*$CL_{max}(N)$*
Deciduous forest					
	5th	643	323	71	1025
	25th	902	1187	382	2489
	50th	1065	2595	465	5987
	75th	1227	4010	513	9615
	95th	1485	14270	715	46351
Coniferous forest					
	5th	480	234	339	747
	25th	482	380	401	884
	50th	543	443	413	1083
	75th	654	596	463	1385
	95th	896	2533	660	6437
Grassland					
	5th	560	205	458	927
	25th	1029	269	610	1140
	50th	1313	1037	921	2570
	75th	1457	1600	921	4565
	95th	1635	2926	921	10312
Heathland					
	5th	397	588	354	1046
	25th	425	619	385	1186
	50th	436	646	385	1376
	75th	457	692	385	1686
	95th	457	1284	385	2535
Coastal dunes					
	5th	699	1236	71	1445
	25th	803	3445	71	6208
	50th	1428	5540	71	6249
	75th	1999	5561	395	9484
	95th	2142	11756	921	18091

A.1.7 References

Bonten, L. T. C., Reinds, G. J., Posch, M. (2016). A model to calculate effects of atmospheric deposition on soil acidification, eutrophication and carbon sequestration. Environmental Modelling & Software, 79, 75-84.

Borremans L., Jacxsens, P., Dalemans F., Van de Peer T., Aertsen W., Aerts R., Van Orshoven J., Muys B. (2014). Verdere ontwikkeling van de Sim4Tree tool. Eindrapport na fase 5a. KOBE-rapport. Agentschap voor Natuur en Bos en Inverde.

CLRTAP (2017). Mapping critical loads for ecosystems, Chapter V of Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. UNECE Convention on Long-range Transboundary Air Pollution.

De Saeger S., Guelinckx R., Oosterlynck P., Erens R., Hennebel D., Jacobs I., Van Oost F., Van Dam G., Van Hove M., Wils C., Paelinckx D. (eds.) (2016). Biologische Waarderingskaart en Natura 2000 Habitatkaart, uitgave 2016. Rapporten van het Instituut voor Natuur- en Bosonderzoek 2016 (12049231). Instituut voor Natuur- en Bos-onderzoek, Brussel.

de Vries, W. (1991). Methodologies for the assessment and mapping of critical loads and of the impact of abatement strategies on forest soils. DLO The Winand Staring Centre, Wageningen (The Netherlands),. Report 46. 109 pp.

de Vries W, Posch M, Reinds GJ, Kämäri J (1993). Critical loads and their exceedance on forest soils in Europe., DLO Winand Staring Centre, Wageningen, The Netherlands, Report 58 (revised version) 116 pp.

Downing, R.J., Hettelingh J.-P., de Smet P.A.M. (eds.) (1993). Calculation and Mapping of Critical Loads in Europe: CCE Status Report 1993 (RIVM Report 259101003). National Institute of Public Health and the Environment, Bilthoven, Netherlands.

Draaijers G., Leeuwen E. V., De Jong P.G.H., Erisman J. (1997). Base cation deposition in Europe - part I. Model description, results and uncertainties. Environmental Science 31.

Jansen, J.J., Sevenster, J., Faber, P.J. (1996). Opbrengsttabellen voor belangrijke boomsoorten in Nederland. IBN-DLO, Wageningen.

Jacobsen, C., Rademachter, P., Meesenburg, H., Meiwes, K. J. (2002). Elementgehalte in Baumkompartimenten: Literaturstudie und Datensammlung. Göttingen: Niedersächsische Forstliche Versuchsanstalt, Report, 80 pp.

Langohr R. (2002). Correlation legend for Belgian soil legend to FAO soil groups. In: Langouche D., Wiedemann T., Van Ranst E., Neirynck J., Langohr R. (2002). Berekening en kartering van kritische lasten en overschrijdingen voor verzuring en eutrofiëring in bosecosystemen in Vlaanderen. In: Neirynck J., de Ridder K., Langouche D., Wiedeman T., Kowalski A., Ceulemans R., Mensink C., Roskams P., Van Ranst E, Bepaling van de verzuring- en vermestinggevoeligheid van Vlaamse bossen met gemodelleerde depositiefluksen. Eindverslag van project VLINA 98/01, studie uitgevoerd voor rekening van de Vlaamse gemeenschap binnen het kader van het Vlaams Impulsprogramma Natuurontwikkeling

Posch, M., de Smedt, P. A. M., Hettelingh, J. P., Downing, R. J. (2001). Calculation and mapping of critical thresholds in Europe. CCE Status Report 2001 (RIVM report 259101010). Bilthoven, The Netherlands: Coordination Center for Effects, National Institute of Public Health and the Environment.

Reinds G.J., Posch M., De Vries W .(2001). A semi-empirical dynamic soil acidification model for use in spatially explicit integrated assessment models for Europe. Alterra Report 084, Alterra Green World Research, Wageningen, The Netherlands, 55 pp.

Schlutow, A., Nagel, D-N, Bouwer, Y., (2018). Critical Load Daten für die Berichterstattung 2015 - 2017 im Rahmen der Zusammenarbeit unter der Genfer Luftreinhaltekonvention (CLRTAP), UBA 60, 154 pp.

Staelens J., Neirynck J., Genouw G., Roskams P. (2006). Dynamische modellering van streeflasten voor bossen in Vlaanderen. Studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij, MIRA, MIRA/2006/03. Rapport INBO.R.2006.12. Instituut voor Natuur- en Bosonderzoek, Brussel. 156 pp.

Sverdrup, H., Warfvinge, P. (1993). The effect of soil acidification on the growth of trees, grass and herbs as expressed by the (Ca+Mg+K)/Al ratio. Reports in Ecology and Environmental Engineering 2, Lund University, Lund, Sweden, 177 pp.

UBA (1996). Manual on methodologies and criteria for mapping critical levels/loads and geographic areas where they are exceeded. Federal Environmental Agency, 142 pp.

van der Salm, C., de Vries, W. (2000). Soil acidification in loess and clay soils in the Netherlands. Water Air and Soil Pollution, 120, 139-167.

van Dobben H.F., Bobbink R., Bal D., van Hinsberg A. (2012). Overzicht van kritische depositiewaarden voor stikstof, toegepast op habitattypen en leefgebieden van Natura 2000. Wageningen, Alterra, Alterra-rapport 2397 2397, 68 pp.

A.2 National report of the Czech Republic

National Focal Centre

Tomáš Chuman
Czech Geological Survey
Geologická 6
CZ-150 00 Prague 5

&
Faculty of Science
Charles University
Albertov 6
CZ-128 00 Prague 2
tomas.chuman@geology.cz

Collaborating experts

Filip Oulehle
Jakub Hruška
Czech Geological Survey
Geologická 6
CZ-150 00 Prague 5

A.2.1 Introduction

This document gives an overview of the response by the Czech Republic to the Call for Data 2019–2021, adopted by the Working Group on Effects (WGE), on the steady-state Critical Loads. The submitted data represent the updated national critical load database and contain "CLacid" and "CLeut". Critical loads of sulphur CLmaxS and critical loads of nitrogen CLminN, CLmaxN in the table "CLacid" are based on the SMB method (CLRTAP, 2017).

A.2.2 Methods and data

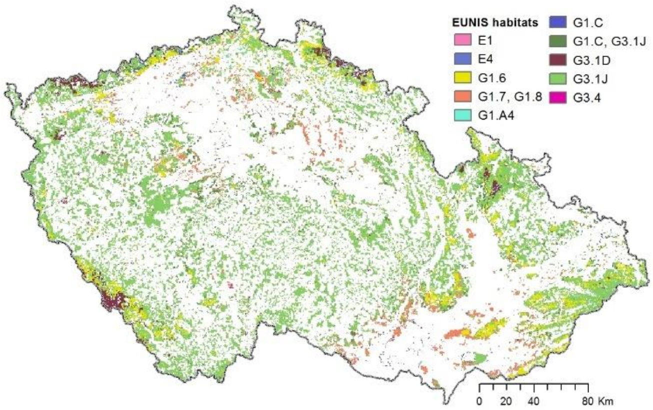
Updated steady-state critical loads for acidification and eutrophication using an updated set of input variables were computed as follows:

We used a new high-resolution database of ecosystems in the Czech Republic (Consolidated layer of ecosystems of the Czech Republic) provided by the Nature Conservation Agency of the Czech Republic, classifying 41 natural ecosystems and anthropogenic types of land use at a scale 1:10 000. This database was converted to raster format with 500m resolution, and ecosystems were converted to EUNIS habitats' classification system.

The Critical Loads were computed only for the EUNIS habitats: (E1) Dry grasslands,

(E4) Alpine and subalpine grasslands, (G1) Broadleaved deciduous woodland and (G3) Coniferous woodland (Figure 22).

Figure 22: Selected EUNIS habitats for Critical Loads Update



Source: NFC Czech Republic

Table 10: Area of the selected EUNIS habitats considered for Critical Loads update

Habitat	EUNIS	EUNIS Code 2017	Area considered [km²]	Area considered in [%] of the national teritory
Dry grasslands	E1	E1	98,5	0,1
Alpine and subalpine grasslands	E4	E4	14	0,0
Beech woodland	G1.6	T1-7/T1-8	2345,75	3,0
Thermophilous deciduous woodland, Acidophilous oak-dominated woodland	G1.7, G1.8	T1-9, T1-B	1857,75	2,4
Ravine and slope woodland	G1.A4	T1-F	72,25	0,1
Highly artificial broadleaved deciduous forestry plantations	G1.C	T1-H	168,5	0,2
Highly artificial broadleaved deciduous forestry plantations and Picea abies reforestation and Native pine plantations	G1.C, G3.1J	T1-H/T3-27/T3-M2	1772,25	2,2
Hercynian subalpine spruce forests	G3.1D	T3-13	713,5	0,9
Pice abies reforestation	G3.1J	T3-27	16721,5	21,2
Temperate continental Pinus sylvestris forest	G3.4	T3-5	67,25	0,1
	Total		**23831,25**	**30,2**

A.2.3 Critical loads of acidity (CLacid)

Maximum critical load of sulphur CLmax(S):

Equation A

$$CL_{max}S = BC_{dep} - Cl_{dep} + BC_w - Bc_u - ANC_{lecrit}$$

BC_w weathering rate of base cations (in eq·ha^{-1}·yr^{-1})
BC_{dep} base cation deposition (in eq·ha^{-1}·yr^{-1})
Cl_{dep} chloride deposition (in eq·ha^{-1}·yr^{-1})
Bc_u base cation uptake (in eq·ha^{-1}·yr^{-1})
ANC_{lecrit} leaching of acid neutralising capacity (in m^{-3}·ha^{-1}·yr^{-1})

- Updated atmospheric deposition of base cations and chlorides is based on data of wet and bulk depositions in 20017-18, provided by the Czech Hydrometeorological Institute.
- Weathering rates of base cations BC_w were derived from texture and parent material classes and computed using so-called weathering rate classes W_{class} and average annual soil temperature (equation V.44, CLRTAP, 2017). The parent material class was derived from a detailed map of the Geochemical reactivity of rocks of the Czech Republic (Chuman et al., 2014). The BC_w was divided into respective cations, for individual rocks, based on their proportions in freshwater streams draining monolithological catchments with no settlement and intensive agriculture, sampled throughout the Czech Republic.
- Uptake fluxes Bc_u, N_{up} equal average removal of Ca^{2+}, Mg^{2+}, K^+ and N in the biomass 2018-2019 fro
  ment Institute (FMI). The average element contents in 4 major tree species for stems were taken from the Mapping Manual (Tab. V.6 CLRTAP, 2017). Tree species wood density was adopted from the GrowUp model.
  - For Dry grasslands and Alpine and subalpine grasslands, we assume no biomass export and therefore, uptake was set to zero.
- Aluminium criteria with limit $[Al]_{crit}$=0.02 eq m^{-3} useful for drinking water protection was considered in the calculation of the critical leaching of acid neutralising capacity.
- The ANCle,crit was computed according to equation:

Equation B

$$ANC_{le,crit} = -Q(([Al]_{crit}/K_{gibb})^{1/3} + [Al]_{crit})$$

- [Al]crit = 0.02 eq·m-3
- Kgibb – gibbsite equilibrium constant derived from Table V.9 of the Mapping Manual (CLRTAP, 2017)
- Q – precipitation surplus (in m^{-3}·ha^{-1}·yr^{-1})

- Precipitation surplus (in mm) (the amount of water percolating from the root zone) for Broadleaved deciduous woodland and Coniferous woodland was computed according to equations derived from empirical data from the long term monitored network of the GEOMON catchments.

$Q_{br} = Thf_{br} - EsT$

$Q_{con} = Thf_{con} - EsT$

- Qbr - broadleaved forest precipitation surplus (in mm)
- Qcon - coniferous forest precipitation surplus (in mm)
- Thf - throughfall precipitation was computed as follows:

  $Thf_{br} = 1{,}24 \cdot Precip - 306{,}26$

  $Thf_{con} = 1{,}12 \cdot Precip - 361{,}20$

  - Thf_{br} – broadleaved forest throughfall precipitation
  - Thf_{con} – coniferous forest throughfall precipitation
  - Precip – mean annual precipitation (mm)
- EsT - Evapotranspiration computed as follows:

  EsT = 45,41*Temp - 2,56

  - Temp – mean annual temperature (°C)
- The resulting Q (in mm) was then converted to $m^{-3} \cdot ha^{-1} \cdot yr^{-1}$.

► This method was applied only in the range of environmental conditions covered by the GEOMON network. In other areas and in other ecosystems, the precipitation surplus was computed according to equation V.96b in the Mapping Manual (CLRTAP, 2017)

Minimum critical load of nitrogen CLmin(N)

The minimum critical load of nitrogen was calculated as follows:

$CLmin(N) = N_{upt} + N_{imacc}$

N_{upt} nitrogen uptake (in $eq \cdot ha^{-1} \cdot yr^{-1}$)
N_{imacc} acceptable immobilisation of N in the soil (in $eq \cdot ha^{-1} \cdot yr^{-1}$)

Temperature-dependent immobilisation rate of nitrogen was used, ranging from 2.5 $kg \cdot ha^{-1} \cdot yr^{-1}$ in a cold climate (Mean annual Temp<2°C) to 0.5 kg/ha/yr in warm areas (Mean annual Temp >10°C) with linear interpolation in between.

Maximum critical load of nitrogen CLmax(N):

The maximum critical load of nitrogen was calculated as follows:

$CLmax(N) = CLmin(N) + CLmax(S)/(1-f_{de})$

- f_{de} denitrification fraction ($0 \le f_{de} < 1$)

For the range of environmental conditions covered by the GEOMON network the $\mathbf{f_{de}}$ was computed from the modelled nitrogen denitrification and modelled nitrogen deposition. Equations for both parameters were derived from empirical data from the long term monitored network of the GEOMON catchments. Outside the environmental range covered by the GEOMON catchments we adopted the denitrification fraction as a function of soil drainage from the Table V.7 in the Mapping Manual (CLRTAP, 2017). Sites covered by Histosols were excluded from the calculation.

$$f_{de\_con} = N_{de\_con} / N_{dep}$$

$$f_{de\_br} = N_{de\_br} / N_{dep}$$

$$N_{de\_con} = 7.95 \cdot (Q_{con}/Precip) -0{,}47$$

$$N_{de\_br} = 7.95 \cdot (Q_{br} / Precip) - 0{,}47$$

- f_{de_con} – denitrification fraction for Coniferous forests
- f_{de_br} – denitrification fraction for Broadleaved forest
- N_{de_con} – denitrification in Coniferous forests (in $kg{\cdot}ha^{-1}{\cdot}yr^{-1}$)
- N_{de_br} – denitrification in Broadleaved forests (in $kg{\cdot}ha^{-1}{\cdot}yr^{-1}$)
- N_{dep} – nitrogen deposition (in $kg{\cdot}ha^{-1}{\cdot}yr^{-1}$)
- Q_{con} - coniferous forest precipitation surplus (in mm)
- Q_{br} - broadleaved forest precipitation surplus (in mm)
- Precip - mean annual precipitation (mm)

A.2.4 Critical loads of eutrophication *(CLeut)*

The table CLeut contains CLeutN values. The minimum values between CLnutN (computed by the SMB method) and CLempN is reported.

Critical load of nutrient nitrogen CLnutN:

The critical load of nutrient nitrogen was calculated as follows:

$CLnutN = N_{upt} + N_{imacc} + N_{leacc}/(1-f_{de})$

- f_{de} denitrification fraction
- $N_{le(acc)}$ acceptable leaching of nitrogen (in $eq{\cdot}ha^{-1}{\cdot}yr^{-1}$)

Acceptable leaching of nitrogen was set according to the Mapping Manual (CLRTAP, 2017) 1 ($mg{\cdot}1^{-1}$) for Coniferous forest and 2 ($mg{\cdot}1^{-1}$) for Broadleaved forest and other ecosystems.

The submitted values of acceptable N concentration were calculated as:

$N_{le(acc)} = [N]_{acc} \cdot Q.$

- Nle(acc) acceptable leaching of nitrogen (in $eq{\cdot}ha^{-1}{\cdot}yr^{-1}$)
- [N]acc acceptable N concentration (in $eq{\cdot}m^{-3}$)
- Q – precipitation surplus (in $m^3{\cdot}ha^{-1}{\cdot}yr^{-1}$)

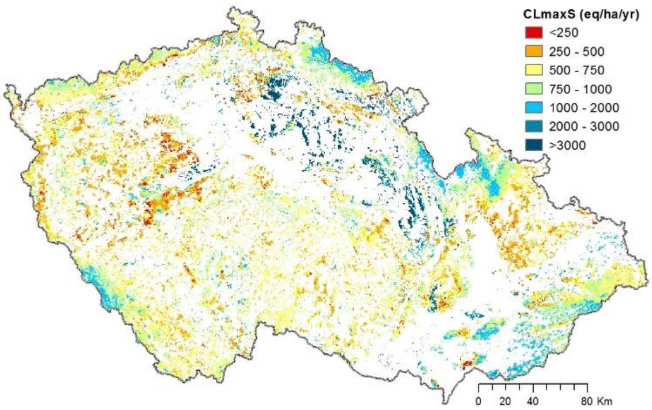
Empirical critical load of nitrogen CLempN

For the selected EUNIS habitats we set an average value of the range listed for these habitats in the Review and revision of empirical critical loads (Bobbink and Hettelingh, 2011).

A.2.5 Results and conclusions

The main aim was to update critical loads of sulphur and nitrogen. The updated critical loads cover the forest area of 23718.25 km^2 and 112,5 km^2 of grasslands, altogether 30% of the Czech Republic. The mean values of updated Critical Loads for selected EUNIS habitats are presented in the Table 11 and respective maps (Figure 23, Figure 24, Figure 25, Figure 26, Figure 27). Maximum critical loads of sulphur CLmaxS range from 24 eq·ha^{-1}·yr^{-1}, on extremely nutrient poor sands or sandstones, to 5286 eq·ha^{-1}·yr^{-1} on calcareous rocks. Minimum critical loads of nitrogen CLminN range from 26 - 1039 eq·ha^{-1}·yr^{-1}. Results of maximum critical loads of nitrogen CLmax fall in the range of 376 – 8555 eq·ha^{-1}·yr^{-1}.

Figure 23: Regional distribution of the CLmaxS



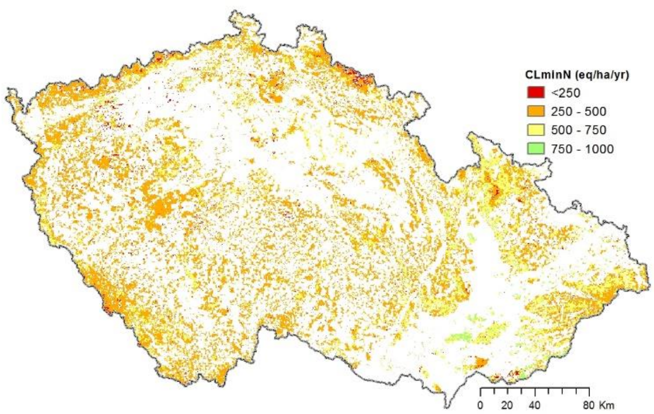
Source: NFC Czech Republic

Table 11: Mean values of updated Critical Loads for selected EUNIS habitats

Habitat	EUNIS	EUNIS 2017	CLmaxS	CLminN	CLmaxN	CLnutN	CLempN	CLempN
			[eq/ha/yr] mean				eq/ha/yr	kg/ha/yr
Dry grasslands	E1	E1	1818	55	2075	478	1249,5	17,5
Alpine and subalpine grasslands	E4	E4	1371	160	2266	2467	535,5	7,5
Beech woodland	G1.6	T1-7/T1-8	765	543	1666	1439	1071	15
Thermophilous deciduous woodland, Acidophilous oak-	G1.7, G1.8	T1-9,T1-B	1054	565	2093	985	1071	15

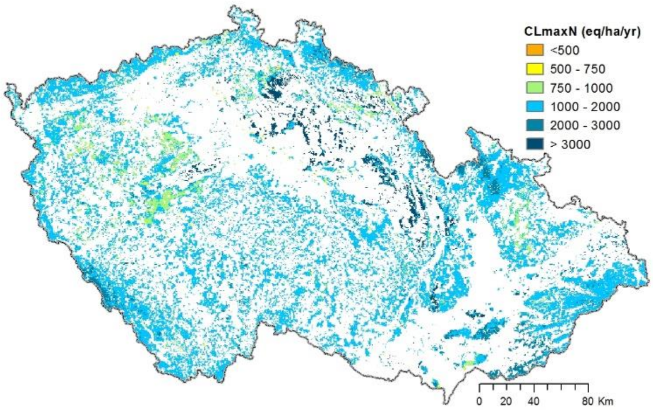
Habitat	EUNIS	EUNIS 2017	CLmaxS	CLminN	CLmaxN	CLnutN	CLempN	CLempN
dominated wood-land								
Ravine and slope woodland	G1.A4	T1-F	855	526	1739	1184	1249,5	17,5
Highly artificial broadleaved decid-uous forestry plan-tations	G1.C	T1-H	793	565	1690	1092	1071	15
Highly artificial broadleaved decid-uous forestry plan-tations and Picea abies reforestation and Native pine plantations	G1.C, G3.1J	T1-H/T3-27/T3-M2	759	532	1606	785	1071	15
Hercynian subal-pine spruce forests	G3.1D	T3-13	776	388	1494	954	892,5	12,5
Pice abies refo-restation	G3.1J	T3-27	856	421	1628	685	714	10
Temperate conti-nental Pinus syl-vestris forest	G3.4	T3-5	796	341	1493	580	714	10

Figure 24: Regional distribution of the CLminN



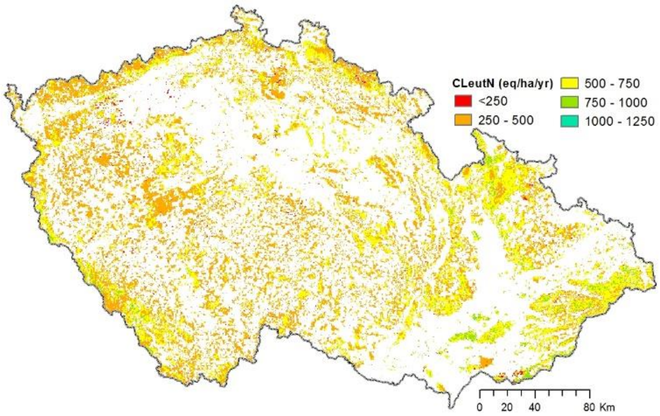
Source: NFC Czech Republic

Figure 25: Regional distribution of the CLmaxN



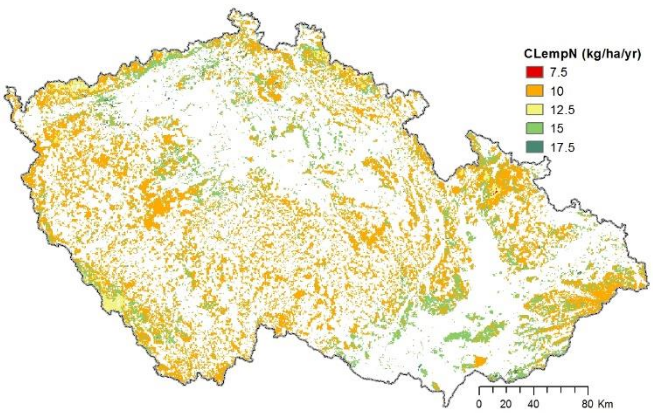
Source: NFC Czech Republic

Figure 26: Regional distribution of the CLeutN



Source: NFC Czech Republic

Figure 27: Regional distribution of CLempN



Source: NFC Czech Republic

A.2.6 References

Bobbink, R., Hettelingh, J.-P. (2011): Review and revision of empirical critical loads and dose-response relationships. Proceedings of an expert workshop, Noordwijkerhout 23-24 June 2010, RIVM, Bilthoven, NL

Chuman, T., Gürtlerová, P., Hruška, J., Adamová, M. (2014): Geochemical reactivity of rocks of the Czech Republic. Journal of Maps, 10 (2): 341-349,

CLRTAP (2017): Mapping critical loads for ecosystems, Chapter V of Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. UNECE Convention on Long-range Transboundary Air Pollution

A.3 National report of Germany

National Focal Centre

Federal Environmental Agency (UBA)
Thomas Scheuschner
Section II 4.3
Air pollution and Terrestrial Ecosystems
Wörlitzer Platz 1
D – 06844 Dessau-Rosslau
thomas.scheuschner@uba.de

Collaborating institutions

OEKO-DATA
Angela Schlutow
angela.schlutow@oekodata.com

The previous response of the German NFC to the call for data 2015 - 2017 focused on applying the latest methods to derive critical loads based on changes in plant species composition. The BERN model was applied for this task. Nevertheless, the critical loads based on the simple mass balance (SMB) approach were also revised and submitted. The dataset was supplemented by information on the protection status of the ecosystems (e.g. SPA or SAC under NATURA 2000) and an overview of the EUNIS classes relevant for Germany. The German dataset consists of 1.26 million records, representing about 30% of the area of Germany. The German NFC has not made any significant updates to its national CL data since then and has therefore confirmed the data submitted in 2017 for further use in the work of the Convention.

A.3.1 Updates on SMB-Critical loads for acidification and eutrophication

Although no new national dataset has been produced, the German NFC actively supports the continuous development of the CL methodology by funding two different projects. One project aims at reviewing and revising the critical limits used in the SMB approach and is carried out in cooperation with the Federal Environment Agency in Austria. The other project is currently being implemented by funding additional personnel at UBA to work on the link between climate change and the impacts on CL modelled by SMB. Both projects will be completed in 2023 and the results will be discussed at the annual ICP Modelling and Mapping meeting.

A.3.2 Updates on SMB-Critical loads for heavy metals

A calculation of Critical Loads for Heavy Metals in Germany was performed in 2017 (Schlutow et al. 2021). CL were determined for three objects of protection:

- CL(M)eco: Critical Load for a metal (As, Cd, Cu, Cr, Hg, Ni, Pb, Zn,) to protect the sensitive biota of the ecosystem;
- CL(M)drink: Critical Load for a metal (As, Cd, Cu, Cr, Hg, Ni, Pb, Zn) for protection of drinking water for human beings;
- CL(Cd)food: Critical Load for Cd for the protection of arable crops (here: wheat-producing as a food for human beings).

The methodological approach for the calculation of CL for HM in this study follows the ICP Manual Chapter V.5.

A.3.3 Areas of application of Critical Loads

Application on national level

Results of Critical Load modelling exercises are used in Germany as indicators for the identification of the environmental condition. The exceedance of critical load for eutrophication at a national level is an indicator in the German Biodiversity Strategy[13] and in the German Sustainability Strategy[14].

Furthermore, the German Federal Agency for Nature Conservation uses critical loads to identify risks for ecosystem listed in the NATURA2000 conservation catalogue.

Recent projects

The use of critical loads (mainly modelled CL with the SMB method) has now been included in the legal regulations for the approval of planned industrial and commercial facilities that emit air pollutants if Natura 2000 sites and protected habitats are affected. Industrial and livestock facilities will only be approved if it has been demonstrated on the basis of critical loads that the additional depositions they cause in near-natural ecosystems are insignificant.

For example, an industrial area is currently being planned in North Rhine-Westphalia for which a permissible quota of nitrogen, sulphur and heavy metal emissions has been calculated on the basis of the critical loads for neighboring protected biotopes. In this way, industrial operations can receive shares of this total quota and thus have planning security.

A.3.4 Updates on BERN model

Recent projects

The database for the BERN model is now based on the evaluation of around 50,000 vegetation records and their site information. About half of these sites are located in Germany and the rest in other parts of Europe. The determination of critical limits for the protection of biodiversity, which are used in the critical load calculation, such as the critical N concentration in the leachate, the critical pH value and the base saturation, were determined for the CL dataset 2015-2017 on this database.

A list of approximately 2000 typical types of Natura 2000 habitats in Germany has been published with corresponding BERN-SMB-modelled critical loads. They are recommended for the preliminary assessment of the environmental impact of a project throughout Germany (TA Luft 2021).

Site-specific BERN-SMB-modelled $CL_{eut}N$ and CL(S+N) were calculated for all 160,000 protected habitats in North Rhine-Westphalia as a basis for approval procedures.

Another current application that uses this BERN database is the current project "Derivation of climate change-adapted indicator forest communities for the forests in the Free State of Saxony". Natural forest communities that occur in southern and eastern Europe under climatic conditions

[13] http://biologischevielfalt.bfn.de/fileadmin/NBS/documents/Veroeffentlichungen/BMU_Natio_Strategie_en_bf.pdf

[14] https://www.bundesregierung.de/Content/DE/_Anlagen/2017/01/2017-01-11-nachhaltigkeitsstrategie.pdf?__blob=publicationFile&v=8

such as those that can be expected in Saxony in the future are selected and recommended as models for forest conversion, considering comparable site conditions.

A.3.5 Further developments

The publication of the BERN database and its documentation is planned for 2023.

A.3.6 References

Bobbink RS, Hettelingh J-P (eds.) (2011): Review and revision of empirical critical loads and dose-response relationships, Proceedings of an international workshop, Noordwijkerhout 23-25 June 2010, PBL-CCE/B-Ware Report 680359002, Bilthoven, (see: http://www.rivm.nl/en/themasites/cce/publications/other-publications/Revemp.html

Schaap, Martijn, Roy Wichink Kruit, Carlijn Hendriks, Richard Kranenburg, Arjo Segers, Peter Builtjes, Sabine Banzhaf, Thomas Scheuschner, Hans-Dieter Nagel (2017): Modelling and assessment of acidifying and eutrophying atmospheric deposition to terrestrial ecosystems (PINETI2) Part I: Atmospheric deposition to German natural and semi-natural ecosystems during 2009, 2010 and 2011, UBA-Project No. (FKZ) 3712 63 240 - 1

Schlutow, A., Dirnböck, T., Pecka. T., Scheuschner, T. (2015): Use of an empirical model approach for modelling trends of ecological sustainability. In: De Vries, W., Hettelingh, J.-P., Posch, M. (ed.): Critical Loads and Dynamic Risk Assessments: Nitrogen, Acidity and Metals in Terrestrial and Aquatic Ecosystems. Springer Series: Environmental Pollution, Vol. 25

Schlutow, A., Bouwer; Y., Nagel, H.-D. (2017): Bereitstellung der Critical Load Daten für den Call for Data 2016/2017 des Coordination Centre for Effects im Rahmen der Berichtspflichten Deutschlands für die Konvention über weitreichende grenzüberschreitende Luftverunreinigungen (CLRTAP), Abschlussbericht zum UBA Projekt Nummer 43848

Schlutow, A., Schröder, W., Scheuschner, T. (2021): Assessing the relevance of atmospheric heavy metal deposition with regard to ecosystem integrity and human health in Germany. Environmental Sciences Europe 33(1). DOI: 10.1186/s12302-020-00391-w. https://www.researchgate.net/publication/348423898_Assessing_the_relevance_of_atmospheric_heavy_metal_deposition_with_regard_to_ecosystem_integrity_and_human_health_in_Germany

A.4 National report of Ireland

National Focal Centre

Environmental Protection Agency
John McEntagart
McCumiskey House, Richview
Clonskeagh Road
IE-Dublin 14
j.mcentagart@epa.ie

Collaborating partners

Katarzyna Sawicka
Canolfan yr Amgylchedd Cymru/Environment Centre Wales
Ffordd Deiniol/Deiniol Road
UK-LL57 2UW Bangor (Gwynedd)
katwic55@ceh.ac.uk

The Republic of Ireland provided acidity critical loads for terrestrial habitats and an update of the critical loads for eutrophication submitted in the previous response to the Call for Data 2019-2021. The Republic of Ireland has been mapped on a 0.10°×0.05° (Longitude-Latitude) grid, and a total of thirteen habitats have been mapped for critical loads of acidity and fourteen habitats (in comparison to nine initially submitted) have been mapped for eutrophication.

For twelve habitats critical loads for eutrophication have been assigned on the basis of the CLempN values agreed for Irish habitats. For two other habitats (managed woodlands) simple mass balance approach have been implemented to derive critical loads instead of previously submitted CLempN values.

The habitats for which data were submitted are summarised in Table 12 below.

Table 12: Summary of Ireland data submitted to the CCE in June 2021

Habitat	Method	EUNIS code	EUNIS table prefix	Number of records in each of the following tables		
				ecords	CLeut	CLacid
Saltmarsh	4	A2.5	A2.5	278	278	232
Sand Dunes	4	B1.4	B1.4	179	179	171
Oligotrophic and Mesotrophic Water bodies	4	C1	C1	344	344	-
Bog	4	D1	D1	1520	1520	1404
Marsh & Fen	4	D2	D2	384	384	306
Dry Calcareous grassland	4	E1.26	E1.26	795	795	794
Dry acid grassland	4	E1.7	E1.7	1974	1974	1603
Wet acid grassland	4	E3.52	E3.52	759	759	662
Moss and lichen-dominated mountain ridges > 300m	4	E4.2	E4.2	123	123	119
Wet heath	4	F4.11	F4.11	632	632	513
Dry dwarf shrub heath	4	F4.2	F4.2	469	469	397
Unmanaged broadleaved woodland	4	G1.8	G1.8	1787	1787	1655
Managed broadleaf woodland	2	G1	G1	1862	1855	1862
Managed coniferous woodland	2	G3.1	G3.1	1857	1855	1857

A.5 National report of the Netherlands

National Focal Centre

Arjen van Hinsberg
PBL Netherlands Environmental Assessment Agency
PO Box 30314
NL-2500 GH The Hague
arjen.vanhinsberg@pbl.nl

Collaborating institutions

Gert Jan Reinds
Wageningen Environmental Research
PO Box 47
NL-6700 AA Wageningen
gertjan.reinds@wur.nl

A.5.1 Introduction

Nitrogen deposition in the Netherlands is recognised as a large threat to protected nature (Wamelink et al., 2013). Various policy measures are taken to reduce this threat. There is international policy to reduce emissions on an international level, as, for example, included in the LRTAP Convention. In addition, Dutch provinces are working on measures to reduce ammonia emissions in the proximity of Natura 2000 areas and local restoration measures to improve effected habitats. In May 2019, the Council of State (the highest administrative court in the Netherlands) ruled that the current strategy for reducing excess nitrogen in vulnerable natural areas is in breach of EU directives. This so-called Integrated Approach to Nitrogen, (Programmatische Aanpak Stikstof; PAS)) was developed to reduce the amount of nitrogen deposition in the Netherlands, while creating room for economic development. On 17 December 2020, Dutch Parliament approved new legislation that aims to reduce nitrogen emissions. The legislation, which amends the Dutch Nature Conservation Act and Environmental Management Act, limits nitrogen deposition levels in Natura 2000 areas.

The new legislation (Wet stikstofreductie en natuurverbetering) sets three targets:

- Nitrogen levels in 40% of the nitrogen-sensitive Natura 2000 areas must be below the critical load by 2025,
- Nitrogen levels in 50% of the nitrogen-sensitive Natura 2000 areas must be below the critical load by 2030, and
- Nitrogen levels in 74% of the nitrogen-sensitive Natura 2000 areas must be below the critical load by 2035.

The current government is trying to speed up the process of emission reduction and aims to reach the target of 74% by 2030.

Both national and international policies make use of information on critical loads for nitrogen. In the Call for Data 2020–2021, the Coordination Centre for Effects (CCE) asked for an update of the critical load levels for acidification and eutrophication, both computed with steady-state methods and empirically determined.

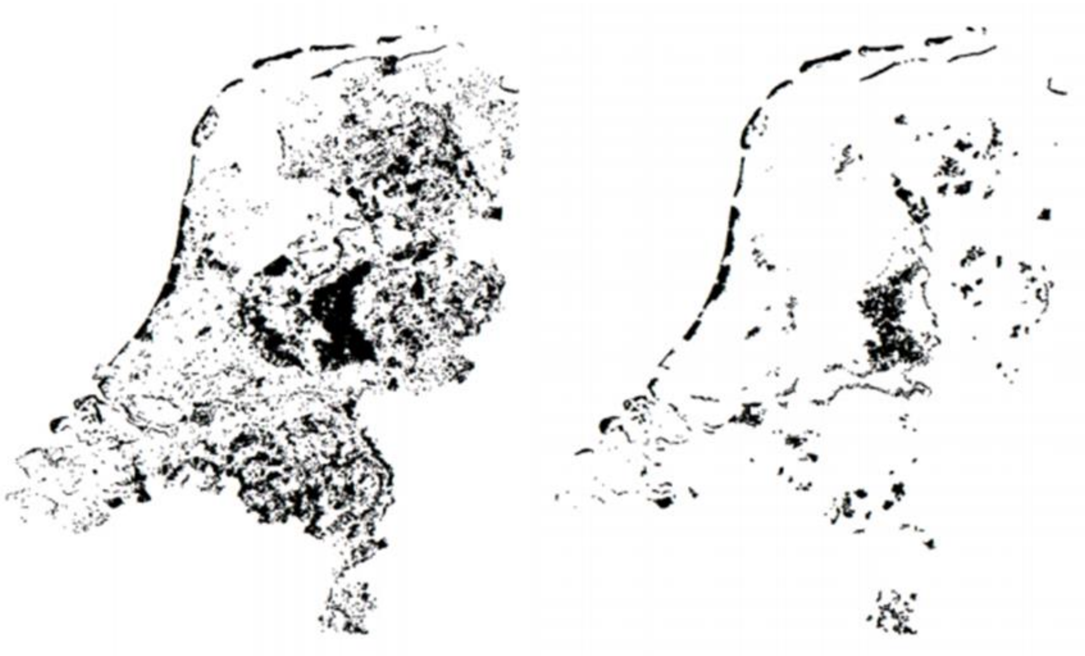
The 2017 dataset has been updated in various ways. Empirical data have been updated for Natura 2000 areas with information on habitats (using Van Dobben et al., 2014) and types of nature management (Van Beek et al., 2018) in other sensitive areas outside Natura 2000. For the computations, the methodology of 2017 was updated using new input data with respect to soil type, groundwater level, seepage fluxes, seepage quality and type of nature management.

A.5.2 General methodology

The Netherlands has a long history of using soil vegetation models for calculating critical loads (Kros et al., 1998; CCE, 2011; CCE, 2014; CCE, 2015; CCE, 2017). The backbone of soil modelling has changed from SMB to SMART2 to VSD+. Limits of abiotic conditions were based on models (MOVE, PROPS) or empirically determined ranges, for various ecosystem types.

In this update, critical loads were calculated for all terrestrial nature areas in the National Ecological Network (NEN; Figure 28, left) using VSD+ and empirical critical limits for the management types used by the provinces. Empirical critical load levels were calculated, separately, for protected habitats in Natura 2000 areas (Figure 28, right) and for nature management types in other nature areas.

Figure 28: 250 x 250 m grids in the Critical Load database with terrestrial nature management (National Nature Network; left) and terrestrial habitat types in the Natura 2000 areas (right).



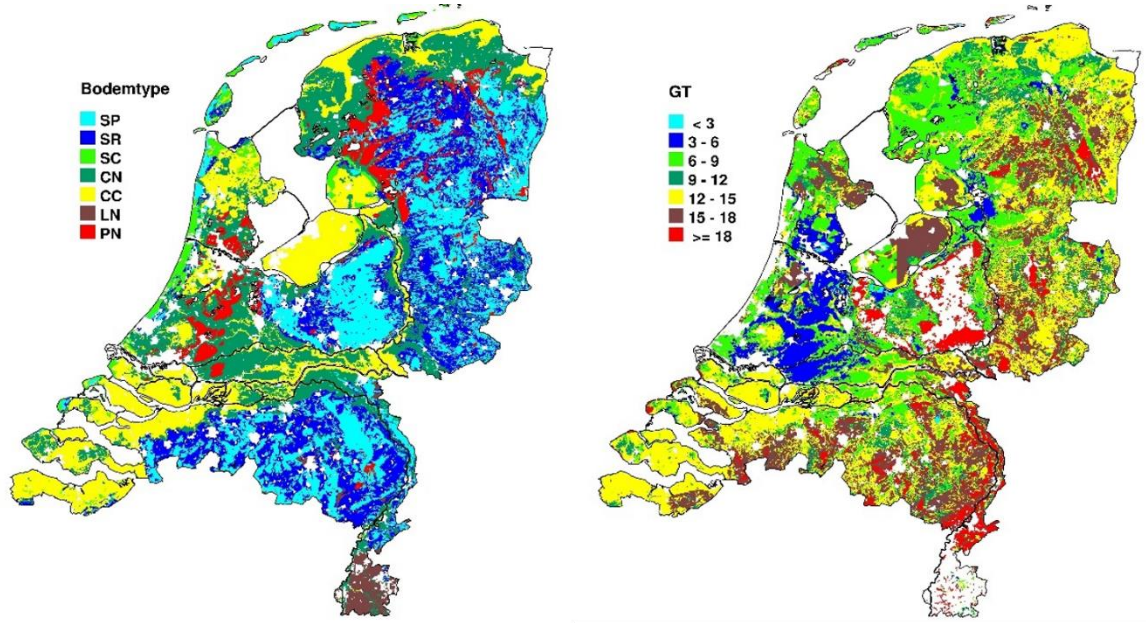
Source: NFC Netherlands

A.5.3 Input data

Within each 250 x 250-metre grid, we determined all nature management types and habitat types based on polygon maps from the provinces and the Dutch Ministry of Agriculture, Nature and Food Quality. In Natura 2000 areas, only the habitats were used in the calculation of critical loads. The soil types for which VSD+ has been parametrised were mapped based on a new updated version of the soil map 1:50000 (Steur and Heijink, 1991). Information on groundwater levels was derived from a recent update of the groundwater level map of the Netherlands (Van Heesen, 1970; Knotters et al., 2018). Seepage fluxes stem from the National Water Model that computes these fluxes on a resolution of 250 × 250 metres (De Lange et al., 2014).

In the Netherlands, sandy soils with low groundwater levels can be found in the middle, east and south of the country (see Figure 29). Clay soils occur along the rivers, in the north and south-west of the Netherlands and in reclaimed areas. Calcareous sandy soils are confined to the southern dune areas along the west coast, and loess soils to the southernmost part of the country. Highest groundwater levels are found in peat soils and part of the clay soils (see Figure 29).

Figure 29: Generalised soil map (left) and groundwater-level map (right). Sandy soils are coded as SP, SR, SC, (sand poor, sand rich and sand calcareous) clay soils are CN, CC (clay non-calcareous, clay calcareous) loess soils are LN and peat soils are PN. Low values for groundwater level (right) indicate wet soils and high values represent dry soils. In white areas, groundwater levels are very low.



Source: NFC Netherlands

Abiotic conditions for pH were derived from empirical information on plant associations, following the same procedure as reported in the CCE reports of 2017 and 2014. Abiotic conditions for nitrogen availability (Navail) were derived from indication values for trophic conditions (Holtland et al., 2009). The trophic index was transformed into values of Navail, using a regression with data from 2017 on Navail and trophic index calculated for the same nature target types as used in the submission of 2017, according to:

Equation C

$$Navail = 0.8651.[Trophic\ index]^2 - 4.5128.[Trophic\ index] + 9.7671$$

With Navail being the N availability in keq N ha^{-1} and Trophic index per plant association (values per plant range from 1 (oligotrophic) to 7 (eutrophic)).

We calculated the trophic index values per plant association by taking the average of all observations of that association. Subsequently, we calculated the average trophic index value of all plant associations relevant for a habitat or nature management type.

A.5.4 Critical load function

Critical loads for nitrogen based on a critical N availability were calculated according to:

Equation D

$$CL(N) = Navail_{crit} - Nupt - Nlf - Nfix - Nseep$$

With $Navail_{crit}$ = critical N availability, Nupt = N uptake, Nlf = total litterfall of N (above and below soil surface), Nfix = N fixation (set to zero), Nseep = N flux via upward seepage.

Since we used nitrogen availability as the criterion to compute N critical loads related to eutrophication, both CLeutN and CLNmax were computed with Equation D. However, for each 250 x 250 metre grid, we compared the calculated CLeutN with the empirical critical range (see CCE, 2011). When CLeutN was within this range, the calculated value was used, otherwise we took the empirical value given by Van Dobben et al. (2014). For CLNmax, we always used the value computed with Equation D. For the acidification critical loads, a critical pH was used as the criterion, which means that CLmaxN is based on pH and thus differs from CLNmax, which is based on N availability. In the data submission, the lowest value of CLNmax (based on *Navail*) and CLmaxN (based on pH) was used for CLmaxN.

Critical loads for sulphur are always based on a critical pH.

From the calculated CLNmax, we calculated CLminS by finding the Sdep at CLNmax (see also Figure 29) according to:

Equation E

$$CLminS = CLmaxS(pH) - (CLmaxN - CLminN) * slope$$

In which the 'slope' was calculated as:

Equation F

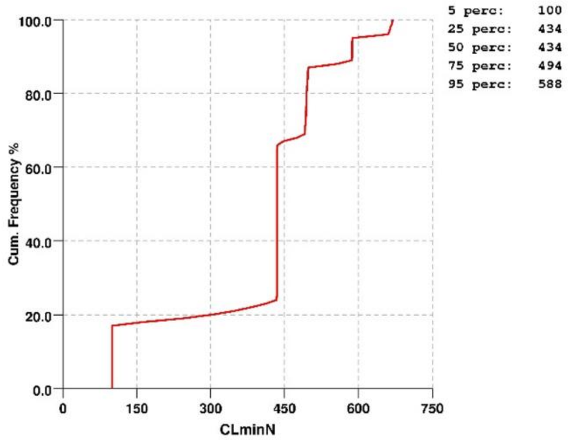
$$slope = fni * (2 - fde) - 1$$

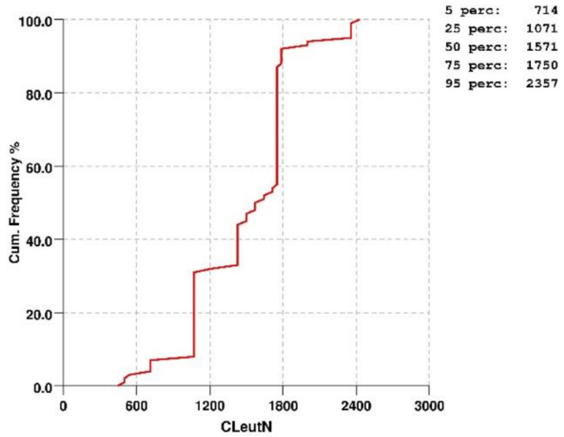
where fni is the nitrification fraction and fde is the denitrification fraction.

A.5.5 Results

Cumulative frequencies for CLminN and CLeutN (Figure 30) show that CLminN varies between 100 and 800 eq ha^{-1} yr^{-1}. For some sites, positive CLminN could not be calculated, because the N input by seepage alone already exceeded the maximum tolerable N availability, leaving no room for any additional deposition of N. Since the seepage concentrations, in practice, may vary in space and are thus uncertain at specific sites, we set the CLminN in such cases to the very low value of 100 eq ha^{-1} yr^{-1}. Furthermore, we assumed grassland and heathland management to be taking place, so we set a fixed N removal rate (i.e. net N uptake) based on a removal of 0.5 Kg of vegetation per m^2. CLeutN varies between 500 eq ha^{-1} yr^{-1} for very sensitive systems (bogs), to about 2500 eq.ha^{-1}.yr^{-1} for far less-sensitive systems, such as moist or wet forests. For the most sensitive systems, such as bogs, CLeutN is determined by the empirical value, not the (higher) SMB value.

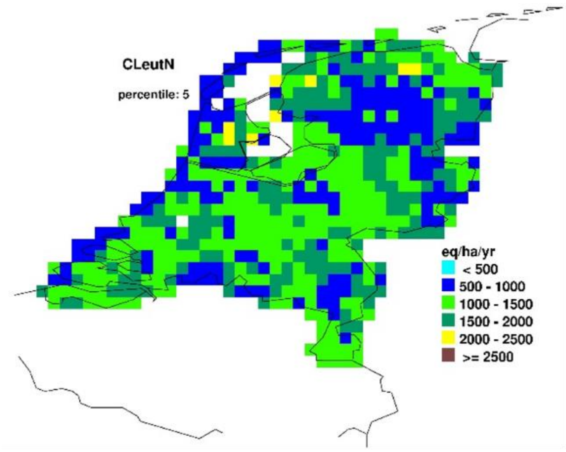
Figure 30: Cumulative frequencies of CLminN and CLeutN in eq.ha^{-1}.yr^{-1}.

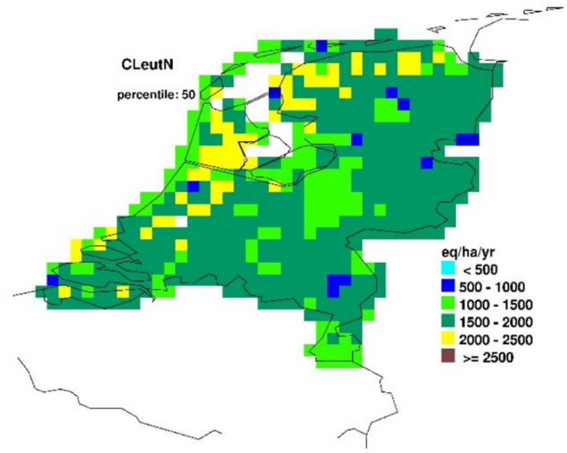




Source: NFC Netherlands

Figure 31: Maps of CLeutN on 0.1 × 0.1˚ resolution; 5 percentile (left) and median values (right) per grid cell.



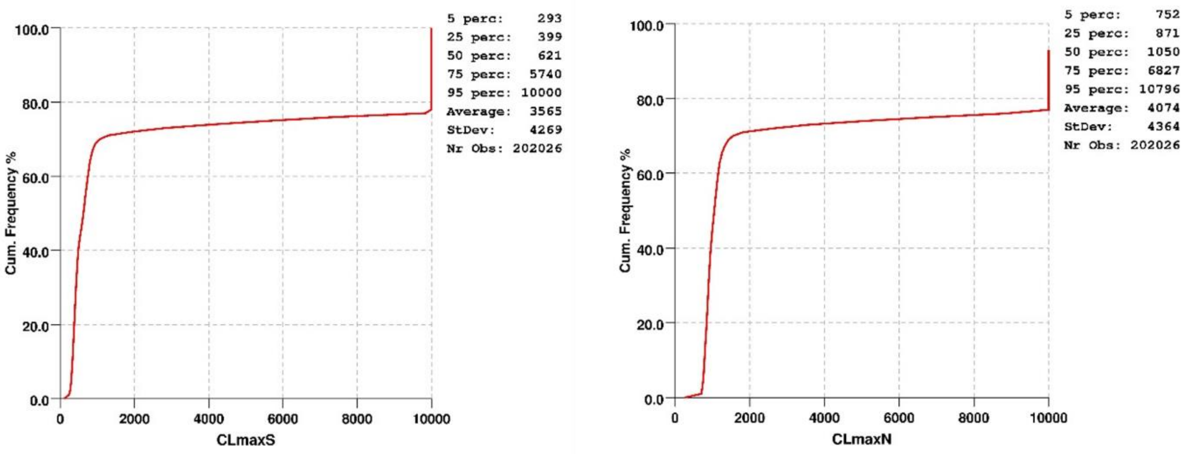


Source: NFC Netherlands

The lowest CLeutN values can be found in dune areas and raised bogs (Figure 31), highest values for clayey soils are those with nutrient-rich vegetations. In some areas, there is little difference between the 5 percentile and median value, which is in accordance with the distribution function that is flat in some trajectories (Figure 30, right).

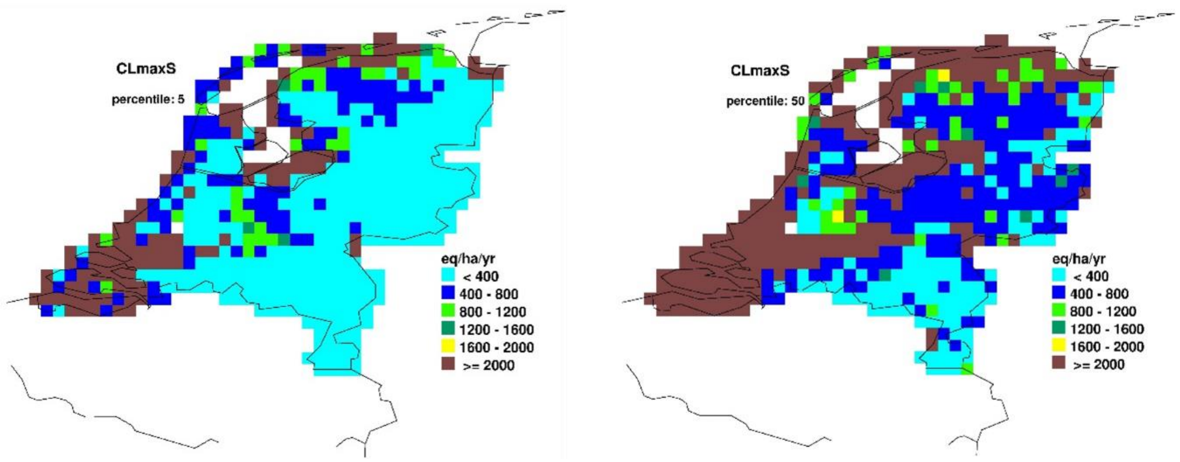
Critical load levels for acidity (CLmaxS and CLmaxN) vary between ecosystems and are lowest on dry sandy soils with low weathering rates with for example heath vegetation or oak forest (Figure 32). CLmaxS varies between 300 and about 1000 eq ha^{-1} yr^{-1}, for non-calcareous soils without seepage. For calcareous soils, both CLmaxS and CLmaxN were set to 10000 eq ha^{-1} yr^{-1} (for about 20% of the sites). CLmaxN is always somewhat higher than CLmaxS, because some nitrogen is removed by denitrification and thus does not contribute to acidification, especially on wet soils. Very high values of CLmaxS and CLmaxN (between 2000 and 10000 eq ha^{-1} yr^{-1}) occur on sites with a high influx of base cations due to high seepage fluxes. It should be noted that, for a small number of sites (about 10%), no CLmaxS (and thus no CLmaxN) value could be computed, because the critical pH cannot be attained with any acid deposition.

Figure 32: Cumulative frequencies of CLmaxS and CLmaxN in eq ha^{-1} yr^{-1}.



Source: NFC Netherlands

Figure 33: Maps of CLmaxS on 0.1 × 0.1° resolution; 5 percentile (left) and median values (right) per grid cell.



Source: NFC Netherlands

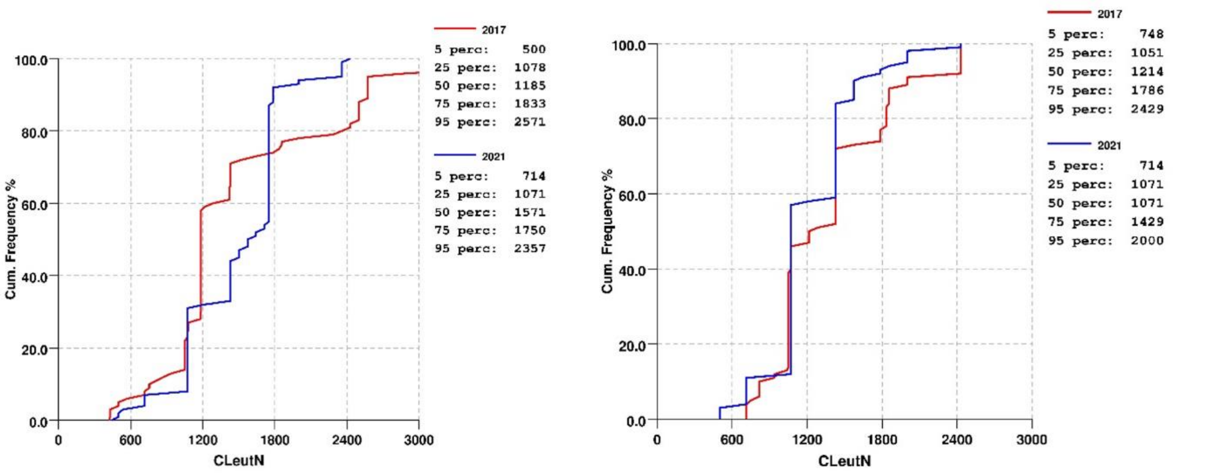
Low values of CLmaxS occur in acid-sensitive areas, such as non-calcareous dunes (along north-western part of the Dutch coastline) and sandy areas in eastern and southern parts of the Netherlands. High values occur in areas with calcareous clay soils (along the southern part of the Dutch coast and in reclaimed areas) (Figure 33).

A.5.6 Comparison with 2017 data

Current critical load levels for CLeutN are somewhat differently distributed than those computed in 2017 (Figure 34). The distribution of sensitive systems is comparable (5 and 25 percentiles are about the same), but the median value is somewhat higher (1600 versus 1250 eq.ha^{-1}.yr^{-1}) and the 95 percentile somewhat lower. This is caused by the use of a new vegetation map with nature management types instead of nature target types, and the fact that we have now used many more receptors, as we no longer limit the computations to the dominant receptor in a 250

× 250 metre grid cell, but use all receptors. If we compare results from the habitats within N2000 areas only, values for CLeutN are very comparable (Figure 34, right).

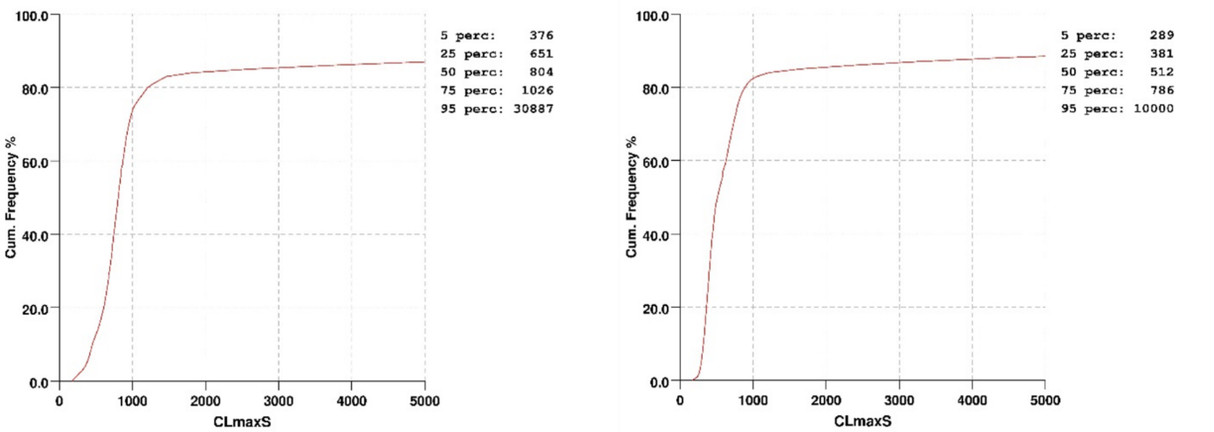
Figure 34: Comparison of CLeutN in eq.ha^{-1}.yr^{-1} from the 2017 data set and the current data set for all receptors (left) and for habitats only (right).



Source: NFC Netherlands

If we limit the results to non-calcareous soils, the critical load levels for S, CLmaxS, in the current data set are somewhat lower than in the previous assessment (Figure 35). This is, again, due to the fact that we shifted from nature target types to nature management types and used all receptors per grid cell. It should be noted, however, that the critical limits for pH used for nature management types were still based on the same information on all underlying vegetation associations. However, the assignment from associations to the new nature management types can perhaps be improved by more careful selection of the most relevant associations.

Figure 35: Comparison of CLmaxS in eq.ha^{-1}.yr^{-1} from the 2017 data set (left) and the current data set (right); non-calcareous soils only.



Source: NFC Netherlands

A.5.7 Assigning nature types to 250 x 250 metre grid cells

In contrast to the previous critical load assessments for the Netherlands, we now used all receptors (habitats or nature management types) with a 250 × 250 metre grid cell instead of the dominant receptor only. In some grid cells, up to 5–8 different habitats occur. Such variation might be realistic in some cases, but unrealistic in others. A drawback of using all receptors could be that the underlying maps of, for example, soil, water regime and seepage in a 250 x 250 metre grid cell may not always be representative of all these receptors, due to their lack of such high spatial detail. An alternative procedure would be to only use the habitats and nature management types that best fit the underlying abiotic maps. This would, however, require a careful process of linking nature types to soil and groundwater classes in order to derive a table of sound combinations. Given the shortcomings of the current procedure, it is clear that the current maps on CLeutN should not be used on a local scale.

A.5.8 General discussion

Results show that calculated critical loads of nitrogen for some soil types are often outside the empirical critical load range for the soil's EUNIS type. For example, calculated CL(N) for bogs, fens, open sand and various forest types are higher than the empirical critical loads. In such cases, we used the empirical value, as this is based on empirical evidence of effects observed in the field. Valid computations are still not always feasible using nation-wide parameterisation. A similar problem was identified when using critical load levels calculated with the SMART model (Dobben et al., 2014). As empirical values are broadly accepted, and the model results are considered a further specification, Dobben et al. (2014) used modelled critical load levels only when ranges overlapped. In that process, model output was critically screened in view of the shortcomings and uncertainties that exist when modelling certain nature types.

Modelling can be further improved by verifying that the underlying maps support the nature types within a grid cell. If, for example, the combination of soil type and groundwater regime on the map is very different from what would be expected for a certain habitat that occurs on the map, the accuracy of the underlying maps is insufficient, which can lead to unrealistic critical load levels. Furthermore, the assignment of a critical pH to nature management types can probably be improved by a stricter way of assigning plant associations. Also, the use of critical pH values per association derived from PROPS-NL curves needs to be investigated further.

A.5.9 References

Bal D., H.M. Beije, J.H. Van Dobben, A. Van Hinsberg, 2007. Overzicht van kritische stikstofdeposities voor natuurdoeltypen. Dutch Ministry of LNV, Directie Kennis, Ede.

Bonten L., J. Mol J, G.J. Reinds, 2009. Dynamic modelling of effects of deposition on carbon sequestration and nitrogen availability: VSD plus C and N dynamics (VSD+). In: Hettelingh et al. (eds): CCE Status Report 2009, Bilthoven; www.wge-cce.org.

De Lange, W. J., G. F. Prinsen, J. C. Hoogewoud, A. A. Veldhuizen, J. Verkaik, G. H. P. Oude Essink, P. E. V. Van Walsum, J. R. Delsman, J. C. Hunink, H. T. L. Massop & T. Kroon (2014). An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument. Environ. Model. Softw., 59, 98–108. doi:10.1016/j.envsoft.2014.05.009.

Hennekens, S.M., J.H.J. Schaminée, 2001.TURBOVEG, a comprehensive data base management system for vegetation data. Journal of Vegetation Science 12, 589–591.

Holtland, W. J., C.J.F. ter Braak,, M.G.C. Schouten, 2010. Iteratio: Calculating environmental indicator values for species and relevés. Applied Vegetation Science, 13(3), 369–377.

Kros J, G.J. Reinds, W. De Vries, J.B. Latour, M.J.S. Bollen, 1995. Modelling the response of terrestrial ecosystems to acidification and desiccation scenarios. Water, Air and Soil Pollution 85(3), 1101–1106.

De Lange, W.J., G. F. Prinsen, J. C. Hoogewoud, A. A. Veldhuizen, J.Verkaik, G.H.P. Oude Essink, P.E.V. van Walsum, J.R. Delsman, J.C. Hunink, H.Th.L. Massop, T. Kroon, 2014. An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument. Environmental Modelling & Software, 59, 98–108.

Steur, G.G.L., W Heijink, Bodemkaart van Nederland, Schaal 1:50 000; Algemene begrippen en indelingen 4e UITGAVE. 1991 Staring Centrum – STIBOKA, Wageningen.

Van Beek, J.G, R.F. van Rosmalen, B.F. van Tooren, P.C.van der Molen, 2018. Werkwijze Monitoring en Beoordeling Natuurnetwerk en Natura 2000/PAS. Utrecht: BIJ12.

Van Dobben H.F., A. Van Hinsberg, E.P.A.G. Schouwenberg, M. Jansen, J.P. Mol-Dijkstra, H.J.J, Wiegers, J. Kros, W. De Vries W, 2006. Simulation of critical loads for nitrogen for terrestrial plant communities in the Netherlands. Ecosystems 9, 32–45.

Van Dobben H., R. Bobbink, D. Bal, A. Van Hinsberg, 2014. Overview of critical loads for nitrogen deposition of Natura 2000 habitat types occurring in The Netherlands. Alterra, Wageningen University, Wageningen.

Van Heesen, H.C., 1970. Presentation of the seasonal fluctuation of the water table on soil maps. Geoderma 4, 257–278.

Van Hinsberg A., H. Kros, 2001. Dynamic modelling and the calculation of critical loads for biodiversity. In: Posch et al. (eds): CCE Status Report 2001, Bilthoven; www.wge-cce.org.

Van Hinsberg A., G.J. Reinds, J.P. Mol, 2011. The Netherlands. In: Posch et al. (eds): CCE Status Report 2011, Bilthoven; www.wge-cce.org.

Van Hinsberg A., G.J. Reinds, J.P. Mol, 2012. The Netherlands. In: Posch et al. (eds): CCE Status Report 2012, Bilthoven; www.wge-cce.org.

Wamelink G.W.W., H.F. Van Dobben HF, F. Berendse, 2009. Vegetation succession as affected by decreasing nitrogen deposition, soil characteristics and site management: a modelling approach. Forest Ecol. Manage. 258(8), 1762–1773; DOI: 10.1016/j.foreco.2009.05.043.

Wamelink G.W.W., B. De Knegt, R. Pouwels, C. Schuiling, R.M.A. Wegman, A.M. Schmidt, A.F. Van Dobben, M.E. Sanders, 2013. Considerable environmental bottlenecks for species listed in the Habitats and Birds Directives in the Netherlands. Biological Conservation 165, 43–53.

A.6 National report of Norway

National Focal Centre
Kari Austnes
Norwegian Institute for Water Research (NIVA)
Økernveien 94
NO-0579 Oslo
tel: +47 22185100
fax: +47 22185200
email: kari.austnes@niva.no

Collaborating institutions

Norwegian Institute for Air Research (NILU)
P.O. Box 100
NO-2027 Kjeller

Norwegian Institute for Nature Research (NINA)
P.O. Box 5685 Torgarden,
NO-7485 Trondheim

IVL Swedish Environmental Institute
P.O.Box 53021
SE-40014 Gothenburg

Centre for Ecology & Hydrology
Environment Centre Wales
Deiniol Road
Bangor Gwynedd
UK-LL57 2UW

Norway reports critical loads for acidification of surface waters (and their catchments) as well has empirical critical loads for nutrient nitrogen to the CCE. For surface waters both the First-order Acidity Balance (FAB) and Steady-State Water Chemistry (SSWC) models (Henriksen and Posch, 2001) are applied nationally, but only the FAB critical loads are reported to the CCE. Critical loads for acidification of forest soils are also calculated, but not reported, as they are always higher than those of surface waters. No changes have been made to the critical loads since the reporting in 2017, documented in the 2017 CCE Report (Hettelingh et al., 2017), but the approach is repeated below. In 2022 there are plans to update the critical loads.

Dynamic modelling of surface water acidification is done using the MAGIC model. National projections are based on the calibration of the approximately 1000 lakes included in the national lake survey. The latest calibration was conducted in 2016 as described in Hettelingh et al. (2017) and repeated below. In 2022 a recalibration will be finalised.

There has been no further work on critical loads of biodiversity after the work reported in Hettelingh et al. (2017). A new national monitoring programme on ground vegetation[15] will provide a better basis for further progress in this area.

[15] https://www.miljodirektoratet.no/ansvarsomrader/overvaking-arealplanlegging/miljoovervaking/overvakingsprogrammer/basisovervaking/arealrepresentativ-naturovervakning-ano/

A.6.1 Critical loads for surface waters

The database for critical loads for surface waters is based on a 0.25°×0.125° longitude-latitude grid (Henriksen 1998). The chemistry of surface water within a grid cell was set by comparing available water chemistry data for lakes and rivers within each grid cell. The water chemistry data were primarily results from the national lake survey conducted in 1986 (Lien et al., 1987). The chemistry of the lake that was judged to be the most typical was chosen to represent the grid cell. If there were wide variations within a grid cell, the most sensitive area was selected, if it amounted to more than 25% of the grid cell area. Sensitivity was evaluated based on water chemistry, topography, and bedrock geology. Geology was determined from the geological map of Norway (1:1 million) prepared by the Norwegian Geological Survey (NGU). The critical loads of the original grid were assigned to the new 0.10°×0.05° longitude-latitude grid without further data collection. The mid-point critical load values of the new grid cells were used as critical load for the entire grid cell. When the mid-point was at the border between two original grid cells or at the corner of four original grids cells, the average critical load of the original grid cells in question was used.

The FAB methodology for Norway was described by Henriksen (1998) and the application later updated in Larssen et al. (2008b) and Austnes et al., (2018). A variable ANC_{limit} as described by Henriksen and Posch (2001) is used, but adjusted for the strong acid anion contribution from organic acids after Lydersen et al. (2004). $[BC]_0*$ was originally calculated by the F-factor approach, using the sine function of Brakke et al. (1990), but in recent applications $[BC]_0*$ has instead been estimated from MAGIC model (Cosby et al., 1985; Cosby et al., 2001) runs used for calculating target loads (Larssen et al., 2005). Here MAGIC was applied to 131 lakes in Southern Norway, of which 83 lakes were acidified (ANC < the variable ANC_{limit}). A linear regression of MAGIC modelled $[BC]_0*$ ($[BC]_{1860}*$) vs $[BC]_{1986}*$ for these 83 lakes is used to estimate $[BC]_0*$ for each grid cell using the water chemistry data assigned to each cell.

Nitrogen removal in harvested forest biomass was estimated by Frogner et al. (1992) and mapped for all of Norway based on forest cover and productivity. Nitrogen immobilisation in the catchments was assumed constant at 0.5 kg N ha^{-1} yr^{-1} and the denitrification factor in the catchments was set to 0.1 (CLRTAP, 2017). In the lakes the mass transfer coefficients for N and S were held constant at 5 m yr^{-1} and 0.5 m yr^{-1}, respectively; these are the mid-values of the ranges proposed by Dillon and Molot (1990) and Baker and Brezonik (1988), respectively. The lake to catchment area was set constant to 5%. Mean annual runoff data were taken from runoff maps prepared by the Norwegian Water Resources and Energy Directorate (NVE) based on the 1961-1990 normal.

In 2020 the methodology for critical loads for surface waters was evaluated (Austnes et al., 2020). In 2022 minor updates to the critical loads methodology are planned, based on conclusions in this report. This will be carried out in connection with the update of the critical loads exceedances for Norway, which takes place every fifth year.

A.6.2 Empirical critical loads for nutrient nitrogen

The empirical critical loads for nutrient nitrogen for Norway were updated following the revision in 2011 (Bobbink and Hettelingh, 2011), see CCE Status Report 2011 (Posch et al., 2011). For the 2014/2015 call empirical critical loads were provided in the new 0.10°×0.05° longitude-latitude grid. Moreover, critical loads were reported per ecord, defined as an area within a grid cell with homogenous vegetation.

In 2017 the vegetation map used as basis for assigning empirical critical loads was replaced. Previously the satellite-based map produced by the *Stockholm Environment Institute*, SEI, in cooperation with the CCE, was used. The new map, produced by the *Northern Research Institute* (Norut) (Johansen, 2009), is also satellite based, but it is more detailed and better reflects Norwegian vegetation. The vegetation types used in the original map were translated into the relevant EUNIS classes. Some of the vegetation types in the original map were grouped. The EUNIS classes were assigned the same critical loads as used before, or if a specific EUNIS class was not used in the previous map, critical loads were set in accordance with Bobbink and Hettelingh (2011). The resulting critical loads map was overlaid by the 0.10°×0.05° longitude-latitude grid. Given the high detail of the map, the ecords were defined as the total area of a specific EUNIS class within a grid cell, with coordinates given as the mid-point of the grid cell.

In 2022 the empirical critical loads for Norway will be updated based on the recent revision of the empirical critical loads (report to be published by the CCE in 2022).

A.6.3 Dynamic modelling of surface water acidification

Modelling of aquatic ecosystems (lakes) has been carried out for the entire country using the MAGIC model (Cosby et al., 1985; Cosby et al., 2001). The procedure was described in the CCE Status Report 2008 (Hettelingh et al., 2008). The model was recalibrated in 2016 using updated deposition scenarios (Austnes et al., 2016). In other respects the procedure was similar to that followed in 2008.

The model was calibrated to observational data from 990 of the 1007 statistically selected lakes in the 1995 national lake survey (Skjelkvåle et al., 1996). (17 lakes of the total 1007 lakes in the survey were disregarded due to very high phosphorus concentrations (and ANC) from local pollution, extremely high sea salt concentrations or inconsistencies in the catchment characteristics data available.) The model was calibrated to observed water chemistry for each of the lakes and to soil base saturation from the nearest available (or most relevant) sample. In the automatic calibration routine of MAGIC the following switches were set: BC optimizer (weathering calibration): on, SO4 adsorption optimizer: off, soil pH optimizer: on, N dynamics optimizer: off (this means that nitrogen uptake in the catchment was assumed proportional (with a constant proportion) to the input at all times). Input data and data sources are described in the CCE Status Report 2008 (Hettelingh et al., 2008). For more details, see Larssen et al. (2008a).

Atmospheric deposition data were provided by the CCE. In 2008 data were supplied on the 50km*50km EMEP grid, while in 2016 they were on the 0.25 latitude*0.5 longitude grid. In addition to the changed grid, the whole deposition sequence was changed, taking into account both changes to the 1990-2010 deposition and effects of the revised Gothenburg Protocol on future deposition. In 2008 14 scenarios of future deposition were compared, while in 2016 only one scenario was applied. The 990 lakes were assigned the deposition of the grid cell in which they were located. The model was calibrated to the year 1995 and run for the time-period 1880-2100 (the deposition was set constant after 2030).

The calibrated lakes were used to assign MAGIC output to all grid cells in the Norwegian 0.25°×0.125° longitude-latitude critical loads grid (2304 cells) using a matching routine called “MAGIC library” (IVL, 2016). The 2304 grid cells were matched to the 990 lakes according to a Eucledian distance routine based on water chemistry and location. Each of the 2304 grid cells was thus assigned a MAGIC modelled lake.

In 2022 a major re-calibration of MAGIC to the national lake dataset will be finalised, following the re-sampling of the lakes in 2019. This includes running MAGIC on the new Mobius platform (Norling et al., 2021), including data from both the 1995 and 2019 surveys in a two-point calibration, adding uncertainty analysis to be able to provide confidence intervals for the projections, and using revised input data and model parameters. The new approach builds partly on the evaluation conducted in 2020 (Austnes et al., 2020). Here the lake concentrations from the 2019 national lake survey were compared with the MAGIC modelled concentrations from the 2016 recalibration.

A.6.4 References

Austnes, K., E. Lund, S. Valinia, Cosby, B.J. (2016). Modellbasert klassifisering av forsuringstilstand i innsjøer uten måledata. NIVA report 7047-2016. Norwegian Institute for Water Research, Oslo, 21 p. (in Norwegian)

Austnes, K., Lund, E., Sample, J.E., Aarrestad, P.A., Bakkestuen, V., Aas, W. (2018). Overskridelser av tålegrenser for forsuring og nitrogen for Norge. Oppdatering med perioden 2012–2016. M-966, NIVA report 7239-2018. Norwegian Institute for Water Research, Oslo, 26 p. (in Norwegian)

Austnes, K., Wright, R.F., Sample, J.E., Clayer, F. (2020). Critical loads and the MAGIC model. Evaluating the country-scale applications in Norway using data from the 2019 national lake survey. NIVA report 7557-2020. Norwegian Institute for Water Research, Oslo, 52 p.

Baker, L.A., Brezonik, P.L. (1988). Dynamic model of in-lake alkalinity generation. Water Resources Research, 24, 65–74.

Bobbink R., Hettelingh J.-P. (eds) (2011). Review and revision of empirical critical loads and dose response relationships. Proceedings of an international expert workshop, Noordwijkerhout, 23-25 Juni 2010, RIVM report 680359002, Coordination Centre for Effects, RIVM, Bilthoven.

Brakke, D.F., Henriksen, A., Norton, S.A. (1990). A variable F-factor to explain changes in base cation concentrations as a function of strong acid deposition. Verh. Internat. Verein. Limnol. 24, 146-149.

CLRTAP (2017). Mapping critical loads for ecosystems, Chapter V of Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. UNECE Convention on Long-range Transboundary Air Pollution. Accessed on 11 December 2017 on Web at www.icpmapping.org. 116 p.

Cosby, B. J., Hornberger, G.M., Galloway, J.N., Wright, R.F. (1985). Modelling the effects of acid deposition: assessment of a lumped parameter model of soil water and streamwater chemistry. Water Resources Research, 21, 51-63.

Cosby, B. J., Ferrier, R.C., Jenkins, A., Wright, R.F. (2001). Modelling the effects of acid deposition: refinements, adjustments and inclusion of nitrogen dynamics in the MAGIC model. Hydrology and Earth System Sciences, 5, 499-518.

Dillon, P.J., Molot, L.A. (1990). The role of ammonium and nitrate retention in the acidification of lakes and forested catchments. Biogeochemistry, 11, 23–43.

Frogner, T., Wright, R.F., Cosby, B.J., Esser, J.M., Håøya, A.O. and Rudi, G., 1992. Map of critical loads for coniferous forest soils in Norway. Naturens Tålegrenser Fagrapport 33, NIVA report 2830-1992. Norwegian Institute for Water Research, Oslo, 30 p.

Henriksen, A., Posch, M. (2001). Steady-state models for calculating critical loads of acidity for surface waters. Water, Air and Soil Pollution: Focus 1: 375–398.

Henriksen, A. (1998). Application of the First-order Acidity Balance (FAB) model to Norwegian surface waters. NIVA Report 3809-98. Norwegian Institute for Water Research, Oslo. 33 p.

Hettelingh, J.-P., Posch, M., Slootweg, J. (eds.) (2008). Critical load, dynamic modelling and impact assessment in Europe: CCE Status Report 2008, Coordination Centre for Effects, RIVM, Bilthoven, The Netherlands, www.rivm.nl/cce.

Hettelingh, J.-P., Posch, M., Slootweg, J. (eds.) (2017). European critical loads: database, biodiversity and ecosystems at risk, CCE Final Report 2017, Coordination Centre for Effects, RIVM Report 2017-0155, Bilthoven, Netherlands.

IVL (2016). Description of the MAGIC library. http://www.ivl.se/magicbibliotek. (In Swedish)

Johansen, B.E. (2009). Vegetasjonskart for Norge basert på Landsat TM/ETM+ data. Norut report 4/2009. Northern Research Institute, Tromsø, 87 p. (in Norwegian)

Larssen, T., Høgåsen, T., Wright, R.F. (2005). Target loads for acidification of Norwegian surface waters. NIVA Report 5099-2005. Norwegian Institute for Water Research, Oslo. 33 p.

Larssen, T., Cosby, B.J., Høgåsen, T., Lund, E., Wright, R.F. (2008a). Dynamic modelling of acidification of Norwegian surface waters. NIVA Report 5705-2008. Norwegian Institute for Water Research, Oslo, 45 pp.

Larssen, T., Lund, E., Høgåsen, T. (2008b). Overskridelser av tålegrenser for forsuring og nitrogen for Norge. Oppdatering med perioden 2002–2006. NIVA Report 5697-2008. Norwegian Institute for Water Research, Oslo, 24 p. (in Norwegian)

Lien, L., Sevaldrud, I.H., Traaen, T.S., Henriksen, A. (1987). 1000 sjøers undersøkelsen 1986. Rapport 282/87. Statlig program for forurensningsovervåking. Statens forurensningstilsyn, Oslo, 31 p. (in Norwegian)

Lydersen, E., Larssen, T., Fjeld, E. (2004). The influence of total organic carbon (TOC) on the relationship between acid neutralizing capacity (ANC) and fish status in Norwegian lakes. Sci. Tot. Env. 42, 307-316.

Norling, M.D., Jackson-Blake, L.A., Calidonio, J.L.G., Sample, J.E. (2021). Rapid development of fast and flexible environmental models: The Mobius framework v1.0. Geoscientific Model Development, 14, 1885–1897.

Posch M., Slootweg J., Hettelingh J.-P. (eds.) (2011). Modelling critical thresholds and temporal changes of geochemistry and vegetation diversity. CCE Status Report 2011, Coordination Centre for Effects, Bilthoven, The Netherlands, www.rivm.nl/cce.

A.7 National report of Poland

National Focal Centre

Tomasz Pecka
Rafał Ulańczyk
Dariusz Kozik
Institute of Environmental Protection – National Research Institute (IOS-PIB)
Department of Integrated Monitoring
ul. Kolektorska 4
PL-01-692 Warszawa
tel.: +48 506104243
tomasz.pecka@ios.edu.pl

Collaborating institutions

Chief Inspectorate of Environmental Protection (GIOŚ)
Department of Monitoring and Information on Environment
ul. Wawelska 52/54
PL-00-922 Warszawa
sekretariatdm@gios.gov.pl

Forest Research Institute (IBL)
ul. Braci Leśnej 3
Sękocin Stary
PL-05-090 Raszyn
tel. +48 22 7150300
ibl@ibles.waw.pl

Institute of Meteorology and Water Management, Wrocław Branch (IMiGW o/Wrocław)
ul. Parkowa 30
PL-51-616 Wrocław
tel. +48 71 3200161
Sekretariat.Wroclaw@imgw.pl

A.7.1 Introduction

In response to the CCE "call for data 2019-21", the Polish NFC is submitting an updated critical loads database (CL2021), to be used by CIAM as environmental receptors for integrated assessment modelling with GAINS-Europe.

A.7.2 Ecosystem database

As in the previous CL's databases the calculation grid for Polish ecosystems was based on 0.1° x 0.05° longitude latitude EMEP spatial reference. The spatial resolution for Polish ecosystems was set on 0.02° x 0.01° what resulted grid dimensions from (lon x lat) 1.1 x 1.3 km in Northern Poland to 1.1 x 1.6 km in Southern Poland.

Terrestrial ecosystem database, was based on CLC18 [GIOS 2019], and linked with spatial database of wetland and non-forest ecosystems [IMUZ 2012]. EUNIS codes were based on Corrine LC codes. Thus, ecosystems D, E and F were extended to 2nd level of EUNIS classification. The SPAs and SACs from Natura 2000 database for Poland were used [EEA, 2016] to obtain area conservation status and indicate areas of special concern due to atmospheric deposition.

The final database covered 96 858.3 km^2 of ecosystems area, with one or more habitats in each grid cell and contains 240530 records. According to provide full spatial information for non-forest sensitive ecosystems (D,E,F) on Natura 2000 areas the CL2021 area limit was set >100 m^2 ("EcoArea">0.0001 km^2) wile for forest ecosystems (G) area limit was set > 0.5 ha ("EcoArea">0.05 km^2). Forests cover 98.4% of total ecosystems area.

Table 13: CL2021 Ecosystem database for Poland

EUNIS code	EUNIS habitat name	Ecosystem Area			Total cover change since CL2017 [%]
		Total	Covered by Natura 2000		
		[km^2]	[km^2]	% of Total	
D1	Raised and blanket bogs	47.4	39.8	84.1	0.57
D2	Valley mires, poor fens and transition mires	105.8	59.3	56.0	0.23
D4	Base-rich fens	1041.7	766.0	73.5	0.09
E2	Mesic grasslands	245.9	211.5	86.0	0.07
E4	Alpine and subalpine grasslands	78.8	76.5	97.1	0.18
F2	Arctic, alpine and subalpine scrub	36.5	36.5	100.0	0.30
F4	Temperate shrub heathland	4.8	4.5	94.6	0.84
G1	Broad-leaved forests	15163.8	7903.5	52.1	2.00
G3	Coniferous forests	55980.8	38424.1	68.6	-0.12
G4	Mixed forests	24394.0	11434.9	46.9	0.04
	TOTAL	97099.4	58956.5	60.7	0.25

A.7.3 Critical Loads of Acidity

Critical loads of acidity calculations were based on the SMB model as it was described in Chapter 5 of UBA Manual [UBA 2004, updated 2017].

The spatial distribution and soils properties were obtained from European Soils Database [ESDB, 2016], with additional data taken from Polish ICP Forest II-level monitoring system [Wawrzoniak et al. 2005, IBL 2011, 2019] and other published data [Brożek and Zwydak 2003]. Base cation weathering were calculated from weathering rates classes (WRc) obtained from soil texture (eq. 5.39, UBA Manual). Long-term precipitation and temperature dataset was derived from latest database described in New et al. 2002. The base cation depositions were obtained from national monitoring stations (10 year average) and spatially distributed. Chemical criterion used was molar [Bc]/[Al].

CLacid average calculated values for EUNIS ecosystem classes are shown in Table 14. Spatial distribution of CLmax(S) is presented in Figure 36.

Table 14: CL_{acid} values for terrestrial ecosystems in Poland

EUNIS code	CLacid – Critical Load Function of Acidity [eq/ha/a]		
	CLmaxS	CLminN	CLmaxN
D1	1854.2	137.6	3346.3
D2	1469.2	124.2	2595.1
D4	1880.2	120.3	3432.3
E2	1849.3	115.4	2860.8
E4	1967.4	216.0	3102.2
F2	2312.2	423.9	3967.3
F4	1822.0	395.6	3112.5
G1	1178.7	546.9	2397.5
G3	1286.4	425.7	2398.0
G4	1248.0	498.3	2413.9
Average	1265.8	466.8	2426.1

A.7.4 Critical Loads of Eutrophication

Critical loads of eutrophication (CL_{eut}) for forests were derived from $CL_{nut}(N)$ calculation methods based on SMB model in Chapter 5 of UBA Manual [UBA 2004, updated 2017] and for non-forest ecosystems as combinations of $CL_{nut}(N)$ and $CL_{emp}(N)$.

Nitrogen immobilisation in soli (N_i) was calculated as a function related to temperature range 5-8°C [UBA, 1996]. The polynomial equation was used for interpolation values between temperature range.

Nitrogen uptake (N_u) was obtained from State Forest Inventory [GDLP 2011] as forest biomass (stems and branches) removed from forest ecosystems.

Calculation of precipitation surplus (Q) was based on long-term climatic data [New et al. 2002] and derived with Penman-Monteith evapotranspiration equations.

The acceptable nitrogen leaching (N_{acc}) was calculated with data establish both in Sweden and the Netherlands (Table 5.7 from UBA Manual, updated 2007). For the lower threshold value of the growing season N_{acc} empirically determined in Scandinavia were used while for the upper threshold N_{acc} reported for the Netherlands were taken. The values of N_{acc} between the both threshold values of growing season were calculated for considered ecosystems using simple linear functions.

Additionally, $CL_{emp}(N)$ were calculated for all ecosystems types as an average of their min and max values [Bobbink et al. 2011] and recalculated to eq/ha/year for further $CL_{emp}(N)$ and $CL_{nut}(N)$ comparisons to derive final CL_{eut}.

Comparison of modelled and empirical CL revealed large split of values for non-forest ecosystems, in particular in mountain areas. Only for forests both $CL_{emp}(N)$ and $CL_{nut}(N)$ values didn't differ more than 4% for G1 and 12% for G3 up to 10% for G4. $CL_{nut}(N)$ for mire bog and fen habitats (D) don't reflect their different trophic status. For E and F habitats $CL_{nut}(N)$ show higher values for mountain habitats (E4, F2) than for lowland ecosystems located on richer soils (E2, F4) and it also doesn't correspond to result of field studies and $CL_{emp}(N)$ data.

Based on above the final CL_{eut} were derived with following conditions:

- non-forest ecosystems: (D, E and F) lower from $CL_{nut}(N)$ and $CL_{emp}(N)$
- G class: directly as $CL_{nut}(N)$.

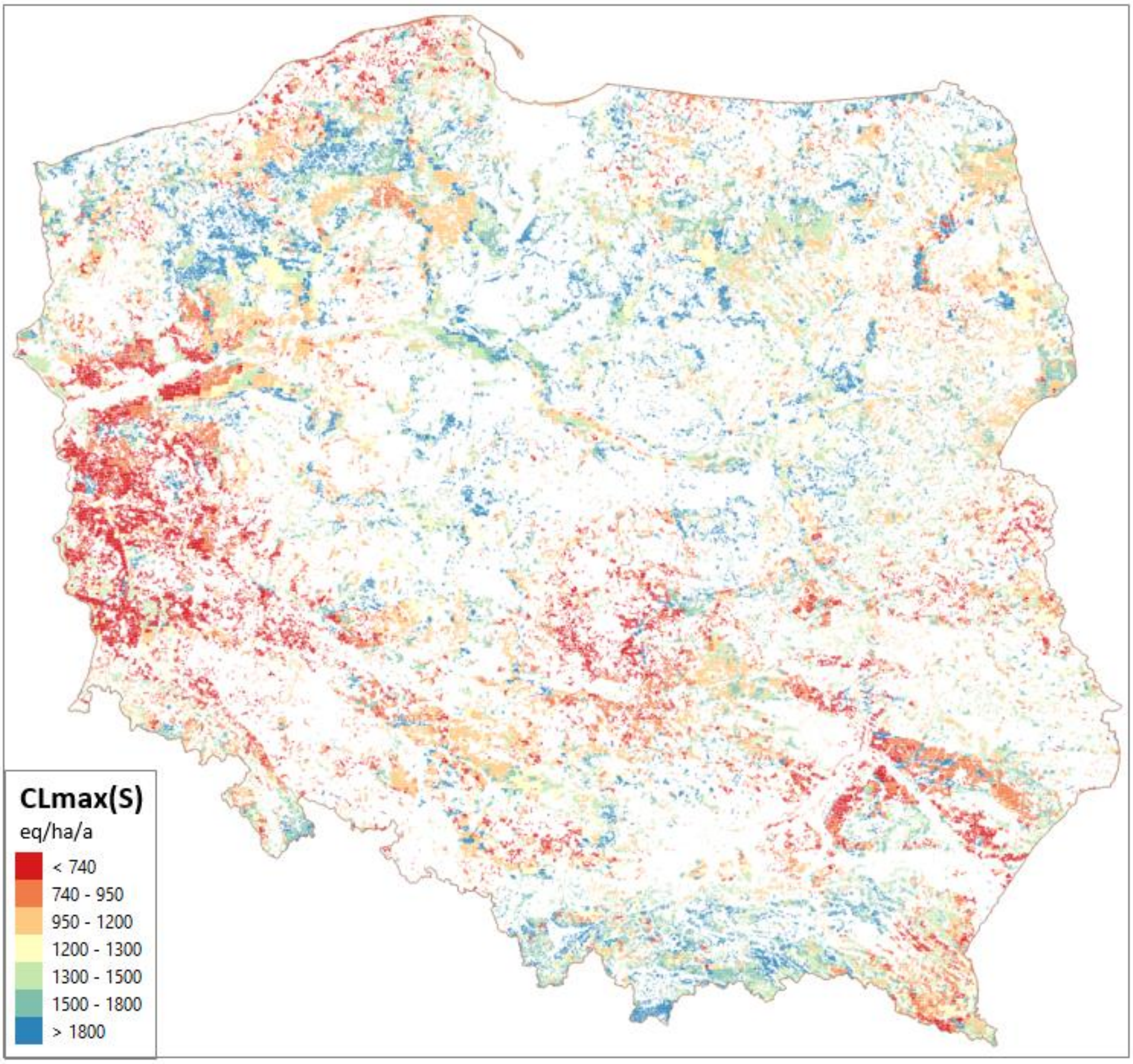
Calculation procedure and final CL_{eut} results for each EUNIS class are shown in Table 15. Spatial distribution of CL_{eut} is presented in Figure 37.

Table 15: CL_{eut} calculation method and values derived for terrestrial ecosystems in Poland

EUNIS code	$CL_{nut}(N)$	$CL_{emp}(N)$		CL_{eut}		
	eq/ha/a	kg/ha/a*	eq/ha/a	eq/ha/a	kg/ha/a	derivation method
D1	838.0	7.5	535.7	463.4	6.5	CLnutN or CLempN (lower value)
D2	529.8	12.5	892.8	479.3	6.7	CLnutN or CLempN (lower value)
D4	472.0	22.5	1607.1	463.8	6.5	CLnutN or CLempN (lower value)
E2	916.6	10	714.3	620.4	8.7	CLnutN or CLempN (lower value)
E4	1617.6	7.5	535.7	535.7	7.5	CLnutN or CLempN (lower value)
F2	2627.7	10	714.3	711.4	10.0	CLnutN or CLempN (lower value)
F4	1193.9	15	1071.4	921.5	12.9	CLnutN or CLempN (lower value)
G1	1129.2	15	1071.4	1129.2	15.8	ClnutN
G3	836.9	10	714.3	836.9	11.7	ClnutN
G4	1023.1	12.5	892.9	1023.1	14.3	ClnutN
Average	953.8	12.1	863.5	949.4	13.3	–

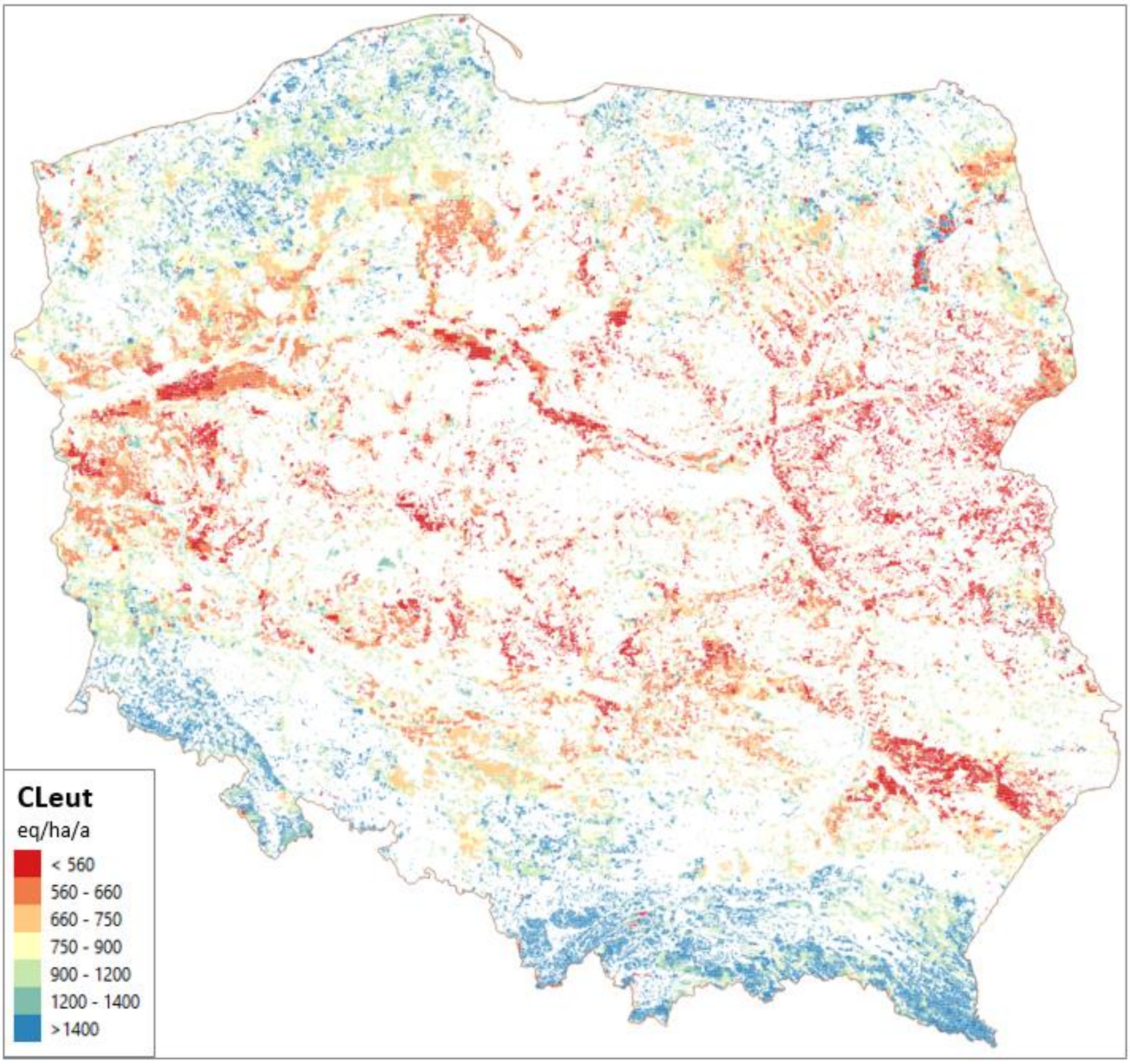
* $CL_{emp}(N)$ calculated as average from min and max range from Bobbink et al. 2011

Figure 36: Spatial distribution of $CL_{max}(S)$ values for terrestrial ecosystems in Poland.



Source: NFC Poland

Figure 37: Spatial distribution of CL_{eut} values for terrestrial ecosystems in Poland.



Source: NFC Poland

A.7.5 References

Bobbink R. Hettelingh JP. (eds); 2011, Review and revision of empirical critical loads and dose-response relationships. Proceedings of an expert workshop. Noordwijkerhout. 23-25 June 2010, RIVM Report 680359002, Coordination Centre for Effects. Bilthoven. Netherlands. 244 pp www.rivm.nl/cce.

Brożek S. Zwydak M. 2003, Atlas gleb leśnych Polski [Atlas of forest soils in Poland], CILP, Warszawa,

Davies C.E., Moss D., and Hill M.O., 2004, EUNIS Habitat Classification Revised 2004, European Environment Agency, European Topic Centre On Nature Protection And Biodiversity, October 2004

EEA 2016, Natura 2000 spatial database, https://www.eea.europa.eu/data-and-maps/data/natura-8

ESDAC 2016, European soil database and soil properties, http://esdac.jrc.ec.europa.eu/resource-type/european-soil-database-soil-properties

GDLP 2011, Forest uptake data in Polish State Forest (LP) in 1997 – 2008, Generalna Dyrekcja Lasów Państwowych, Warszawa

GIOŚ 2019, Corine Land Cover 2018 (CLC18), http://clc.gios.gov.pl/index.php

IBL 2011, Forest II level soil chemistry monitoring data, Forest Research Institute (IBL), Sekocin Stary

IBL 2019, Forest II level soil chemistry monitoring data, Forest Research Institute (IBL), Sekocin Stary

IMUZ, 2012, System Informacji Przestrzennej o Mokradłach Polski [Spatial Information System of Wetland in Poland], Instytut Melioracji i Użytków Zielonych w Falentach

Moss D. Davies CE. 2002, Cross-references between the EUNIS habitat classification, lists of habitats included in legislation, and other European habitat classifications.

New M. Lister D. Hulme M. and Makin I., 2002, A high-resolution data set of surface climate over global land areas, Climate Research 21:1-25

UBA 1996, Manual on Methodologies and Criteria for Modelling and mapping critical Loads and Levels and Air Pollution Effects, Risks and Trends, Umweltbundesamt, Berlin

UBA 2004, Manual on Methodologies and Criteria for Modelling and mapping critical Loads and Levels and Air Pollution Effects, Risks and Trends, Umweltbundesamt, Berlin

Wawrzoniak J. et al. 2005, Stan uszkodzenia lasów w Polsce w 2004 roku na podstawie badań monitoringowych [Forest condition in Poland in 2004]. Biblioteka Monitoringu Środowiska. GIOŚ, Warszawa, 2005

A.8 National report of Sweden

National Focal Centre

IVL Swedish Environmental Research Institute
Filip Moldan, Sara Jutterström, Johanna Stadmark
P.O. Box 53021
SE - 400 14 Göteborg
Phone: +46 10 788 6781
filip.moldan@ivl.se

Collaborating institutions

SLU, Swedish University of Agricultural Sciences
Jens Fölster
P.O. Box 7050
SE -750 07 Uppsala
jens.folster@slu.se

Swedish Environmental Protection Agency
Salar Valinia
SE - 106 48 Stockholm
salar.valinia@naturvardsverket.se
New email: salar.valinia@ensucon.se

A.8.1 Introduction

The Call for Data 2019-2021 on Critical Loads was adopted by the Working Group on Effects (WGE) during the 5th joint session of the EMEP Steering Body and the Working Group on Effects in Geneva, 9-13 September 2019. The main objective of this Call for Data is to review and update empirical Critical Loads ($CL_{emp}N$), and to update Critical Loads for acidity (CL_{acid}) and Critical loads for eutrophication (CL_{eut}). The Swedish NFC answers the call by reconfirming CL data submitted as a response to the previous call (2015-2017) with respect to both CL_{acid} and CL_{eut}.

A.8.2 CL_{acid}

The CL for acidity has been revised in a major way prior to the submission to the call 2015 – 2017 (Hettelingh et al., 2017) but not since. We kindly ask CCE to consider our previous submission as valid. The methodology used is described in Hettelingh et al (2017) as follows:

The MAGIC library is used in the critical loads calculations to set the ANClimit for individual lakes and to provide the base cations at steady state (BC*0 (1860)). In cases where historical ANC_{1860} is very low, restrictions (e.g. lowest ANClimit set to 0 µeq/l) are used to avoid setting a negative ANClimit. For ANClimit an upper threshold is set for pH 6.2, which means that for high pH lakes the maximum demanded target pH is 6.2. Nitrogen (N) immobilisation was set to 2 kg N/ha/yr in forest soils and non-acidifying leaching of organic nitrogen has also been accounted for in the critical load calculation. Deposition in excess of the sum of these two terms is considered acidifying according to the precautionary principle.

For the grid cells with no assessed lakes, we have used inverse distance weighting interpolation (IDW). IDW determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. This method assumes that the variable being mapped decreases in influence with distance from its sampled location. Between 3 and 10 lakes within 30 km radius were considered for interpolation for each grid. For the grid cells with several assessed lakes, we have used the average critical loads at these lakes.

The submitted ecosystem area (EcoArea) for critical loads for acidity is the area of Sweden reduced by the area of the nine largest Swedish lakes along with densely populated areas and agricultural land. Thus, the EcoArea for critical loads of acidification (395 226 km^2) is 88% of the total area of Sweden (449 964 km^2).

A.8.3 CLeut

For N as a nutrient Sweden uses empirical critical loads i.e $CL_{emp}N$. Swedish calculations $CL_{emp}N$ have been revised in response to the Call for data issued in 2013 and delivered in March 2014 (Hettelingh and Mathijssen 2014). For that submission, Swedish NFC has, in co-operation with national experts, reviewed habitats represented in 3798 Swedish Natura 2000 sites and established empirical critical loads of N as a nutrient. This was done either by assigning the Natura 2000 sites empirical critical loads values from Bobbink and Hettelingh (2011) according to their habitats, or by modifying the values in Bobbink and Hettelingh (2011) for Swedish conditions. In addition, we have developed new empirical critical loads values for habitats not specified in Bobbink and Hettelingh (2011). The full list of habitats and the used $CL_{emp}N$ is in Hettelingh and Mathijssen (2014). The same calculations were re-gridded and re-submitted in 2015 (Slootweg et al., 2015) and in response to the call 2015-2017 (Hettelingh et al., 2017).

The $CL_{emp}N$ submission might be revised in the future, when the ongoing revision of the empirical critical loads undertaken under this Call for data is completed. But for now we kindly ask CCE to consider the previous Swedish NFC submission of $CL_{emp}N$ (to the Call 2015 – 2017) as valid.

A.8.4 In conclusion

In Sweden, the impact of air pollution on ecosystems is of major concern, both with respect to acidification and eutrophication of soils and waters. Historically, we have recalculated critical loads multiple times to reflect the current knowledge and the most recent data and scientific findings. The critical loads submitted in response to the Call for data 2015 – 2017, however, still reflect our view on acceptable level of air pollution which – if not exceeded – provides sufficient level of protection of Swedish ecosystems from harmful effects of acidification and eutrophication. Therefore, we hereby confirm that the previous CL data submission to the Call for data 2015-2017 is still valid with respect to both CL_{acid} and $CL_{emp}N$.

A.8.5 References

Bobbink, R., Hettelingh, JP. (eds.), 2011. Review and revision of empirical critical loads and dose-response relationships. Proceedings of an expert workshop, Noordwijkerhout, 23-25 June 2010, RIVM report 68035900. Coordination Centre for Effects, National Institute for Public Health and the Environment (RIVM).

Hettelingh J-P, Mathijssen L (eds.) 2014. Modelling and Mapping impacts of atmospheric deposition on plant species diversity in Europe: CCE Status Report 2014, Coordination Centre for Effects, www.wge-cce.org.

Hettelingh J-P, Posch M, Slootweg J (eds.) (2017)European critical loads: database, biodiversity and ecosystems at risk, CCE Final Report 2017, Coordination Centre for Effects,RIVM Report 2017-0155, Bilthoven, Netherlands. https://www.rivm.nl/bibliotheek/rapporten/2017-0155.pdf

Slootweg, J., Posch, M., Hettelingh, J.-P. & Mathijssen, L. (eds) 2014. Modelling and Mapping the impacts of atmospheric deposition on plant species diversity in Europe. CCE Status Report 2014, Coordination Centre for Effects, www.wge-cce.org.

Slootweg J, Posch M, Hettelingh J-P (eds.) 2015 Modelling and mapping the impacts of atmospheric deposition of nitrogen and sulphur: CCE Status Report 2015, Coordination Centre for Effects, www.wge-cce.org

A.9 National report of Switzerland

National Focal Center

Federal Office for the Environment
Air Pollution Control and Chemicals Division
Reto Meier
CH - 3003 Bern

Collaborating Institutions

Beat Rihm, Meteotest AG, Bern
Dani Kurz, EKG Geo-Science, Bern

A.9.1 Empirical critical loads for nitrogen

Switzerland actively contributed to the review and revision of the empirical critical loads for nitrogen in 2021/2022. The revised empirical critical loads will be applied in the national critical load dataset and they are included for evaluating critical loads exceedances from 1990 to 2020. A corresponding national report will be available early 2023.

A.9.2 Steady-state critical loads

Steady-state critical loads for Switzerland were updated in context of the CCE Data Call 2015/2017 (CCE Final Report 2017). The Swiss submission to this call is considered to still be valid. Detailed information about the update of the critical loads for nutrient nitrogen (CLnutN) is given in FOEN 2016 and about the update of the critical loads for acidity (CLacid) in Kurz and Posch 2015. A brief summary of the most relevant input parameters for deriving the steady-state critical loads is described below.

A.9.3 Critical Loads for nutrient nitrogen

CLnutN based on the simple mass balance were calculated for 301 forest sites with full soil profiles used for dynamic models and 10’331 forest sites of the National Forest Inventory (1km^2 grid, NFI 1990/92).

The following Table 16 gives an overview of the main input parameters:

Table 16: Input parameters for the SMB calculation in Switzerland

Parameter	Values	Remarks
N leaching	4 kg N ha^{-1} yr^{-1} at 500m, 2 kg N ha^{-1} yr^{-1} at 2000m altitude, linear interpolation in between	Total acceptable nitrogen leaching was defined based on total annual amounts given in chapter V.3.1.2 of the Mapping Manual (CLRTAP 2017) because limits based on N concentration in soil water are not applicable in high precipitation areas. The rationale for this choice was presented in the CCE Status Report 2007. Assumption for changes along the altitudinal gradient: leaching is closely linked to management, which is more intense at lower altitudes.
N immobilization	1.5 kg N ha^{-1} yr^{-1} at 500m, 2.5 kg N ha^{-1} yr^{-1} at 1500m altitude	Assumption for changes along the altitudinal gradient: Decomposition of organic matter is slower at lower temperatures and therefore accumulation rates of N are higher. Recent findings from Höhle et al. 2017 and an expert workshop of ICP Modelling and Mapping have currently not been implemented. As reflected in the Mapping Manual it has been concluded that average immobilization rates are between 0.2 to 0.8 kg N ha^{-1} yr^{-1}
N uptake	Average Uptake between 1.6 and 8.5 kg N ha^{-1} yr^{-1} depending on region and altitude.	N uptake was calculated with the MAKEDEP model (Alveteg et al. 2002) for 301 forest sites used for dynamic models, based on biomass data from the 3rd National Forest Inventory (2013) and extrapolated to the rest of the forest sites based on region and altitude.
Denitrification fraction f_{DE}	f_{DE} between 0.2 (no groundwater) to 0.7 (very wet soils)	Denitrification fraction was determined according to wetness class of the soil according to the digital soil suitability map of Switzerland (FOAG 2012)

A.9.4 Critical Loads for acidity

CLacid were calculated for 301 forest sites based on the Simple Mass Balance (SMB) model (CLRTAP 2017). Weathering rates were calculated with the Sverdrup-Warfvinge Weathering algorithm (Sverdrup and Warfvinge 1995) linked to the SMB (SWW/SMB).

The critical value for the BC/Al-ratio was set at 7 as this would not allow a development of base saturation towards values substantially below 20%. This value was chosen with regard to information provided in the Mapping Manual and data from monitoring sites of the inter-cantonal monitoring network in Switzerland (Braun 2020).

The list of input parameters for running SWW/SMB is given in the CCE Final Report 2017 and in Kurz and Posch 2015.

A.9.5 References

Alveteg M., Kurz D., Becker R., 2002, Incorporating nutrient content elasticity in the MAKEDEP model. Sustainable Forestry in Temperate Regions – Proceedings from the SUFOR International Workshop, April 7-9, 2002 Lund, Sweden. Reports in Ecology and Environmental Engineering 1:2002: 52-67

Braun S., Tresch S., Augustin S., 2020, Soil solution in Swiss forest stands: a 20 year's time series, doi: 10.1371/journal.pone.0227530

CCE Final Report 2017, European critical loads: database, biodiversity and ecosystems at risk, Hettelingh J-P, Posch M, Slootweg J (eds), RIVM Report 2017-0155, Bilhoven, Netherlands, https://www.umweltbundesamt.de/sites/default/files/medien/4038/dokumente/1_cce_sr2017.pdf

CLRTAP 2017, Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends, UNECE Convention on long-range transboundary air pollution, www.icpmapping.org

FOAG 2012, Digitale Bodeneignungskarte der Schweiz. Federal Office for Agriculture (FOAG). https://opendata.swiss/de/dataset/digitale-bodeneignungskarte-der-schweiz-vernassung

FOEN 2007, Posch M., Eggenberger U., Kurz D., Rihm B., 2007. Critical Loads of Acidity for Alpine Lakes. A weathering rate calculation model and the generalized First-order Acidity Balance (FAB) model applied to Alpine lake catchments. Environmental studies no. 0709. Federal Office for the Environment, Bern https://www.bafu.admin.ch/bafu/en/home/topics/water/water--publications/publications-water/critical-loads-of-acidity-for-alpine-lakes.html

FOEN 2016; Rihm B., Achermann B.: Critical Loads of Nitrogen and their Exceedances. Swiss contribution to the effects-oriented work under the Convention on Long-range Transboundary Air Pollution (UNECE). Federal Office for the Environment, Bern. Environmental studies no. 1642 https://www.bafu.admin.ch/bafu/en/home/topics/air/publications-studies/publications/Critical-Loads-of-Nitrogen-and-their-Exceedances.html

Kurz D. and Posch M., 2015, Revising critical loads of acidity for forests in Switzerland for the call for data 2014/2015. Report

NFI 1990/92. National Forest Inventory (NFI), Datenbankauszüge vom 30. Mai 1990 und vom 8. Dezember 1992. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft (WSL)

A.10 National report of the UK

National Focal Centre

Katarzyna Sawicka
Canolfan yr Amgylchedd Cymru/Environment Centre Wales
Ffordd Deiniol/Deiniol Road
UK-LL57 2UW Bangor (Gwynedd)
katwic55@ceh.ac.uk

In response to the "[UNECE ICP M&M] CCE Call for Data 2019-2021" dated 7th Jan 2020, the UK NFC submitted a status report on the methods applied to calculate Steady-State Mass-Balance Critical Load (CLSMB) values in March 2020. In April 2020 the UK NFC attended and reported to the annual Task Force M&M meeting. The UK NFC is now submitting a response to both aspects of the third part of the Call for Data:

- Two of the habitat chapters of the updated report on "review and revision of empirical critical loads for nutrient-N" are being led by UK authors, and four other chapters have UK co-authors.
- The most recent data for CLSMB are those that were provided to the CCE in January 2017, in response to the Call for Data 2015-18. The data have been reviewed and checked. Work on underlying datasets (e.g. habitat maps) is in progress and expected to be revised to the CLSMB datasets later in 2021.

The database includes UK 1x1 km acidity and nitrogen critical loads data for 16 EUNIS habitat classes, as summarised in Table 1 below. A separate set of tables (ecords, SiteInfo, CLacid, CLeut, CLbdiv) was submitted for each EUNIS habitat as per CCE instructions.

Habitat	EUNIS code	EUNIS table prefix	SiteID = CEHid*1000 + value below	Number of record in each of the following tables				
				Ecords	SiteInfo	CLacid	CLeut	CLbdiv
Saltmarsh	A2.5	A25	20	3867	None	None	2867	none
Dune grassland	B1.4	B14	1	3502	None	None	3502	none
Freshwaters	C1 or C2	C1_C2	#	14816	14816	14816	None	none
Bog	D1	D1	4	19019	18181	18181	19019	11717
Calcareous grassland	E1.26	E126	5	35472	16325	16325	35472	none

Habitat	EUNIS code	EUNIS table prefix	SiteID = CEHid*1000 + value below	Number of record in each of the following tables				
Dry acid grassland	E1.7	E17	6	26034	25889	25889	26034	none
Wet acid grassland	E3.52	E352	7	51900	51721	52721	51900	none
Montane	E4.4	E42	8	5614	5474	5474	5614	none
Wet dwarf shrub heath	F4.11	F411	9	58380	58159	58159	58380	none
Dry dwarf shrub heath	F4.2	F42	10	20562	20348	20348	20562	none
Managed broad-leaved woodland	G1	G1	11	75698	75698	75698	76698	none
Unmanaged beech (Fagus) woodland	G1.6	G16	14	7399	7366	7366	7399	none
Unmanaged acidophilous oak woodland	G1.8	G18	15	15162	14654	14654	15162	none
Managed coniferous woodland	G3	G3	12	37457	37457	37457	37457	none
Unmanaged Scots pine woodland	G3.4	G34	16	1817	1742	1742	1817	none

Habitat	EUNIS code	EUNIS table prefix	SiteID = CEHid*1000 + value below	Number of record in each of the following tables				
Other unmanaged coniferous/broadleaved woodland	G4	G4	13	19333	17882	17882	19333	none

Freshwaters consist of a total of 1752 sites across the UK, but sub-divided in the data submission since they cross the borders between different EMEP grid squares. As a consequence the SiteID is derived as (CEHid * 100000)+(uniqpart*10) + 2 for C1 or +3 for C2. CEHid is a unique ID (unique1km) for each 1x1 km grid square of the UK.

As in the previous data submission (Hall et al, 2015: CCE Status Report 2015) the protection code (in each ecords table) and empirical nitrogen critical loads (now in the CLeut table) are set accordingly if a 1x1 km square contains a SAC/SPA with a designated habitat of that EUNIS class.

B Call for Data 2019/20: Instructions

B.1 1. Introduction

At the 5th Joint Session of the Steering Body to the EMEP and the Working Group on Effects (Geneva, 9-13 September 2019) the Coordination Centre for Effects was requested to issue a Call for Data in the autumn of 2019 with a deadline in 2021. As announced at the virtual ICP M&M meetings (21-23 April 2020), the deadline is set at 31 March 2021.

This document contains the instructions on how to reply to this Call for Data 2019-21. The call asks for (updates of) critical loads of acidification (SMB model) and eutrophication ($CL_{nut}N$ from SMB or $CL_{emp}N$).

Please note:

Please indicate as early as possible if you are planning to deliver new data within this call. You can also choose to reconfirm the data you sent for the previous call (2015-17) via a written statement and without sending any data. Please be aware that any early indication of your choice will help us to organize our workplan more efficient.

Please use the latest database template (from the previous call 2015-17) or plain text files (e.g. *.csv) for submitting your critical loads.

B.2 2. Documentation and other general information

The documentation should substantiate and justify sources and methods applied in response to this call, but be restricted to the data sources and deviations from the Mapping Manual (ICP M&M, 2016).

To facilitate the integration into the European database at the CCE, you should use the Access database template developed by the CCE. This template is described in Section 5 and can be downloaded from the CCE website (https://www.umweltbundesamt.de/en/call-for-data). Comma-delimited text files will be accepted, if the column headers are identical to the variable names of section 5.

If you are planning to submit data please send an E-Mail to cce@uba.de. We will then contact you in order to establish the data exchange.

B.3 3. Types of Critical Loads and how to submit them

For the data submission we now distinguish two types of critical loads (variable names are also used in the Tables in Section 5):

1. Critical loads of acidity (CL_{acid}): This is characterized by a Critical Load Function (CLF) of S and N (See page V – 29 Figure V.3 in the Mapping Manual) and is quantified by $CL_{max}S$, $CL_{min}N$ and $CL_{max}N$, and generally computed by the SMB model.
2. Critical loads of eutrophication (CL_{eut}): For eutrophication by N the critical load can either be computed by the SMB model (formerly known as $CL_{nut}N$) or by an empirical CL (as summarised in Bobbink and Hettelingh 2011) (formerly known as $CL_{emp}N$). In line with the definition of a critical load, if both a $CL_{nut}N$ and a $CL_{emp}N$ are determined for same ecosystem, the CL of eutrophication, denoted as $CL_{eut}N$, is the minimum of both. And only $CL_{eut}N$ should be reported.

B.4 4. The grid system

An *ecord* is the part of an ecosystem that lies entirely in a single **0.10°×0.05° Longitude- Latitude grid cell**. A grid cell is referred to by its lower-left (south-west) grid coordinates in decimal degrees. You will need to overlay the grid with your maps containing the data to determine the locations (and potentially splitting up) of your critical loads.

B.5 5. Access Database template

The tables in the database have different purposes and are listed below.

ecords – General site data, such as coordinates.

CLacid, CLeut – Critical loads, one table for each type, with its related limits.

SiteInfo – General background data for the site.

Table 17 Attributes of the database-table '*ecords*'

Variable	Explanation	Note
SiteID	Unique(!) identifier of the site	1)
Lon	Longitude (decimal degrees)	2)
Lat	Latitude (decimal degrees)	2)
EcoArea	Area of the ecosystem within the grid cell (km^2)	3)
Nmethod	Method with which $CL_{eut}N$ of the site is derived: 2 – modelled nutrient nitrogen 4 – empirical N critical load 8 – any other method	
Protection	0: No specific nature protection applies 1: Special Protection Area (SPA), Birds Directive applies 2: Special Area of Conservation (SAC), Habitats Directive applies 3: SPA *and* SAC (1 *and* 2) 4: SPA *or* SAC (1 *or* 2) [don't know which one(s)] 9: A national nature protection program applies (but *not* 1 to 4!) -1: protection status unknown	
EUNIScode	EUNIS code, max. 6 characters	4)

Table notes (see last column):

1) Use integer values only (4-bytes)!

2) The geographical coordinates of the site or a reference point of the polygon (sub-grid) of the receptor under consideration (in decimal degrees, i.e. 48.533 for 48º31', etc.);

3) Please don't submit spurious records with an ecosystem area smaller than 0.5 ha, unless it has relevance other than for exceedance calculations (e.g. Natura 2000 sites). Furthermore, make sure that the total ecosystem area does not exceed the size of the land area of your country in the respective grid cell;

4) You can find information on EUNIS at https://eunis.eea.europa.eu/

Table 18: Attributes of the database-table '*CLacid*'

Variable	Explanation
SiteID	Identifier of the site (see *ecords* Table)
CLmaxS	Maximum critical load of sulphur (eq ha^{-1} a^{-1})
CLminN	Minimum critical load of nitrogen (eq ha^{-1} a^{-1})
CLmaxN	Maximum critical load of nitrogen (eq ha^{-1} a^{-1})
Crittype	Chemical criterion used for acidity CL calculations: =1: molar [Al]:[Bc]; =2: [Al] (eq m^{-3}); =3: base sat.(-); =4: pH; =5: [ANC] (eq m^{-3}); =6: molar[Bc]:[H]; =7: molar [Bc]:[Al]; =8: molar [Ca]:[Al]; =11: molar [Al]:[Bc] AND [Al]>0.1meq/L; = –1: other
Critvalue	Critical value for the chemical criterion given in 'Crittype'

Table 19: Attributes of the database-table '*CLeut*'

Variable	Explanation
SiteID	Identifier of the site (see *ecords* Table)
CLeutN	Critical load of eutrophication (eq ha^{-1} a^{-1})
cNacc	Acceptable (critical) N concentration if CLnutN calculation (meq^{-3}) only if CLeutN = CLnutN! (otherwise, if CLempN is used, set to –1)

Table 20 Attributes of the database-table '*SiteInfo*'

Variable	Explanation
SiteID	Identifier of the site (see *ecords* Table)
thick	Thickness (root zone!) of the soil (m)
nANCcrit	The quantity $-ANC_{le(crit)}$ (eq ha^{-1} a^{-1})
Cadep	Total deposition of calcium (eq ha^{-1} a^{-1})
Mgdep	Total deposition of magnesium (eq ha^{-1} a^{-1})
Kdep	Total deposition of potassium (eq ha^{-1} a^{-1})
Nadep	Total deposition of sodium (eq ha^{-1} a^{-1})
Cldep	Total deposition of chloride (eq ha^{-1} a^{-1})
Cawe	Weathering of calcium (eq ha^{-1} a^{-1})
Mgwe	Weathering of magnesium (eq ha^{-1} a^{-1})
Kwe	Weathering of potassium (eq ha^{-1} a^{-1})
Nawe	Weathering of sodium (eq ha^{-1} a^{-1})
Caupt	Net growth uptake of calcium (eq ha^{-1} a^{-1})
Mgupt	Net growth uptake of magnesium (eq ha^{-1} a^{-1})
Kupt	Net growth uptake of potassium (eq ha^{-1} a^{-1})
Qle	Amount of water leaving at the bottom of the root zone (mm a^{-1})
lgKAlox	Equilibrium constant for the Al-H relationship (log10) (The variable formerly known as K_{gibb})
expAl	Exponent for the Al-H relationship (=3 for gibbsite equilibrium)
cOrgacids	Total concentration of organic acids (m*DOC) (eq m^{-3})
Nimacc	Acceptable nitrogen immobilised in the soil (eq ha^{-1} a^{-1})
Nupt	Net growth uptake of nitrogen (eq ha^{-1} a^{-1})
fde	Denitrification fraction (0≤fde<1) (-)
Nde	Amount of nitrogen denitrified (eq ha^{-1} a^{-1})
Prec	Annual precipitation (mm a^{-1})

Variable	Explanation
TempC	Annual average temperature (°C)
CNrat	C/N ratio in the topsoil (g g^{-1})
Measured	On-site measurements included in the data for CL calculations: 0: No measurements, 1: ICP Forest, 2: ICP Waters, 4: ICP Integrated Monitoring, 8: ICP Vegetation, 16: Other measurement programme. (if more than one of the listed possibilities applies, add the numbers!)

B.6 References

Bobbink R, Hettelingh J-P (eds), 2011. Review and revision of empirical critical loads and dose response relationships. Proceedings of an international expert workshop, Noordwijkerhout, 23-25 Juni 2010, RIVM Report 680359002, Coordination Centre for Effects, RIVM, Bilthoven

ICP M&M, 2016. Mapping Manual, https://www.umweltbundesamt.de/en/manual-for-modelling-mapping-critical-loads-levels?parent=68093, accessed 28 Sep 2020

C Overview of revised 2022 $CL_{emp}N$ values

Table 21 Overview of empirical N critical loads (kg N ha^{-1} yr^{-1}) to natural and semi-natural ecosystems (column 1), classified according to EUNIS (column 2), as established in 2011 (column 3), and as revised in Bobbink et al., 2022 (column 4). The reliability is indicated by ## reliable; # quite reliable and (#) expert judgement (column 5). Column 6 provides a selection of effects that may occur when critical loads are exceeded. Finally, changes with respect to 2011 are indicated as values in bold.

Ecosystem type	EUNIS code	2011 kg N ha^{-1} yr^{-1}	2022 kg N ha^{-1} yr^{-1}	2022 reliability	Indication of exceedance
Marine habitats (MA)					
Atlantic upper-mid salt marshes	MA223	20-30	**10-20**	(#)	Increase in dominance of graminoids; decline positive indicator species
Atlantic mid-low salt marshes	MA224	20-30	**10-20**	(#)	Increase in late successional species; decline positive indicator species
Atlantic pioneer salt marshes	MA225	20-30	20-30	(#)	Increase in late successional species; increase in productivity species
Coastal habitat (N)					
Shifting coastal dunes	N13, N14	10-20	10-20	**#**	Biomass increase; increased N leaching; reduced root biomass
Coastal dune grasslands (grey dunes)	N15	8-15	**5**-15	**##**	Increased biomass and cover of graminoids and mesophilic forbs; decrease in oligotrophic species including lichens; increased tissue N; increased N leaching; soil acidification
Coastal dune heaths	N18, N19	10-20	10-**15**	**#**	Increased plant production; increased N leaching; accelerated succession; typical lichen C:N decrease; increased yearly increment *Calluna*
Moist and wet dune slacks	N1H	10-20	**5-15**	**#**	Increased cover of graminoids and mesophilic forbs; decrease in oligotrophic species; increased Ellenberg N
Dune-slack pools (freshwater aquatic communities of permanent Atlantic and Baltic or	N1H1, N1J1	10-20	10-20	(#)	Increased biomass and rate of succession

Mediterranean and Black Sea dune-slack water bodies)					
Inland surface water habitats (C) [a]					
Permanent oligotrophic lakes, ponds and pools (including soft-water lakes)	C1.1	3-10	**2**-10 [b]	##	Increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P; shifts in macrophyte community
Alpine and sub-Arctic clear water lakes	C1.1		**2-4**	**##**	Increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P
Boreal clear water lakes	C1.1		**3-6**	**##**	Increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P
Atlantic soft water bodies	C1.1, elements C1.2	3-10	**5**-10	##	Change in species composition of macrophyte communities
Permanent dystrophic lakes, ponds and pools	C1.4	3-10	**5**-10 [c]	(#)	Increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P
Mire, bog and fen habitats (Q)					
Raised and blanket bogs	Q1	5-10	5-10	##	Increase in vascular plants; decrease in bryophytes; altered growth and species composition of bryophytes; increased N in peat and peat water
Valley mires, poor fens and transition mires	Q2	10-15	**5**-15	**##**	Increase in sedges and vascular plants; negative effects on bryophytes
Palsa and polygon mires	Q3		**3-10**	**(#)**	Increase in graminoids, tissue N concentrations and decomposition rate
Rich fens	Q41-Q44	15-30	15-**25**	**#**	Increase in tall vascular plants (especially graminoids); decrease in bryophytes
Arctic-alpine rich fens	Q45	15-25	15-25	(#)	Increase in vascular plants; decrease in bryophytes
Grasslands and tall forb habitats (R)					

Semi-dry Perennial calcareous grassland (basic meadow steppe)	R1A	15-25	**10-20**	##	Increase in tall grasses; decline in diversity; change in species composition; increased mineralisation; N leaching; surface acidification
Mediterranean closely grazed dry grasslands or Mediterranean tall perennial dry grassland or Mediterranean annual-rich dry grassland	R1D or R1E or R1F	15-25	**5-15**	(#)	Increased production; dominance by graminoids; changes to soil crusts; changes to soil nutrient cycling
Lowland to montane, dry to mesic grassland usually dominated by *Nardus stricta*	R1M	10-15	**6-10**	##	Increase in graminoids; decline of typical species; decrease in total species richness
Oceanic to subcontinental inland sand grassland on dry acid and neutral soils or Inland sanddrift and dune with siliceous grassland	R1P or R1Q	8-15	**5**-15	(#)	Decrease in lichens; increase in biomass
Low and medium altitude hay meadows	R22	20-30	**10-20**	(#)	Increase in tall grasses; decrease in diversity; decline of typical species
Mountain hay meadows	R23	10-20	10-**15**	**#**	Increase in nitrophilous graminoids; changes in diversity; decline of typical species
Moist or wet mesotrophic to eutrophic hay meadow	R35	15-25	15-25	(#)	Increase in tall graminoids; decreased diversity; decrease in bryophytes
Temperate and boreal moist and wet oligotrophic grasslands	R37	10-20	10-20	#	Increase in tall graminoids; decreased diversity; decrease in bryophytes
▶ Moss and lichen dominated mountain summits	(Earlier E4.2)	5-10	5-10	#	Change in species composition; effects on bryophytes or lichens

▶ Temperate acidophilous alpine grasslands	R43	5-10	5-10	#	Changes in species composition; increase in plant production
Arctic-alpine calcareous grassland	R44	5-10	5-10	#	Changes in species composition; increase in plant production
Heathland, scrub and tundra habitats (S)					
Tundra	S1	3-5	3-5 [d]	#	Changes in biomass; physiological effects; changes in bryophyte species composition; decrease in lichen species richness
Arctic, alpine and subalpine scrub habitats	S2	5-15	5-**10** [d]	#	Decline in lichens; bryophytes and evergreen shrubs
Lowland to montane temperate and submediterranean *Juniperus* scrub	S31		**5-15**	**(#)**	Shift in vegetation community composition; reduced seed viability
Northern wet heath	S411				
▶ U' Calluna-dominated wet heath (upland)	S411	10-20	**5–15** [e]	**##**	Decreased heather dominance; decline in lichens and mosses; increased N leaching
▶ 'L' Erica tetralix-dominated wet heath (lowland)	S411	10-20	**5-15** [e]	**##**	Transition from heather to grass dominance; decrease in heather cover; shift in vegetation community composition
Dry heaths	S42	10-20	**5-15** [e]	##	Transition from heather to grass dominance; decline in lichens; changes in plant biochemistry; increased sensitivity to abiotic stress
Maquis, arborescent matorral and thermo- Mediterranean scrub	S5	20-30	**5-15**	(#)	Change in plant species richness and community composition; nitrate leaching; acidification of soil.
Garrigue	S6		**5-15**	**#**	Changes in species composition; decline in shrub cover;

					increased invasion of annual herbs
Forest habitats (T)					
Broadleaved deciduous forest	T1	10-20	10-**15**	##	Changes in soil processes; nutrient imbalance; altered composition mycorrhiza and ground vegetation
Fagus forest on non-acid and acid soils	T17, T18	10-20	10-**15**	(#)	Changes in ground vegetation and mycorrhiza; nutrient imbalance; changes in soil fauna
Mediterranean *Fagus* forest on acid soils	T18		**10-15**	**(#)**	Annual height and volume tree growth; analogy to temperate *Fagus* forest
Acidophilous *Quercus* forest	T1B	10-15	10-15	(#)	Decrease in mycorrhiza; loss of epiphytic lichens and bryophytes; changes in ground vegetation
Carpinus and *Quercus* mesic deciduous forest	T1E	15-20	15-20	(#)	Changes in ground vegetation
Mediterranean evergreen *Quercus* forest	T21	10-20	10-**15**	(#)	NO_3 in soil water and streams
Coniferous forests	T3	5-15	**3**-15	##	Changes in soil processes; nutrient imbalance; altered composition mycorrhiza and ground vegetation; increase in mortality with drought
Temperate mountain *Picea* forest, Temperate mountain *Abies* forest	T31, T32	10-15	10-15	(#)	Decreased biomass of fine roots; nutrient imbalance; decrease in mycorrhiza; changed soil fauna
Mediterranean mountain *Abies* forest	T33		**10-15**	**(#)**	Tree foliar stoichiometry; tree physiology; soil N losses
Temperate continental *Pinus sylvestris* forest	T35	5-15	5-15	#	Changes in ground vegetation and mycorrhiza; nutrient imbalances; increased N_2O and NO emissions
Mediterranean montane *Pinus sylvestris-Pinus nigra* forest	T37		**5-17**	**(#)**	Lichen chemistry and community changes in Mediterranean mixed-conifer forests in USA

Mediterranean lowland to sub-montane *Pinus* forest	T3A	3-15	**5-10**	(#)	Reduction in fine-root biomass; shift in lichen community
Dark taiga	T3F	5-10	**3-5** [f]	##	Changes in epiphytic lichen and ground-layer bryophyte communities; increase in free-living algae; decline in N-fixation
Pinus sylvestris light taiga	T3G	5-10	**2-5** [f]	#	Changes in epiphytic lichen and ground-layer bryophyte communities; increase in free-living algae; decline in N-fixation

a) The lower part of the $CL_{emp}N$ range should be applied for lakes in small catchments (with high lake to catchment ratios), because these are most exposed to atmospheric deposition, given that a relatively high fraction of their N inputs is deposited directly on the lakes and is not retained in the catchments. Similarly, the lower part of the range should be applied for lakes in catchments with thin soils, sparse vegetation and/or with a high proportion of bare rock.

b) This $CL_{emp}N$ should only be applied to oligotrophic waters with low alkalinity and with no significant agricultural or other human inputs. Apply the lower end of the range to clear-water sub-Arctic and alpine lakes, the middle range to boreal lakes and the higher end of the range to Atlantic soft waters.

c) This $CL_{emp}N$ should only be applied to waters with low alkalinity and with no significant agricultural or other direct human inputs. Apply the lower end of the range to boreal dystrophic lakes.

d) Use towards high end of range if phosphorus limited, and towards lower end if phosphorus is not limiting.

e) Use towards high end of range with high intensity management, and use towards lower end of range with low intensity management.

f) Mainly based on N deposition impacts on lichens and bryophytes.