TEXTE
105/2026

CCE Status Report 2026

ICP Modelling and Mapping, Convention on Long-Range Transboundary Air Pollution (CLRTAP)

by:

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On behalf of the German Environment Agency

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Abstract: CCE Status Report 2026

The Coordination Centre for Effects (CCE) is the program center for the International Coordinative Programme on Modelling and Mapping (ICP M&M) of the Working Group on Effects of the Geneva Convention on Long-range Transboundary Air Pollution (CLRTAP). ICP M&M asses the large-scale effects of atmospheric deposition of air pollutants on sensitive ecosystems, using critical loads (critical deposition rates) and model-based approaches. The CCE's mandate is to develop and update methods for determining Critical Loads (CL), compile CL data, and produce maps of CL and CL-exceedances. In addition, the CCE coordinates international cooperation with the National Focal Centers (NFC) on this topic. Based on this mandate, the report summarises the main CCE activities and results from 2023-2025 and includes NFC reports on CL data deliveries in 2024 and 2025.

The activities of the CCE during this period were significantly influenced by the revision of the Gothenburg Protocol. This report provides the scientific basis developed and coordinated by the CCE to support the revision of the Protocol. Chapter 1 describes the empirical Critical Loads database and discusses its use as an indicator for assessing biodiversity risks associated with atmospheric nitrogen deposition in the context of the Gothenburg Protocol revision. Chapter 4 describes the methods and data applied in the assessment of critical levels for atmospheric ammonia concentration. Chapters 2 and 3 describe further developments in the CCE toolbox. These include initial results from the expansion of the background database on SMB-/Steady State CL (Chapter 2) and the revision of the receptor map as a cornerstone for CL modeling (Chapter 3).

Kurzbeschreibung: CCE Status Report 2026

Das Coordination Centre for Effects (CCE) ist das Programmzentrum für das „International Coordinative Programme on Modelling and Mapping (ICP M&M)“ der Wirkungsarbeitsgruppe der Genfer Luftreinhaltekonvention (CLRTAP). Das ICP M&M bewertet mithilfe von Modellen die großräumigen Auswirkungen der atmosphärischen Deposition von Luftschadstoffen auf empfindliche Ökosysteme, insbesondere mit Hilfe von Critical Loads (kritische Eintragsraten). Das Mandat des CCE umfasst die Entwicklung und Aktualisierung von Methoden zur Ermittlung der Critical Loads (CL), die Zusammenstellung von CL-Daten sowie die Erstellung von Karten zu CL und deren Überschreitungen. Zudem koordniniert das CCE die internationale Zusammenarbeit mit den nationalen Programmzentren (NFC). Dieser Bericht fasst die wichtigsten CCE-Aktivitäten und Ergebnisse in den Jahren 2023-2025 zusammen und enthält die Berichte der nationalen Programmzentren zu den CL-Datenlieferungen 2024 und 2025.

Die Arbeiten des CCE waren im Berichtszeitraum maßgeblich durch die Überarbeitung des Göteborg Protokolls geprägt. Dieser Bericht liefert die vom CCE entwickelnden und koordinierenden wissenschaftlichen Grundlagen zur Unterstützung des Revisionsprozesses. Kapitel 1 beschreit die Datenbasis der Empirischen Critical Loads und diskutiert deren Anwendung als Indikator zur Bewertung von Biodiversitätsrisiken im Zusammenahng mit atmsphärischer Stickstoffdeposition im Kontext der Revision des Göteborg-Protokolls. Ein weiterer Indikator für diesen Prozess sind die in Kapitel 4 erläuterten Methoden und Daten zur Bewertung der atmosphärischen Konzentration von Ammoniak mit Hilfe von Critical Levels. Nicht zuletzt werden in den Kapiteln 2 und 3 Weiterentwicklungen am Werkzeugkasten des CCE beschrieben. Dazu gehören erste Ergebnisse bei der Erweiterung der Hintergrund-Datenbank zu SMB-/Steady State Critical Loads (Kapitel 2) und die Überarbeitung der Rezeptor-Karte als Grundbaustein für die CL-Modellierung (Kapitel 3).

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List of abbreviations

Abbreviation	Explanation
AAE	Average accumulated exceedance
AAR	Area at risk; absolute or relative area affected by Critical Load exceedance
BGDB	Background Database (for modelled Critical Loads)
CDF	Cumulative distribution function
CCE	Coordination Center for Effects
CfD	Call for Data
CL	Critical Load
CLC	Corine Land Cover
CLE	Current legislation
CIAM	Centre for Integrated Assessment Modelling
$CL_{emp}N$	Empirical Critical Load
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CRU	Climatic Research Unit
E-OBS	Europe-wide dataset for temperature and precipitation
EECCA countries	Eastern European, Caucasian and Central Asian countries
EU 27	all EU countries
EUNIS	European Nature Information System (https://eunis.eea.europa.eu/index.jsp)
EUNIS Level-1 ecosystem class	C Inland surface waters M Marine habitats N Coastal habitats Q Wetlands R Grasslands and lands dominated by forbs, mosses, or lichens S Heathland, scrub, and tundra T Forest and other wooded land U Inland habitats with no or little soil and mostly with sparse vegetation V Vegetated man-made habitats
EVA	European Vegetation Archive
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GPNV	Global Potential Natural Vegetation
HWSD	Harmonized World Soil Database
ICP M&M	ICP Modelling & Mapping
$kg\ ha^{-1}\ a^{-1}$	kilogram per hectar and year
$kg\ ha^{-1}\ yr^{-1}$	kilogram per hectar and year
MTFR	maximum technically feasible reduction

Abbreviation	Explanation
MSC-West	Meteorological Synthesizing Centre West
NFC	National Focal Center
Non-EU	European countries not in the EU nor WB or EECCA
TFIAM	Task Force on Integrated Assessment Modelling
UNECE	United Nations Economic Commission for Europe
WB	West-Balkan countries

Summary

Objectives of the report

The CCE Status Report 2026 was prepared by the Coordination Centre for Effects (CCE) under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). Its main objective is to provide a scientifically robust, policy-relevant assessment of risks to ecosystems and biodiversity from atmospheric nitrogen pollution and related air pollutants across Europe and the EECCA region. A central aim is to support the ongoing revision of the Gothenburg Protocol by supplying harmonized datasets, impact indicators, and scenario-based evaluations that link emission reductions to measurable reductions in biodiversity risks.

Specifically, the report seeks to:

- Update and map empirical Critical Loads for nutrient nitrogen ($CL_{emp}N$) across the UNECE region using a harmonized ecosystem receptor map;
- Publish national reports and integrate national data submitted by National Focal Centres (NFCs) through the Call for Data (CfD) 2023/2024 and assess their implications;
- Perform ex-post analyses of future emission scenarios to quantify remaining risks to ecosystems;
- Advance and extend steady-state and simple mass balance (SMB) Critical Load modelling to a broader geographical domain;
- Develop and test a harmonized approach for mapping and assessing Critical Levels for atmospheric ammonia.

Overall, the report aims to strengthen the scientific basis for ecosystem protection under European air pollution policy while communicating results in a way that is transparent and accessible to both scientists and informed members of the public.

Scope and structure

The report is structured around five major thematic components. First, it focuses on the mapping and assessment of $CL_{emp}N$, including results from the CfD 2023/2024. This part documents both a harmonized UNECE-wide approach developed by CCE and an alternative dataset reflecting national choices submitted by NFCs. Second, it briefly describes how $CL_{emp}N$ datasets are used in Integrated Assessment Modelling (IAM) to optimize emission reduction strategies for both human health and biodiversity. Third, the report presents detailed ex-post analyses, evaluating how different emission scenarios for 2040 affect exceedance of $CL_{emp}N$ and the associated risks to biodiversity. Fourth, it documents progress in mapping steady-state and SMB Critical Loads for acidification and eutrophication, including major updates to receptor map, soil data, and meteorological inputs, and the extension of the modelling framework to the EECCA region and Turkey. Finally, the report introduces a harmonized approach to mapping and assessing Critical Levels for atmospheric ammonia (NH3) and evaluates ammonia-related ecosystem risks under future scenarios. In the annex all National Focal Center reports to the Calls for data submitted to CCE are published.

Mapping and assessment of empirical Critical Loads for nutrient nitrogen ($CL_{emp}N$) (Chapter 1)

$CL_{emp}N$ represent deposition thresholds above which harmful effects on ecosystems are likely to occur. These effects are primarily linked to biodiversity loss, such as reductions in plant species richness, shifts in species composition, and declines of oligotrophic and characteristic species.

$CL_{emp}N$ values are derived from long-term empirical studies and are expressed as ranges rather than single values to reflect ecological variability and methodological uncertainty.

The most recent update of $CL_{emp}N$, published in 2022, provides ranges for 51 European ecosystem types, with values spanning from approximately 2 to 30 kg N ha^{-1} yr^{-1}. Based on scientific review and policy discussions within CLRTAP, $CL_{emp}N$ are now recognized as particularly suitable indicators for biodiversity-related impacts of nitrogen pollution.

Harmonized UNECE-wide mapping approach

CCE developed a harmonized approach to map $CL_{emp}N$ across large parts of the CLRTAP region. This approach assigns ecosystem-specific $CL_{emp}N$ ranges to ecosystem classes defined in the updated receptor map, which is based on the EUNIS classification system and provides coverages at EUNIS level 1, 2 and 3. The receptor map has a high spatial resolution, which was aggregated to the EMEP grid (0.1° × 0.1°) for use in international-scale assessments. For each grid cell, minimum, maximum, and mid-point $CL_{emp}N$ values were calculated, allowing sensitivity analyses of different protection levels. This harmonized dataset ensures methodological consistency across countries and enables direct integration into integrated assessment models.

Incorporation of national data (CfD 2023/2024)

In parallel, CCE coordinated a Call for Data in which National Focal Centres (NFCs) submitted nationally derived $CL_{emp}N$ datasets. 15 countries participated, applying diverse national methods and choosing different values within the recommended $CL_{emp}N$ ranges. The country reports are published in the annex.

CCE compiled these submissions into a second UNECE-wide dataset by directly integrating national data where available and applying gap-filling procedures elsewhere. Several variants were produced, including area-weighted averages and percentile-based representations, to reflect different interpretations of ecosystem sensitivity.

Comparisons between the harmonized CCE dataset and the NFC-based dataset show that national choices generally result in ecosystem sensitivities that lie between the minimum and mid-point values of the harmonized ranges.

Integrated assessment modelling and ex-post scenario analysis

To support the revision of the Gothenburg Protocol, $CL_{emp}N$ datasets were integrated into the GAINS model used by CIAM. The modelling framework jointly optimizes emission reductions to reduce risks to human health (primarily from fine particulate matter) and to biodiversity (using $CL_{emp}N$ exceedance as an indicator).

A central policy objective tested in the modelling is a collective 50% reduction in risks to both health and biodiversity by 2040, compared to a 2015 baseline. Within the chapter on ex-post-analysis, the report evaluates five main scenarios:

- A 2015 baseline scenario;
- A 2040 current legislation (CLE) scenario;
- A 2040 scenario optimized for health risk reduction (OPT);
- A 2040 scenario optimized jointly for health and biodiversity (OPT_hv);
- A 2040 maximum technically feasible reduction (MTFR) scenario.

Scenario tests demonstrated that the choice of $CL_{emp}N$ values has a strong influence on the apparent attainability of biodiversity targets. Using mid-point $CL_{emp}N$ values, a 50% reduction in Average Accumulated Exceedance (AAE) appears achievable under relatively moderate scenarios. In contrast, when minimum $CL_{emp}N$ values are applied – representing a more precautionary protection level – the same scenarios no longer achieve the target, and remaining exceedance is substantially higher.

Biodiversity risks are assessed using the following two complementary indicators:

- Average Accumulated Exceedance (AAE), representing the intensity of nitrogen deposition above Critical Loads;
- Area at Risk (AAR), representing the proportion of ecosystem area where deposition exceeds $CL_{emp}N$.

Together, these indicators provide both intensity- and area-based perspectives on ecosystem risk.

Across the UNECE region, emission reduction scenarios lead to substantial reductions in $CL_{emp}N$ exceedance compared to the 2015 baseline. The strongest improvements are observed under the OPT_hv and MTFR scenarios, particularly in EU countries. However, results vary regionally. While Western and Central Europe generally show declining risks, some West Balkan and EECCA regions experience smaller improvements or even increases under less ambitious scenarios.

At the ecosystem level, forests, heathlands, wetlands, and coastal ecosystems show pronounced reductions in both AAE and AAR under ambitious scenarios. In contrast, several grassland ecosystem types remain highly sensitive. Even under the MTFR scenario, some grassland ecosystems – such as Mediterranean dry grasslands, Nardus-dominated grasslands, inland sand grasslands, and boreal-alpine grasslands – do not achieve a 50% risk reduction. This indicates that technical emission controls alone may be insufficient and that broader structural changes, such as improved fertilizer management and dietary shifts, may be required.

Mapping SMB-/steady state CL and extension of the BGDB (Chapter 2)

The report summarizes major methodological updates to steady-state and SMB Critical Load modelling, including:

- Adoption of a new harmonized receptor map covering the full UNECE domain;
- Replacement of soil input data with the Harmonized World Soil Database (HWSD);
- Use of globally consistent meteorological data from the CRU dataset, with adapted water balance calculations.

These updates enable consistent Critical Load assessments beyond the EU, particularly in the EECCA region and Turkey, while maintaining compatibility with established modelling approaches.

Harmonized receptor map (published 2023) (Chapter 3)

The receptor map is a core input for Critical Load assessments under the LRTAP Convention, as it provides spatially explicit information on the distribution of ecosystems that are potentially affected by air pollution. The updated receptor map replaces earlier versions that were no longer adequate, particularly because they did not fully cover the extended assessment domain, including the EECCA countries and Turkey. It is based on a harmonized methodological framework and uses the European Nature Information System (EUNIS) classification to represent ecosystems consistently across countries. Ecosystems are mapped at EUNIS levels 1 to 3, allowing both broad-scale assessments and more detailed differentiation between ecosystem types. At EUNIS level 1 and 2, the map provides a comprehensive overview of major ecosystem groups such as forests, grasslands, wetlands, inland surface waters, coastal and marine habitats. At EUNIS level 3, a much finer thematic resolution is achieved, enabling the assignment of ecosystem-specific Critical Loads and critical levels for air pollutants. In total, the receptor map distinguishes more than 200 ecosystem classes. An update carried out in 2024 further refined the classification of freshwater lake ecosystems by introducing regional subdivisions. Overall, the harmonized receptor map provides a robust, transparent, and consistent basis for UNECE-wide assessments of ecosystem sensitivity and is a key prerequisite for reliable evaluations of air pollution impacts on biodiversity.

Mapping and assessing ammonia critical levels (Chapter 4)

For the first time at UNECE scale, the report presents a harmonized mapping of ecosystem Critical Levels for atmospheric ammonia. Sensitivity information derived from EUNIS ecosystem classes and species composition was combined with the receptor map to produce Critical Level maps. Scenario analyses show that ammonia-related risks decrease slightly in much of Western and Central Europe but may increase in parts of the West Balkans, EECCA region, and Turkey. Overall exceedance levels are relatively low, but uncertainties remain high due to coarse model resolution and limitations in ecosystem sensitivity data.

Overall conclusions and policy relevance

The CCE Status Report 2026 provides a comprehensive and policy-relevant assessment of ecosystem risks from nitrogen pollution across the UNECE region. It demonstrates that $CL_{emp}N$ are robust and suitable indicators for evaluating biodiversity risks and for supporting policy decisions under the CLRTAP. Results from integrated assessment modelling show that ambitious emission reduction strategies can substantially reduce risks to ecosystems, particularly when health and biodiversity objectives are addressed jointly. However, the report also demonstrates that current technical emission control measures alone are insufficient to achieve the agreed 50% biodiversity risk-reduction target for all ecosystem types. Highly sensitive ecosystems, especially certain grasslands, remain at risk even under the most ambitious scenarios.

These findings underline the need for a precautionary policy approach, including the use of minimum $CL_{emp}N$ values in international assessments. They also indicate the importance of complementary structural measures, particularly in agriculture, such as improved nitrogen management and reduced fertilizer use, to close the remaining gap between emission reductions and ecosystem protection.

Overall, the report strengthens the scientific basis for the revision of the Gothenburg Protocol and provides clear guidance for integrating biodiversity protection more effectively into air pollution policy across the UNECE region.

Zusammenfassung

Ziele des Berichts

Der CCE-Statusbericht 2026 wurde vom Coordination Centre for Effects (CCE) im Rahmen des UNECE-Übereinkommens über weiträumige grenzüberschreitende Luftverunreinigung (CLR-TAP) erstellt. Ziel ist es, eine wissenschaftlich fundierte und politisch relevante Bewertung der Risiken für Ökosysteme und die biologische Vielfalt durch atmosphärische Stickstoffbelastung und damit verbundene Luftschadstoffe in Europa und der EECCA-Region bereitzustellen. Ein zentrales Anliegen ist die Unterstützung der laufenden Revision des Göteborg-Protokolls durch die Bereitstellung harmonisierter Datensätze, Wirkungsindikatoren und szenariobasierter Bewertungen, die Emissionsminderungen mit messbaren Reduktionen der Biodiversitätsrisiken verknüpfen.

Konkret verfolgt der Bericht folgende Ziele:

- Aktualisierung und Kartierung empirischer kritischer Belastungen für Nährstoffstickstoff ($CL_{emp}N$) im gesamten UNECE-Raum unter Verwendung einer harmonisierten Ökosystem-Rezeptorkarte;
- Veröffentlichung nationaler Berichte und Integration der von den nationalen Programmzentren (NFCs) im Rahmen des Datenaufrufs (Call for Data, CfD) 2023/2024 eingereichten nationalen Daten sowie Bewertung ihrer Implikationen;
- Durchführung von Ex-post-Analysen zukünftiger Emissionsszenarien zur Quantifizierung verbleibender Risiken für Ökosysteme;
- Weiterentwicklung der Steady-State- (Fließgleichgewicht) sowie der Simple-Mass-Balance- (SMB-) Modellierung kritischer Belastungen (Critical Loads, CL) auf ein größeres geografisches Gebiet;
- Entwicklung und Erprobung eines harmonisierten Ansatzes zur Kartierung und Bewertung kritischer Konzentrationen (Critical Levels, CLe) für atmosphärischen Ammoniak.

Insgesamt zielt der Bericht darauf ab, die wissenschaftliche Grundlage für den Schutz von Ökosystemen im Rahmen der europäischen Luftreinhaltepolitik zu stärken und die Ergebnisse zugleich transparent und verständlich sowohl für Wissenschaftlerinnen und Wissenschaftler als auch für eine informierte Öffentlichkeit aufzubereiten.

Umfang und Aufbau

Der Bericht ist in fünf zentrale thematische Komponenten gegliedert. Erstens konzentriert er sich auf die Kartierung und Bewertung von $CL_{emp}N$, einschließlich der Ergebnisse aus dem CfD 2023/2024. Dieser Teil dokumentiert sowohl einen vom CCE entwickelten harmonisierten, UNECE-weiten Ansatz als auch einen alternativen Datensatz, der nationale Entscheidungen der NFCs widerspiegelt. Zweitens wird kurz beschrieben, wie $CL_{emp}N$-Datensätze in der integrierten Bewertungsmodellierung (Integrated Assessment Modelling, IAM) zur Optimierung von Emissionsminderungsstrategien für die menschliche Gesundheit und die biologische Vielfalt eingesetzt werden. Drittens präsentiert der Bericht detaillierte Ex-post-Analysen, die bewerten, wie sich unterschiedliche Emissionsszenarien für 2040 auf die Überschreitung von $CL_{emp}N$ und die damit verbundenen Biodiversitätsrisiken auswirken. Viertens werden Fortschritte bei der Kartierung von SMB-/Steady State Critical Loads für Versauerung und Eutrophierung dokumentiert, einschließlich wesentlicher Aktualisierungen der Rezeptorkarte, der Bodendaten und der meteorologischen Eingangsdaten sowie der Ausdehnung des Modellierungsrahmens auf die EECCA-Region und die Türkei. Schließlich stellt der Bericht einen harmonisierten Ansatz zur Kartierung und Bewertung kritischer Konzentrationen für atmosphärischen Ammoniak (NH_3) vor und bewertet ammoniakbedingte Ökosystemrisiken unter zukünftigen Szenarien. Im Anhang sind alle nationalen Berichte der nationalen Programmzentren zu den an CCE übermittelten Datenaufrufen veröffentlicht.

Kartierung und Bewertung empirischer kritischer Belastungen für Nährstoffstickstoff ($CL_{emp}N$) (Kapitel 1)

$CL_{emp}N$ stellen Depositionsschwellen dar, oberhalb derer schädliche Wirkungen auf Ökosysteme wahrscheinlich auftreten. Diese Wirkungen stehen in erster Linie mit dem Verlust biologischer Vielfalt in Zusammenhang, etwa mit Rückgängen der Pflanzenartenvielfalt, Verschiebungen der Artenzusammensetzung sowie dem Rückgang oligotropher und charakteristischer Arten. $CL_{emp}N$-Werte werden aus langfristigen empirischen Studien abgeleitet und als Wertebereiche angegeben, um ökologische Variabilität und methodische Unsicherheiten abzubilden.

Die jüngste Aktualisierung der $CL_{emp}N$, veröffentlicht im Jahr 2022, liefert Wertebereiche für 51 europäische Ökosystemtypen, mit Spannweiten von etwa 2 bis 30 kg N ha^{-1} a^{-1}. Auf Grundlage wissenschaftlicher Bewertungen und politischer Diskussionen im Rahmen des CLRTAP gelten $CL_{emp}N$ inzwischen als besonders geeignete Indikatoren für biodiversitätsbezogene Auswirkungen der Stickstoffbelastung.

Harmonisierter UNECE-weiter Kartierungsansatz

Das CCE entwickelte einen harmonisierten Ansatz zur Kartierung von $CL_{emp}N$ über große Teile des CLRTAP-Gebiets. Dieser Ansatz ordnet ökosystemspezifische $CL_{emp}N$-Bereiche Ökosystemklassen zu, die in der aktualisierten Rezeptorkarte definiert sind. Diese basiert auf dem EUNIS-Klassifikationssystem und stellt Flächenabdeckungen auf den EUNIS-Ebenen 1, 2 und 3 bereit. Die Rezeptorkarte weist eine hohe räumliche Auflösung auf, die für internationale Bewertungen auf das EMEP-Raster (0,1° × 0,1°) aggregiert wurde. Für jede Rasterzelle wurden minimale, maximale und mittlere $CL_{emp}N$-Werte berechnet, um Sensitivitätsanalysen unterschiedlicher Schutzniveaus zu ermöglichen. Dieser harmonisierte Datensatz gewährleistet methodische Konsistenz zwischen den Ländern und erlaubt die direkte Integration in integrierte Bewertungsmodelle.

Einbeziehung nationaler Daten (CfD 2023/2024)

Parallel dazu koordinierte das CCE einen Datenaufruf, in dessen Rahmen Nationale Fokuszentren (NFCs) national abgeleitete $CL_{emp}N$-Datensätze einreichten. 15 Länder beteiligten sich und wendeten unterschiedliche nationale Methoden an sowie verschiedene Werte innerhalb der empfohlenen $CL_{emp}N$-Bereiche. Die Länderberichte sind im Anhang veröffentlicht.

Das CCE erstellte aus den nationalen Datensätzen einem zweiten UNECE-weiten Datensatz. Sofern keine nationalen Daten verfügbar waren, wurden die Lücken durch CCE-Daten aufgefüllt. Es wurden mehrere Varianten erstellt, darunter flächengewichtete Mittelwerte und perzentilbasierte Darstellungen, um unterschiedliche Interpretationen der Ökosystemempfindlichkeit widerzuspiegeln.

Vergleiche zwischen dem harmonisierten CCE-Datensatz und dem NFC-basierten Datensatz zeigen, dass nationale Entscheidungen im Allgemeinen zu Ökosystemempfindlichkeiten führen, die zwischen den Minimal- und den Mittelwerten der harmonisierten Bereiche liegen.

Integrierte Bewertungsmodellierung und Ex-post-Szenarioanalyse

Zur Unterstützung der Revision des Göteborg-Protokolls wurden $CL_{emp}N$-Datensätze in das von CIAM genutzte GAINS-Modell integriert. Die Optimierungsberechnungen mit dem GAINS-Modell wurden gemeinsam für die Emissionsminderungen zur Verringerung von Risiken für die menschliche Gesundheit (vor allem durch Feinstaub) und für die biologische Vielfalt (unter Verwendung der $CL_{emp}N$-Überschreitung als Indikator) durchgeführt.

Ein zentrales politisches Ziel, das in der Modellierung geprüft wurde, ist eine kollektive Reduktion der Risiken für Gesundheit und Biodiversität um 50 % bis 2040 gegenüber dem Basisjahr 2015. Im Kapitel zur Ex-post-Analyse werden fünf Hauptszenarien bewertet:

- ein Basisszenario 2015;
- ein Szenario „aktuelle Gesetzgebung“ (CLE) für 2040;
- ein auf Gesundheitsrisikominderung optimiertes Szenario für 2040 (OPT);
- ein gemeinsam auf Gesundheit und Biodiversität optimiertes Szenario für 2040 (OPT_hv);
- ein Szenario der maximal technisch machbaren Reduktion (MTFR) für 2040.

Die Szenariotests zeigen, dass die Wahl der $CL_{emp}N$-Werte einen starken Einfluss auf die scheinbare Erreichbarkeit von Biodiversitätszielen hat. Bei Verwendung mittlerer $CL_{emp}N$-Werte erscheint eine Reduktion der durchschnittlich akkumulierten Überschreitung (Average Accumulated Exceedance, AAE) um 50 % unter vergleichsweise moderaten Szenarien erreichbar. Werden hingegen minimale $CL_{emp}N$-Werte angewandt – die ein vorsorglicheres Schutzniveau repräsentieren –, so wird dasselbe Ziel mit diesen Szenarien nicht mehr erreicht und die verbleibenden Überschreitungen sind deutlich höher.

Biodiversitätsrisiken werden anhand zweier komplementärer Indikatoren bewertet:

- Average Accumulated Exceedance (AAE), die die Intensität der Stickstoffdeposition oberhalb der kritischen Belastungen beschreibt;
- Area at Risk (AAR), die den Anteil der Ökosystemfläche angibt, in dem die Deposition $CL_{emp}N$ überschreitet.

Gemeinsam liefern diese Indikatoren sowohl eine intensitäts- als auch eine flächenbezogene Perspektive auf Ökosystemrisiken.

Im gesamten UNECE-Raum führen Emissionsminderungsszenarien zu erheblichen Reduktionen der $CL_{emp}N$-Überschreitung im Vergleich zum Basisjahr 2015. Die stärksten Verbesserungen werden unter den Szenarien OPT_hv und MTFR beobachtet, insbesondere in EU-Ländern. Die Ergebnisse variieren jedoch regional. Während West- und Mitteleuropa generell sinkende Risiken aufweisen, zeigen einige Regionen des westlichen Balkans und der EECCA unter weniger ambitionierten Szenarien geringere Verbesserungen oder sogar Zunahmen.

Auf Ökosystemebene zeigen Wälder, Heiden, Feuchtgebiete und Küstenökosysteme unter ambitionierten Szenarien deutliche Rückgänge sowohl bei AAE als auch bei AAR. Im Gegensatz dazu bleiben mehrere Grasland-Ökosystemtypen hoch empfindlich. Selbst unter dem MTFR-Szenario erreichen einige Graslandökosysteme – etwa mediterrane Trockenrasen, von Nardus dominierte Grasländer, Binnendünen-Grasländer sowie boreal-alpine Grasländer – keine Reduktion der Risiken um 50 %. Dies weist darauf hin, dass technische Emissionsminderungen allein möglicherweise nicht ausreichen und breitere strukturelle Veränderungen, etwa ein verbessertes Düngemanagement und Ernährungsumstellungen, erforderlich sein könnten.

Kartierung von SMB-/Steady State Critical Loads und Erweiterung der BGDB (Kapitel 2)

Der Bericht fasst wesentliche methodische Aktualisierungen der Modellierung von SMB-/Steady State Critical Loads zusammen, darunter:

- die Einführung einer neuen harmonisierten Rezeptorkarte, die den gesamten UNECE-Raum abdeckt;
- der Ersatz der Bodeneingangsdaten durch die Harmonized World Soil Database (HWSD);
- die Verwendung global konsistenter meteorologischer Daten aus dem CRU-Datensatz mit angepassten Wasserbilanzberechnungen.

Diese Aktualisierungen ermöglichen konsistente Bewertungen kritischer Belastungen über die EU hinaus, insbesondere in der EECCA-Region und in der Türkei, bei gleichzeitiger Wahrung der Kompatibilität mit etablierten Modellierungsansätzen.

Harmonisierte Rezeptorkarte (veröffentlicht 2023) (Kapitel 3)

Die Rezeptorkarte ist eine zentrale Eingangsgröße für die Bewertung kritischer Belastungen im Rahmen des LRTAP-Übereinkommens, da sie räumlich explizite Informationen über die Verteilung potenziell durch Luftverschmutzung betroffener Ökosysteme liefert. Die aktualisierte Rezeptorkarte ersetzt frühere Versionen, die insbesondere aufgrund der fehlenden vollständigen Abdeckung des erweiterten Bewertungsgebiets – einschließlich der EECCA-Länder und der Türkei – nicht mehr ausreichend waren. Sie basiert auf einem harmonisierten methodischen Rahmen und nutzt die Klassifikation des Europäischen Naturinformationssystems (EUNIS), um Ökosysteme länderübergreifend konsistent darzustellen. Die Ökosysteme sind auf den EUNIS-Ebenen 1 bis 3 kartiert, was sowohl großräumige Bewertungen als auch eine detailliertere Differenzierung zwischen Ökosystemtypen ermöglicht. Auf den EUNIS-Ebenen 1 und 2 bietet die Karte einen umfassenden Überblick über große Ökosystemgruppen wie Wälder, Grasländer, Feuchtgebiete, Binnengewässer sowie Küsten- und Meereslebensräume. Auf EUNIS-Ebene 3 wird eine deutlich feinere thematische Auflösung erreicht, die die Zuordnung ökosystemspezifischer kritischer Belastungen und kritischer Konzentrationen für Luftschadstoffe ermöglicht. Insgesamt unterscheidet die Rezeptorkarte mehr als 200 Ökosystemklassen. Eine im Jahr 2024 durchgeführte Aktualisierung verfeinerte zudem die Klassifikation von Süßwasserseen durch die Einführung regionaler Unterteilungen. Insgesamt bietet die harmonisierte Rezeptorkarte eine robuste, transparente und konsistente Grundlage für UNECE-weite Bewertungen der Ökosystemempfindlichkeit und ist eine zentrale Voraussetzung für verlässliche Einschätzungen der Auswirkungen von Luftverschmutzung auf die biologische Vielfalt.

Kartierung und Bewertung kritischer Konzentrationen für Ammoniak (Kapitel 4)

Erstmals auf UNECE-Ebene präsentiert der Bericht eine harmonisierte Kartierung ökosystembezogener kritischer Konzentrationen für atmosphärisches Ammoniak. Sensitivitätsinformationen aus EUNIS-Ökosystemklassen und zur Artenzusammensetzung wurden mit der Rezeptorkarte kombiniert, um Karten kritischer Konzentrationen zu erstellen. Szenarioanalysen zeigen, dass ammoniakbedingte Risiken in weiten Teilen West- und Mitteleuropas leicht abnehmen, in Teilen des westlichen Balkans, der EECCA-Region und der Türkei jedoch zunehmen könnten. Insgesamt sind die Überschreitungsniveaus relativ gering, die Unsicherheiten bleiben jedoch hoch, aufgrund der groben Modellauflösung und der vorahndenen Einschränkungen in den Daten zur Ökosystemempfindlichkeit.

Gesamtfazit und politische Relevanz

Der CCE-Statusbericht 2026 liefert eine umfassende und politisch relevante Bewertung der Risiken für Ökosysteme durch Stickstoffbelastung im gesamten UNECE-Raum. Er zeigt, dass $CL_{emp}N$ robuste und geeignete Indikatoren zur Bewertung von Biodiversitätsrisiken und zur Unterstützung politischer Entscheidungen im Rahmen des CLRTAP sind. Die Ergebnisse der integrierten Bewertungsmodellierung verdeutlichen, dass ambitionierte Emissionsminderungsstrategien die Risiken für Ökosysteme deutlich reduzieren können, insbesondere wenn Gesundheits- und Biodiversitätsziele gemeinsam verfolgt werden. Gleichzeitig zeigt der Bericht jedoch, dass die derzeitigen technischen Emissionsminderungsmaßnahmen allein nicht ausreichen, um das vereinbarte Ziel einer Reduktion der Biodiversitätsrisiken um 50 % für alle Ökosystemtypen zu erreichen. Hoch empfindliche Ökosysteme, insbesondere bestimmte Graslandtypen, bleiben selbst unter den ambitioniertesten Szenarien gefährdet.

Diese Ergebnisse unterstreichen die Notwendigkeit eines vorsorgenden politischen Ansatzes, einschließlich der Verwendung minimaler $CL_{emp}N$-Werte in internationalen Bewertungen. Sie verdeutlichen zudem die Bedeutung ergänzender struktureller Maßnahmen, insbesondere in der Landwirtschaft, wie eines verbesserten Stickstoffmanagements und einer Reduktion des Düngemitteleinsatzes, um die verbleibende Lücke zwischen Emissionsminderungen und Ökosystemschutz zu schließen.

Insgesamt stärkt der Bericht die wissenschaftliche Grundlage für die Revision des Göteborg-Protokolls und liefert klare Leitlinien für eine wirksamere Integration des Biodiversitätsschutzes in die Luftreinhaltepolitik im gesamten UNECE-Raum.

1 Mapping and assessment of Empirical Critical Loads ($CL_{emp}N$), including results of the CfD 2023/2024

1.1 Introduction

Empirical Critical Loads ($CL_{emp}N$) were first presented in a background document for a workshop in 1992 in Sweden (Grennfelt & Thörnelöf, 1992). Since then, the data has been updated four times (Bobbink et al. (1996); Achermann and Bobbink (2003); Bobbink and Hettelingh (2011)). The most recent updated was published by the Coordination Center for Effects (CCE) under lead-authorship of Roland Bobbink (Bobbink et al., 2022). In this report $CL_{emp}N$ ranges are given for in total 51 European ecosystems. Recommended ecosystem specific $CL_{emp}N$ values are given in ranges reflecting differences in e.g. methods, conditions and observations in the different empirical studies which had been evaluated. The values vary between 2- 30 kg N ha^{-1} a^{-1}. In nearly all ecosystems the indication of exceedance of the recommended $CL_{emp}N$ value is related to biodiversity (e.g. change in plant species richness or in plant species composition, decrease in oligotrophic species, increase in productivity species or decline of typical species and in diversity). Acknowledging that $CL_{emp}N$ are used in the nature conservation practice in many European countries to assess the conservation status and the relevance of threat factors for endangered habitats and despite uncertainties laying e.g. in the fairly broad ecosystem specific ranges instead of explicit values, the patchy coverage of European ecosystem types and in the difficulties for large-scale accurate mapping for risk assessment, the report recommends that $CL_{emp}N$ are a suitable indicator to identify risks to biodiversity at the ecosystem level, which can be linked to policy-relevant biodiversity targets.

This recommendation has also been presented to the Joint Thematic Session of Air pollution effects on biodiversity at the 9th Joint Session of the EMEP Steering Body and the Working Group on Effects, 11-15 September 2023 (UNECE Working Group on Effects, 2023). The Steering Body and the Working Group noted that the updated $CL_{emp}N$ are expected to be better linked to biodiversity than mass balance based Critical Loads and recommended them to be used for European Assessment. Following that and executing the Convention's Workplan 2024-2025 item 1.1.1.22, CCE developed an approach to map $CL_{emp}N$ across the domain of the CLRTAP region for Europe and EECCA countries (CLRTAP domain) using and applying the updated, harmonized receptor map (Gebhardt, 2023). The resulting data has been transferred to the Center for Integrated Assessment (CIAM) in March 2024, which uses it for different scenario calculations to support the revision of the Gothenburg Protocol.

At the same time, as a follow-up to the publication of the latest update of $CL_{emp}N$, National Focal Centers (NFC) of the ICP Modelling & Mapping (ICP M&M) were invited to participate in a Call for Data (CfD) 2023-2024 on $CL_{emp}N$, which had been agreed at the 38th meeting of the ICP M&M Task Force on 3–5 May 2022 (CCE, 2024a). In total 15 NFC responded to the last CfD. The results of this Call were reported to CCE in spring 2024 with updates in autumn 2024 and discussed at the 40th and 41st meetings of the ICP M&M Task Force in Oslo and in Helsinki. The TF M&M meetings acknowledged that countries applied different methods for the mapping and differently decided to use specific values within the range of $CL_{emp}N$. After the Helsinki meeting in February 2025 the ICP M&M Task Force asked CCE to use NFC data for UNECE wide mapping of $CL_{emp}N$ and recommended the NFC-data for application in the integrated assessment modelling for optimisation to support the revision of the Gothenburg Protocol. However, after discussion at the EMEP/WGE Bureaux meeting in Ljubljana in May 2025, at the Meeting of the Task Force on Integrated Assessment Modelling in Laxenburg in April 2025 and at the Meeting of the Working

Group on Strategies and Review in May 2025 it was decided to use the NFC-data for ex-post-analysis only(see chapter 1.4.1 of this report).

In this chapter, the different methods and $CL_{emp}N$ maps and datasets prepared by CCE are described in a condensed way. The objective is to illustrate, document and discuss the different datasets developed and provided to support the revision of the Gothenburg Protocol.

1.2 Mapping $CL_{emp}N$

1.2.1 Harmonized, UNECE-wide approach

To create the maps of the $CL_{emp}N$, the established values from Bobbink et al. (2022) were assigned to the mapped EUNIS classes of the harmonized and updated receptor map (Gebhardt, 2023). Further details are provided in chapter 3.

The current receptor map covers Europe, the EECCA region and Turkey representing an extended geographical scope. The map is based on a harmonized methodology for deriving information on the spatial distribution of ecosystems as well as other land-use types (e.g. man-made structures). In total 223 different classes based on the EUNIS classification system[1], up to level 3 detail can be destingushed. The spatial resolution of the current receptor map is about 100 x 100 m, which is too fine for the purpose of mapping Critical Loads and Critical Load exceedances at an international scale. Therefore, the receptor information was aggregated to the spatial resolution of the EMEP grid, which is defined by grid cells of 0.1x0.1 degree in the longitude/latitude coordinate system. For a visual evaluation and further details on this receptor map, reference is made to chapter 3 of this report.

Although the precise location of individual raster cells extracted from the original receptor map is lost during this aggregation step, the aggregated receptor information remains fully representative at the EMEP grid-cell level. In particular, information on which receptor types are present and their proportional contribution within each EMEP grid cell is preserved. In this context, a “single record” refers to the aggregated information for each relevant EUNIS class within an EMEP grid cell, including its summarised area-based weight (absolute and relative).

To be able to assign the existing $CL_{emp}N$ to the receptor map, the main table with $CL_{emp}N$ reported by Bobbink et al. (2022) was slightly adapted in order to allow a unique attribution of the published Critical Load ranges to the mapped EUNIS class in the receptor map. This adaptation did not change any level of sensitivity, but in some cases rows with aggregated information for several EUNIS classes were divided into single data records. The resulting table describes $CL_{emp}N$ for 62 different EUNIS classes which. In the last step this table was linked to the mapped EUNIS classes from the receptor map, resulting in a list of 50 EUNIS classes from the receptor map for which a $CL_{emp}N$ could be assigned (Table 14). This linking created a database containing information on the EUNIS class, the $CL_{emp}N$ as a range, the area covered by the EUNIS class and the corresponding EMEP grid cell. The mapping of these results shows a quite comprehensive coverage of natural and semi-natural ecosystems within the mapped area. In total, there are about 1.47 million ecosystem records. Only about 9 % of the EMEP grid cells appear white in the maps shown below, which means that either no natural or semi-natural ecosystem was mapped in the receptor map or the mapped ecosystem could not be linked to the $CL_{emp}N$ table. However, the percentage area with natural or semi-natural ecosystems in all EMEP grid cell is on average 64 % and varies between 0.02 % to 100 %.

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[1] https://eunis.eea.europa.eu/habitats.jsp

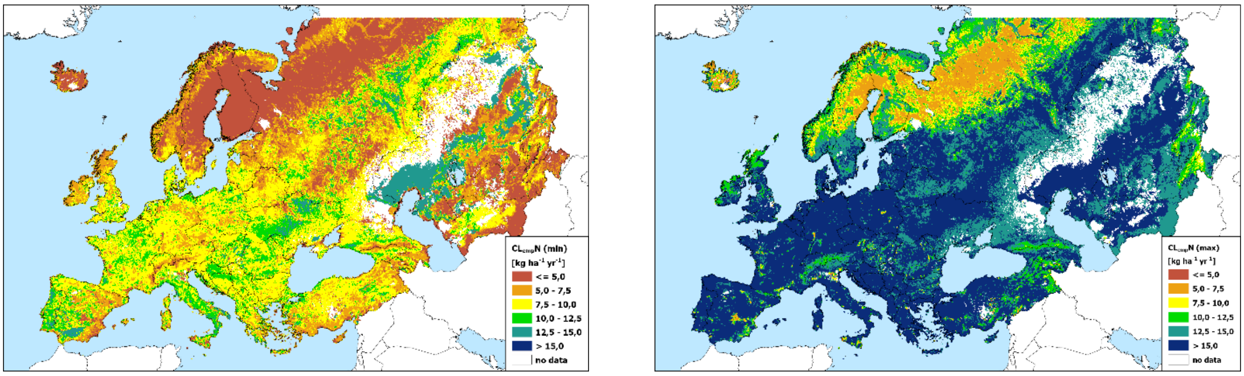
The final step involved processing the collected information and aggregating it on the basis of the EMEP grid cells. As it is not possible to directly aggregate the previously assigned ranges of the $CL_{emp}N$ and display them in a single map, three variations of maps and datasets are produced, using the minimum, the mid-point and the maximum values of the $CL_{emp}N$ ranges. In each of the three variations the selected values were assigned to the roughly 1.47 million individual ecosystem records. To display the them in a map on the basis of EMEP grid cells in each of the variations all minimum- mid-point- and maximum-values were aggregated on an area-weighted basis for each individual EMEP grid cell. This resulted in three data sets:

1. a map reflecting the area-weighted average of all minimum values of the $CL_{emp}N$ ranges (Figure 1 A)
2. a map reflecting the area-weighted average of all mid-point values of the $CL_{emp}N$ ranges (Figure 1 B)
3. a map reflecting the area-weighted average of all maximum values of the $CL_{emp}N$ ranges (Figure 1 C)

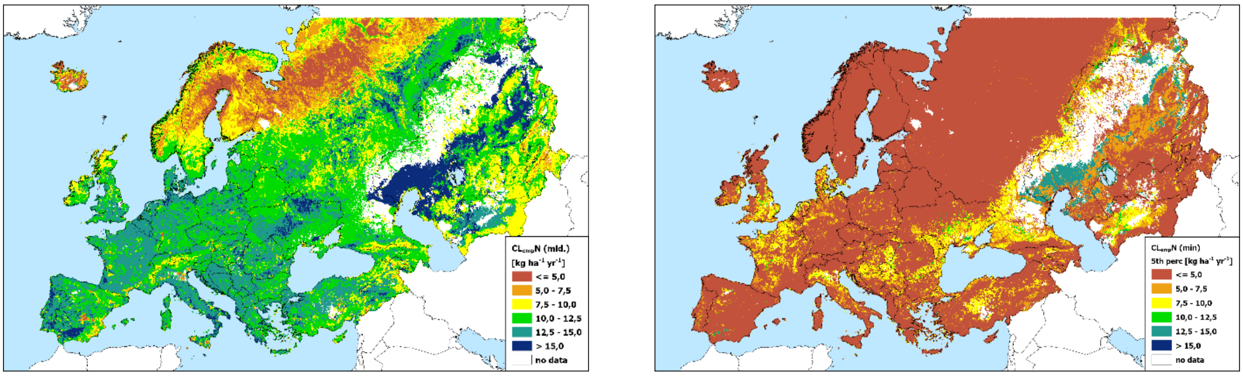
Note that exceedance calculations are not based on comparing the grid-cell deposition value with an area-weighted average of all Critical Load (CL) values within the grid cell. Instead, exceedances are calculated separately for each individual record (e.g. ecosystem type) within a grid cell by comparing the grid-cell-specific deposition to the corresponding CL value. The resulting individual exceedances are then aggregated to derive the Area-Accumulated Exceedance (AAE) for the grid cell.

Figure 1 A reflects the most precautionary of the three approaches described, following the recommendations of the latest report on $CL_{emp}N$ (Bobbink et al., 2022). The report states, that "*for broad regional scale assessments, it is proposed to use the minimum value of the ranges of* $CL_{emp}N$ *in each EUNIS class to enable comparison of their exceedances between different air pollution abatement scenarios*". With this dataset using the area weighted average of all minimum values for each EUNIS class a map is produced displaying the largest sensitivity of biodiversity towards nitrogen deposition across Europe and the EECCA region. Using this map in risk assessments e.g. within the integrate assessment scenario runs means applying most ambitious protection targets to guarantee the protection of the biodiversity of ecosystems. Note that for the purpose of displaying, an even more precautionary presentation of data is thinkable, e.g. by displaying the 5th percentile of the minimum values instead the area weighted average (Figure 1 D).

Figure 1 $CL_{emp}N$ on the basis of the CCE receptor map: A, B & C: displaying the area-weighted average of all values within an EMEP grid cell (A – minimum of CL range; B – mid-point of CL range and C – maximum of CL range); D: displaying the 5th percentile of all minimum values of the CL range within an EMEP grid cell


A: area weighted average of all minimum CL values

C: area weighted average of all maximum CL values


B: area weighted average of all mid-point CL values

D: 5th percentile of all minimum CL values

Source: own illustration, CCE/UBA

1.2.2 Approach reflecting NFC-submitted data for the mapping of $CL_{emp}N$

In the report on $CL_{emp}N$, countries are advised to identify the highly sensitive receptor ecosystems within the EUNIS classification relating to their national interest and available knowledge. Therefore, in 2023 ICP Modelling & Mapping launched a Call for Data asking National Focal Centers (NFC) to apply the $CL_{emp}N$ on their territories[2]. 15 NFC (14 countries because Belgium has 2 NFC) replied to the CfD and delivered national $CL_{emp}N$ data sets. Differences to the UNECE wide approach (chapter 1.2.1) lay in the use of national receptor maps (for example NFC selected only forest ecosystems or only Natura 2000 areas, or applied a national ecosystem distribution map) or in the assignment of CL-values to other EUNIS classes than the 51 listed in Bobbink et al. (2022). Also, NFC were asked to define a specific CL within the CL-range to each ecosystem type. The choices for an upper, lower or the mid-point value of the ranges of the different EUNIS classes are NFC-specific and vary from each other. The summarized results of the 15 responses to the call for data are documented in Annex 2: NFC Response to the Call for Data 2023/24. The country reports themselves are documented in Annex 3: Country Reports CfD 23/24 $CL_{emp}N$. The submissions were discussed the 40th and 41st meeting of the ICP M&M Task Force in Oslo (2024) and Helsinki (2025). It was identified that large parts of the UNECE-region were not covered by NFC responses and that NFCs used various approaches in assigning CL-values to individual ecosystems. As a result of the discussions, the TF M&M meeting asked CCE to use the EUNIS class specific average values of NFC-submitted data (not area-weighted!) as an alternative way for

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[2] https://www.umweltbundesamt.de/en/call-for-data?parent=68310

gap-filling (NFC choices) and harmonized mapping of $CL_{emp}N$ to the one described in chapter 1.2.1. The mapping of NFC submitted data was done in two ways. First the NFC data was integrated in the UNECE-wide map directly, leading to a patchy picture (chapter, 1.2.2.1). Second, the NFC data was reflected in a harmonized map by averaging the NFC choices (chapter 1.2.2.2).

1.2.2.1 Direct integration of national CL data

As a first step, the NFC data from the 14 countries that responded to the call for data were integrated directly into the UNECE-wide dataset without any substantial alteration of the original information. Apart from necessary aggregations for presentation and mapping purposes, as well as minor harmonisation steps required for the statistical analysis (e.g. recoding of EUNIS classes), the results shown for these countries reflects 100% of the data as provided by the NFCs (Figure 2 A). This approach follows the NFCs' request to have their national decisions and data mappings represented directly. In doing so, national data resources and country-specific scientific knowledge on ecosystem sensitivity are explicitly acknowledged. For countries that did not provide national data, established gap-filling procedures were applied.

To illustrate the spatial pattern of $CL_{emp}N$ ranges, it was done with the mid-point $CL_{emp}N$ values (Figure 2 B) and with the minimum values (Figure 2 C) of the harmonized $CL_{emp}N$ data as described in chapter 1.2.1. A certain lack of consistency can be clearly seen in the latter both maps. There are clearly visible border effects in different regions, e.g. between Spain and Portugal or Germany and Austria. The differences are less pronounced, when the gap filling is done with the minimum $CL_{emp}N$ values, which reflects that also most of the NFC tend to choose the minimum end of the ranges for precautionary reasons. In this case, the differences in the border regions between the Netherlands and Germany and Denmark and the border region between France and Belgium are pronounced. Instead, using the mid-point-dataset for gap-filling highlights differences in the border regions between Portugal and Spain and France and Spain and Italy. While these effects are largely due to the fact that the NFCs have chosen different levels of ambition, other undesirable visual effects are also clearly visible. These effects arose, for example, from a lack of spatial coverage, missing data for certain parts of the country and rounding errors in the transmitted location coordinates. Nevertheless, it was also shown by NFC that national mapping of receptors and $CL_{emp}N$ data can be sometimes more reliable and significantly different compared to harmonised aroach of the CCE. For example, in Norway a larger share of the sensitive ecosystem Dark Taiga coniferous forest (3 kg ha^{-1} a^{-1}) is assumed. On average, those assumptions result in more precautionary national data on average across the entire country compared to the harmonized CCE data (minimum) (Annex C.10), while the Spanish NFC developed a complex, national way of receptor mapping resulting in a greater coverage of sensitive grassland (R) ecosystems (Annex C.12). Conversely, in some countries, the opposite is true. In Germany, the Netherlands, and Poland, for example, the sensitivity of ecosystems is slightly reduced by the national data provided.

1.2.2.2 National choices of applying the $CL_{emp}N$ range used for gap-filling

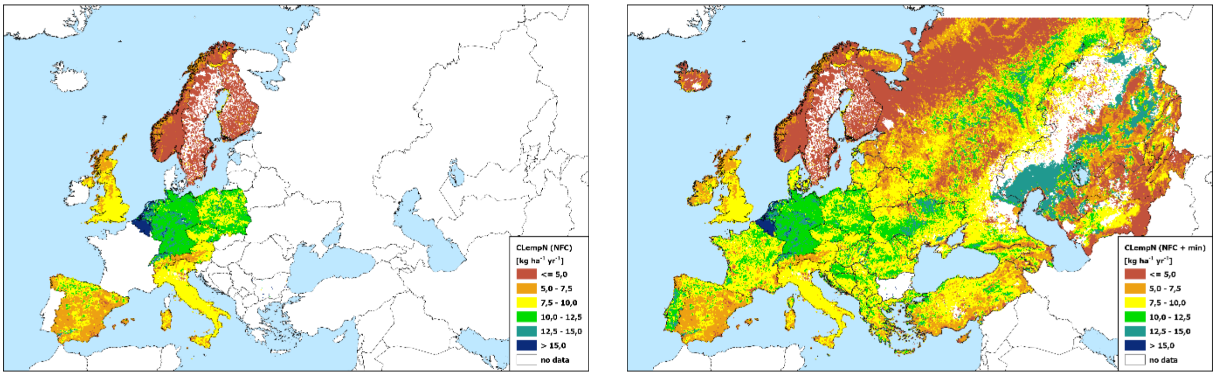
The country data reported by NFC was also used to establish a further harmonized $CL_{emp}N$ dataset to be used with the receptor map across the whole CLRTAP domain or for gap-filling in those countries, which didn't report national $CL_{emp}N$ data. The procedure for harmonizing the $CL_{emp}N$ datasets from 15 NFCs, was defined together with the NFCs at the 40th ICP M&M Task Force Meeting in Oslo (2024). It was agreed, that for each EUNIS class present in the original list of $CL_{emp}N$, the national choices of selecting a value of the given ranges according to Bobbink et al. (2022) (NFC choice) were evaluated and combined by calculating the arithmetic average (not area weighted). Therefore, the processing was done only with the 62 EUNIS classes present in the list of $CL_{emp}N$ used for the harmonized approach (chapter 1.2.1). This means, that $CL_{emp}N$ provided by the NFCs for EUNIS classes not present in the original list of $CL_{emp}N$ were not further processed for this harmonization. For those EUNIS classes, where no NFC data was available, the minimum value of $CL_{emp}N$ range was used. Through the averaging harmonization, the NFC choices were reflected uniformly and made applicable to the rest of the CLRTAP domain.

The calculated average values based on NFC choices are displayed in Table 16 in comparison to the original mid-point values of the original range. The resulting maps are shown in Figure 3 A-D. The data shown in maps B-D, i.e. NFC data with gap-filling based on NFC choices, is used for ex-post analysis (see chapter 1.4.1). Comparing the harmonized maps based on the CCE approach (Figure 1 A-B) with those resulting from the NFC choices approach (Figure 3 A), it appears that the sensitivity of the ecosystems according to the NFC choices approach can be located somewhere between the minimum and mid-point values mapped and described in chapter 1.2.1. For further analysis please also consult chapter 1.5 “discussion and conclusion”.

Figure 2 **$CL_{emp}N$ on the basis of NFC data delivery and the CCE gap filling: A: NFC data without CCE gap-filling; B – D: NFC data with CCE gap-filling (B: using the mid-point of harmonized CLempN; C-D: using the minimum of harmonized CLempN); (A-C: displaying the area weighted average of all CL values in one EMEP grid cell; D: displaying the 5th percentile of all CL values in one EMEP grid cell)**

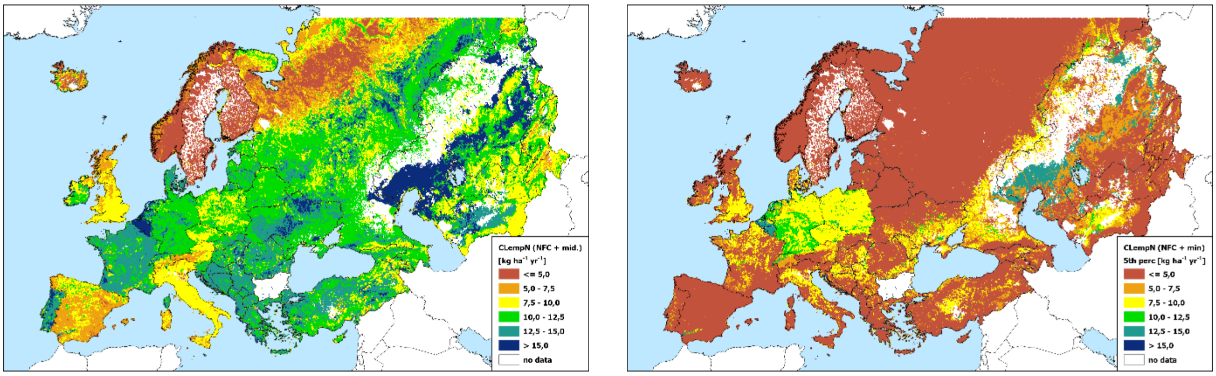
A: NFC data without CCE gap-filling in each grid area weighted average of all CL values shown

C: NFC data with CCE gap-filling ($CL_{emp}N$ minimum) in each grid area weighted average of all CL values shown



B: NFC data with CCE gap-filling ($CL_{emp}N$ mid-point) in each grid area weighted average of all CL values shown

D: NFC data with CCE gap-filling ($CL_{emp}N$ minimum) in each grid 5th percentile of all CL values shown

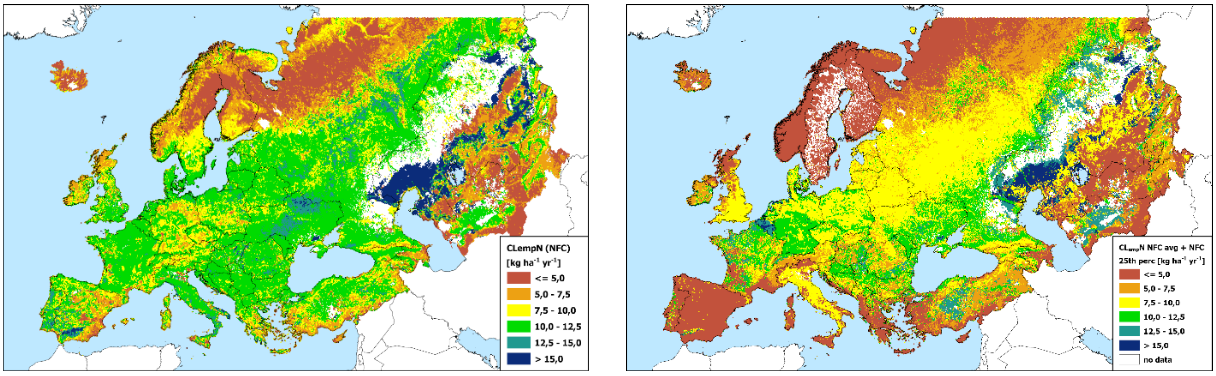


Source: own illustration, CCE/UBA

Figure 3 $CL_{emp}N$ on the basis of NFC data and the NFC choices gap filling: A: harmonized $CL_{emp}N$ based on the NFC choices approach mapped uniformly with the receptor map, B – D: NFC data with gap-filling based on the NFC choices approach (displaying in each EMEP grid the area-weightes average of all CL values (B), the 25th percentile of all CL values (C) and the 5th percentile of all CL values (D).

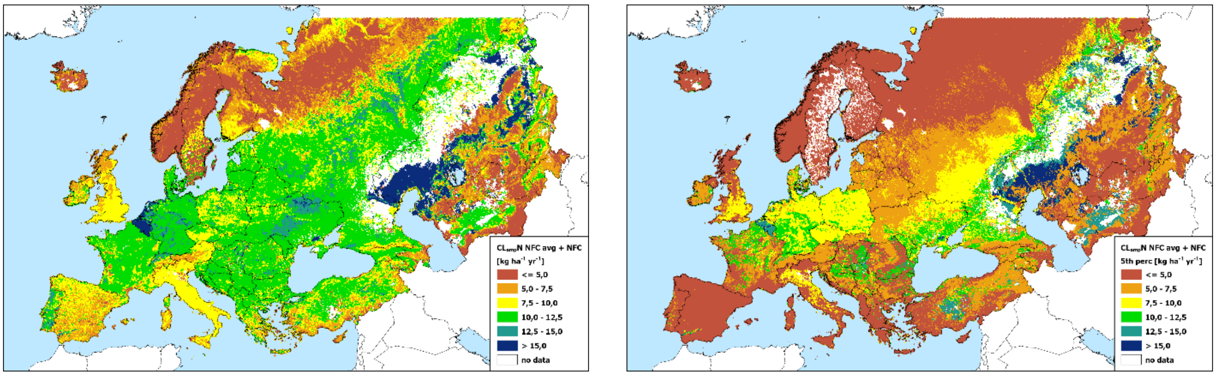
A: harmonized $CL_{emp}N$ based on the NFC choices approach in each grid area-weighted average of all CL values shown

C: NFC data with gap-filling based on NFC choices - in each grid 25th percentile of all CL values shown



B: NFC data with gap-filling based on NFC choices - in each grid area weighted average of all CL values shown

D: NFC data with gap-filling based on NFC choices - in each grid 5th percentile of all CL values shown



Source: own illustration, CCE/UBA

1.3 Integrated Assessment Modelling to optimize for risks for biodiversity

For the revision of the Gothenburg Protocol the Task Force on Integrated Assessment Modelling (TFIAM) and the EMEP Centre for Integrated Assessment Modelling (CIAM) investigated the potential implications of introducing collective risk-based goals for the UNECE region to address air pollution impacts on health and ecosystems. With that they fulfilled Workplan item 2.1.12 of the CLRTAP commom workplan for the years 2024-2025. Rational, methods and assessment results are documented in an informal document (policy brief) published by both TFIAM and CIAM (TFIAM & CIAM, 2025) with contributions of CCE.

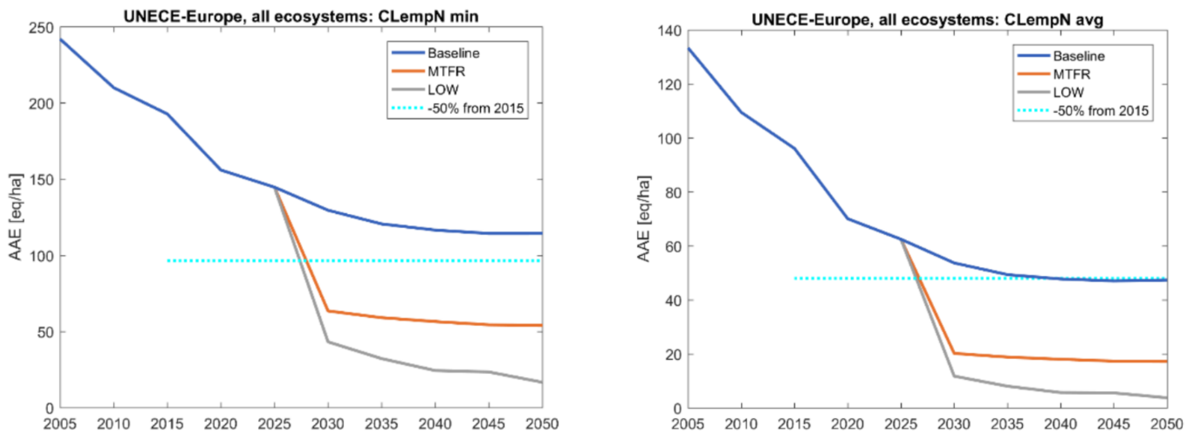
The optimization calculations with the GAINS model were done collectively for human health and biodiversity. That means that for both subjects of protection the overall goals to reduce risks by 50 % were taken as a guiding principle to calculate cost-effective emission scenarios. For biodiversity the $CL_{emp}N$ were used as an indicator. For that CCE provided the $CL_{emp}N$ dataset which is based on the UNECE-wide harmonized approach and described in chapter 1.2.1. to CIAM. The data delivery comprised the minimum $CL_{emp}N$- and the maximum $CL_{emp}N$-data. CIAM itself of both datasets was able to calculate the averge, which is identical to the above-mentioned mid-point values. For calculations in GAINS, CIAM uses the datset consisting of 50 receptor EUNIS classes classes for which a $CL_{emp}N$ could be assigned (Table 14).

CIAM together with WGE decided to use the AAE of Critical Loads in a grid cell as an indicator to evaluate the attainability of 50% risk reduction for biodiversity. With this approach the exceedance is reduced with a higher probability in those ecosystems with higher Critical Load (less sensitive) compared to very sensitive ecosystems with very low Critical Load values. In addition to that, during the ex-post assessments (chapter 1.4), CCE evaluated the risk reduction also through quantification of the area, where the projected deposition is above the Critical Load (area at risk, AAR)

As a first step CIAM tested the minimum and the mid-point Critical Load values of those ranges with different scenarios. Figure 4 underlines the overall larger senisitivity of the minimum $CL_{emp}N$ data compared with the mid-point $CL_{emp}N$ data. While with the mid-point data (right) the attainability of a 50 %-reduction of the AAE is possible even with the baseline scenario for the minimum $CL_{emp}N$ (left) the baseline scenario offers not enough reduction potential for 50%-reduction of AAE. Furthermore, when using the minimum values, the AAE remains almost twice as high as when using the mid-point values.

As a result of those assessments, it was decided in the Working Group on Strategies and Review to include the minimum $CL_{emp}N$ in the optimization runs combining health and biodiversity indicators (TFIAM & CIAM, 2025). In this way, the highest level of biodiversity requirements was integrated into the optimisation calculations. This guarantees highest precaution and protection of the biodiversity of European ecosystems. The scenario in which health risks and biodiversity risks were given equal consideration is known as the OPT_hv scenario ("*health & vegetation*").

Figure 4 **Attainability of 50% reduction of the AAE of the nitrogen Critical Loads for all ecosystems in the UNECE region, excluding North America (minimum Critical Load left, mid-point Critical Loads right; please take note of the different labeling of the y-axis)**



Source: TFIAM and CIAM (2025)

By evaluating the AAE of individual ecosystems in comparison to the MTFR 2040 scenario (maximum technically feasible reduction) and the OPT_hv scenario (optimisation on health & vegetation) it was shown by CIAM that even under the most ambitious scenario for some grassland types and in certain areas, reductions achieved through implementation of available technical measures are insufficient to reach 50% risk reduction. Thus, further structural changes would be needed e.g., a more efficient use of mineral fertilizers or dietary shifts reducing meat consumption (TFIAM & CIAM, 2025). Those grassland ecosystem types are *Mediterranean tall perennial dry grassland* (EUNIS type R1E), *Lowland to montane, dry to mesic grassland usually dom-*

inated by Nardus stricta (EUNIS type R1M), *Oceanic to subcontinental inland sand grassland on dry acid and neutral soils* (EUNIS type R1P) and *Boreal and arctic acidophilous alpine grassland* (EUNIS type R42). Further details and reports of TFIAM and CIAM are available from the CIAM-website (https://iiasa.ac.at/policy/applications/centre-for-integrated-assessment-modelling-ciam).

In the following section (chapter 1.4) a more detailed analysis of risks for biodiversity ($CL_{emp}N$ exceedance) is shown, including the specific grassland ecosystems performed by CCE in relation to the scenario data produced by CIAM in the optimization calculation. This analysis is called ex-post-analysis, because it looks onto a future, projected state of the environment by using scenario data on emission and deposition.

1.4 Ex-post analysis with $CL_{emp}N$ data

To support the revision of the Gothenburg Protocol and project the success of emission scenarios to reduce the risks for biodiversity, in a joint approach under the Working Group on Effects, ex-post analysis of exceedance of $CL_{emp}N$ data were performed and evaluated based on deposition scenarios provided by MSC-West running the outcome of optimization calculations with the GAINS model. The assessment was done with both $CL_{emp}N$ datasets: The harmonized UNECE wide data (1.2.1) and the dataset, reflecting the NFC-submission to the Call for data (1.2.2) The results are presented here and were included in the informal document report for the 45. Session of the Executive Body, summarizing the results of ex-post analyses from various ICPs of the WGE (Working Group on Effects, 2025)

For all ex-post assessments uniformly, the deposition data provided by MSC-West was used and downloaded for a total of five different scenarios:

- 2015 baseline scenario (Base 2015)
- 2040 current legislation (CLE 2040)
- 2040 optimised to 50 % reduction in mortality risk from $PM_{2.5}$ (OPT 2040)
- 2040 health & vegetation 50 % reduction in mortality risk and 50 % reduction in the risks of biodiversity loss (OPT_hv 2040)
- 2040 maximum technical feasible reduction (MTFR 2040)

More details of the emission scenario are described in the 5th version of TFIAM policy brief (TFIAM & CIAM, 2025) and in the EMEP Status report (MSC-West et al., 2025).

1.4.1 Ex-post analysis evaluating exceedance of NFC reported $CL_{emp}N$ data

In this chapter the NFC reported European $CL_{emp}N$ data was evaluated. For that, the data of NFC, which responded to the call for data was included directly into the country's domains and the gap-filling (for those countries without reported national data) was based on the "NFC choices approach" averaging the NFC-submitted data on each EUNIS-level (for more details see chapter 1.2.2.2).

For each of the above-mentioned scenarios (chapter 1.4) the indicators Average Accumulated Exceedance, AAE [kg ha^{-1} a^{-1}] and Area At Risk, AAR [%] (area, where the projected deposition is above the Critical Load) were evaluated. Also, for each of the scenarios the relative changes of those indicators under the projections in comparison to the Baseline scenario (Base 2015) were calculated to assess, if the 50% reduction goal for risks for biodiversits is achievable. The AAR indicator complements the AAE assessment, which focuses on exposure intensity, by adding a spatial dimension and thereby enabling a more comprehensive evaluation of the overall risk potential. This is particularly relevant in regions with low AAE values, where a purely percentage-based reduction of the AAE offers only limited insight. The combined use of both indicators thus provides a more robust basis for prioritizing mitigation measures.

The following figures and tables show the results of the evaluation for different levels of information and aggregation.

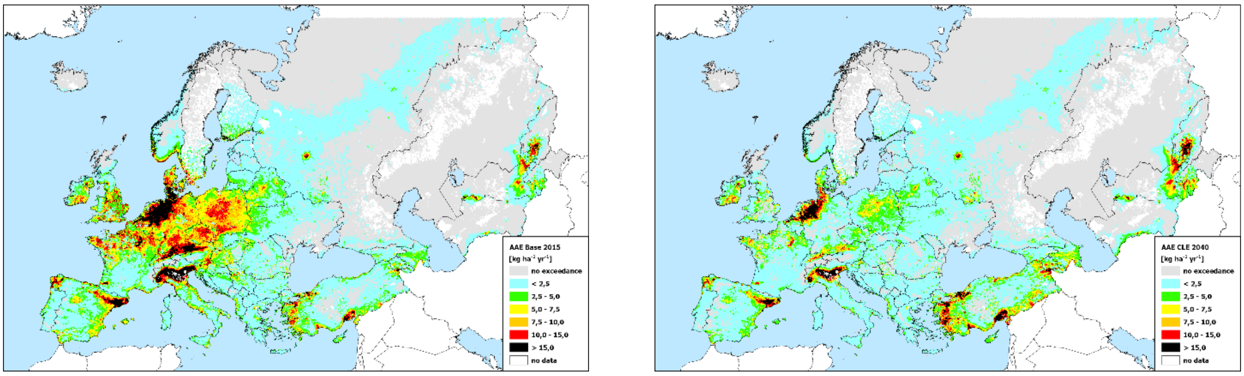
- UNECE wide modelled exceedance of NFC reported $CL_{emp}N$ – coloured areas indicate area weighted AAE; grey areas indicate no remaining risk for biodiversity (Figure 5)
- Regional AAE [kg ha^{-1} a^{-1}] and AAR [%] evaluating regional specific assessment of exceedance of NFC reported $CL_{emp}N$ for different scenarios for 2040 for EU-27 (all EU countries), EECCA (Eastern European, Caucasian and Central Asian countries and Turkey), WB (West-Balkan countries), Non-EU (European countries not in the EU nor WB or EECCA) (Table 1)
- Regional relative change in AAE [%] and AAR [%] of NFC reported $CL_{emp}N$ under the different scenarios for 2040 in comparison to the baseline scenario 2015 (Table 2)
- Country specific and regional AAE [kg ha^{-1} a^{-1}] and AAR [%] evaluating exceedance of NFC reported $CL_{emp}N$ for different scenarios for 2040 (Table 41)
- Country specific and regional relative change in AAE [%] and AAR [%] of NFC reported $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 (Table 42)
- EUNIS level-1 specific AAE [kg ha^{-1} a^{-1}] and AAR [%] evaluating exceedance of NFC reported $CL_{emp}N$ for different scenarios for 2040 (Table 3)
- EUNIS level-1 relative change in AAE and AAR of NFC reported $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 (Table 4)
- EUNIS level-3 specific AAE [kg ha^{-1} a^{-1}] and AAR [%] of NFC reported $CL_{emp}N$ for grassland ecosystems (R) (Table 43)
- EUNIS level-3 relative change in AAE [%] and AAR [%] of NFC reported $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 for grassland ecosystems (R) (Table 44)

The assessments show that under the OPT_hv 2040 scenario for EU-27-, non-EU- and WB-countries for both indicators (AAE [kg ha^{-1} a^{-1}] and AAR [%]) the attainability of 50 % reduction compared to the Baseline 2015 scenario seems feasible (Table 2). However, those numbers integrate the results across all national borders and across all ecosystem types.

Table 2 also shows, that for the EECCA region including Turkey a reduction of > 50 % is only possible for the AAR under the MTFR scenario. For all other scenarios the projected reductions of AAE and AAR are lower than -38 % compared to the Baseline 2015. For this group largest improvements of > 50 % are feasible for both indicators e.g. in Belarus, Georgia, Moldova, Russia and Ukraine. For Turkey the improvements are smaller than 20 % for AAE and10 % for AAR. For Armenia, Azerbaidjan, Kazakhstan, Kyrgistan, Tadjikistan and Turkmenistan even an increase of AAE or AAR is projected (Table 42).

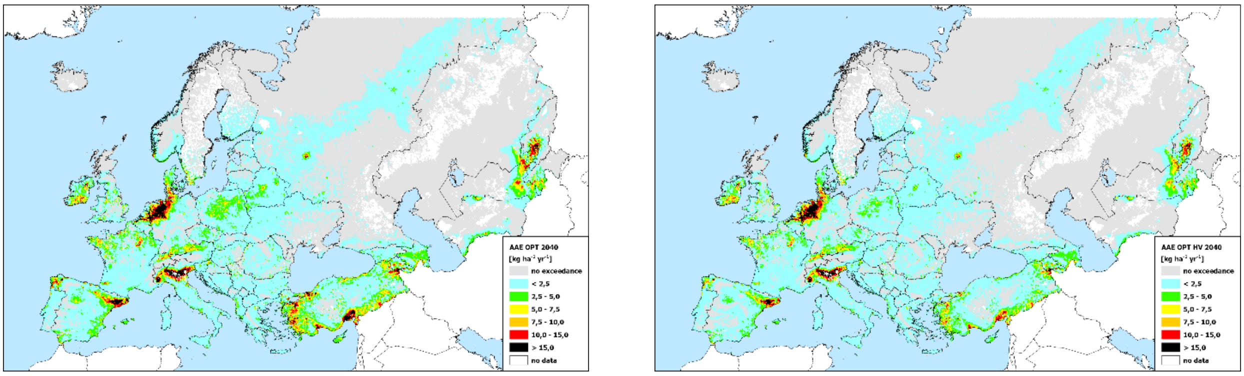
For the EU-27 region the goal of -50 % reduction of AAE under the OPT_hv scenario is only not achievable for Cyprus, Ireland and Malta. In all other EU countries, as well as in all European non-EU countries and in all West-Balkan countries the emission reduction under OPT_hv will lead to the overall attainability of the goal to reduce AAE by at least 50 % (Table 42).

Figure 5 Modelled exceedance of $CL_{emp}N$ on the basis of NFC data and the NFC choices gap filling under five different scenarios (grey areas indicate no remaining risk for biodiversity): A: under the Base 2015 scenario; B: under the CLE scenario; C: under the OPTscenario; D: under the OPT_hv scenario; E: under the MTFR 2024 scenario



A: Exceedance of $CL_{emp}N$ (NFC) under Base 2015 scenario

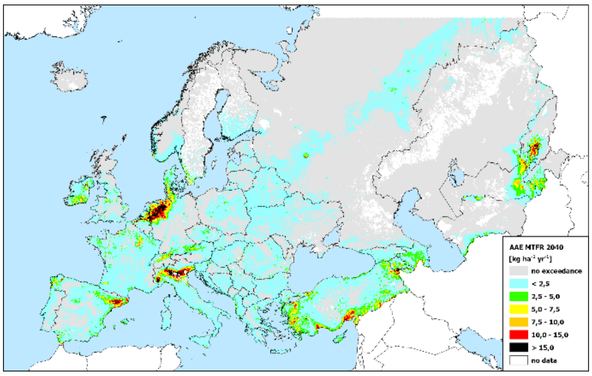
B: Exceedance of $CL_{emp}N$ (NFC) under the CLE scenario



C: Exceedance of $CL_{emp}N$ (NFC) under the OPT scenario

D: Exceedance of $CL_{emp}N$ (NFC) under OPT_hv scenario

E: Exceed. of $CL_{emp}N$ (NFC) under MTFR 2040 scenario



Source: own illustration, CCE/UBA

Table 1 AAE [kg ha^{-1} a^{-1}] and AAR [%] evaluating regional specific assessment of exceedance of NFC reported $CL_{emp}N$ for different scenarios for 2040

	receptor area		Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km^2	% of total country area	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
EU-27	1.594.954	38,5	1,3	50,0	0,4	29,4	0,3	25,3	0,2	20,9	0,1	16,3
Non-EU	470.717	60,9	0,6	26,2	0,1	14,3	0,1	11,9	0,1	11,3	0,0	8,4
WB countries	116.298	56,0	1,1	35,8	0,4	18,2	0,3	14,1	0,2	10,1	0,2	7,8
EECCA countries & Turkey	5.216.576	22,8	0,1	14,1	0,2	15,2	0,1	11,6	0,1	9,1	0,1	6,9

Table 2 Regional relative change in AAE [%] and AAR [%] of NFC reported $CL_{emp}N$ under the different scenarios for 2040 in comparison to the baseline scenario 2015

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]
EU-27	-72,8	-41,2	-79,2	-49,4	-85,1	-58,2	-90,8	-67,3
Non-EU	-80,6	-45,4	-87,2	-54,5	-88,7	-57,0	-95,3	-68,1
WB countries	-59,5	-49,2	-71,0	-60,7	-81,0	-71,7	-85,8	-78,1
EECCA countries & Turkey	95,6	7,1	31,7	-17,9	-30,6	-35,8	-36,5	-50,9

Table 3 **AAE [kg ha^{-1} a^{-1}] and AAR [%] for EUNIS Level-1 ecosystem classes evaluating exceedance of NFC reported $CL_{emp}N$ for different scenarios for 2040**

	receptor area	**Base 2015**		**CLE 2040**		**Opt 2040**		**Opt_hv 2040**		**MTFR 2040**	
	km²	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**
Inland surface waters (C)	60.130	0,2	12,1	0,1	6,4	0,0	5,0	0,0	4,1	0,0	2,6
Marine habitats (M)	364.798	0,0	0,4	0,0	0,8	0,0	0,4	0,0	0,3	0,0	0,2
Coastal habitats (N)	8.910	1,4	31,2	0,6	26,1	0,4	21,8	0,4	20,5	0,3	17,9
Wetlands(Q)	404.477	0,1	4,0	0,0	2,9	0,0	2,3	0,0	2,1	0,0	1,5
Grasslands and lands dominated by forbs, mosses, or lichens (R)	1.436.363	0,3	18,1	0,5	19,6	0,3	16,4	0,2	13,3	0,2	12,0
Heathland, scrub, and tundra (S)	416.835	0,9	32,9	0,9	29,7	0,7	27,8	0,5	24,6	0,4	22,2
Forest and other wooded land (T)	4.696.989	0,2	25,0	0,2	18,1	0,1	14,0	0,1	11,2	0,0	8,0
Inland habitats with no or little soil and mostly with sparse vegetation (U)	9.991	0,0	2,3	0,0	0,2	0,0	0,2	0,0	0,1	0,0	0,1
Vegetated man-made habitats (V)	52	1,1	49,3	0,1	14,0	0,0	8,9	0,0	7,3	0,0	0,8

Table 4 Relative change in AAE [%] and AAR [%] for EUNIS Level-1 ecosystem classes evaluating exceedance of NFC reported $CL_{emp}N$ under the different scenarios for 2040 in comparison to the baseline scenario 2015

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]
Inland surface waters(C)	-75,0	-47,4	-80,2	-58,9	-83,7	-66,1	-91,0	-78,5
Marine habitats (M)	207,9	70,9	43,8	-2,8	-38,2	-42,2	-49,4	-46,5
Coastal habitats (N)	-57,8	-16,5	-67,3	-30,2	-73,0	-34,4	-80,7	-42,7
Wetlands (Q)	-50,4	-27,9	-65,1	-43,9	-66,5	-48,5	-87,5	-63,8
Grasslands and lands dominated by forbs, mosses, or lichens (R)	76,3	8,5	31,7	-9,1	-5,3	-26,3	-14,0	-33,5
Heathland, scrub, and tundra (S)	-7,7	-10,0	-23,2	-15,6	-46,3	-25,4	-52,6	-32,5
Forest and other wooded land (T)	-29,3	-27,5	-51,7	-43,8	-74,5	-55,2	-79,5	-68,0
Inland habitats with no or little soil and mostly with sparse vegetation (U)	-86,5	-89,2	-89,5	-89,9	-91,0	-94,2	-94,4	-96,6
Vegetated man-made habitats (V)	-91,4	-71,6	-95,6	-81,9	-97,1	-85,3	-99,4	-98,5

For the OPT scenario the overall results are similar, however the attainability of the biodiversity goal in the West-Balkan region is very close to the reduction goal of -50 % and therefore more difficult and in Albania the calculated reduction falls with-38 % below the target.

Evaluating the risks for biodiversity on the level of ecosystem groups, it is shown, that especially for the Group of *Grasslands and lands dominated by forbs, mosses, or lichens (R)* the attainability of -50 % AAE under OPT_hv seems impossible. The calculated reduction under OPT_hv is at -5 % across the European UNECE domain. For the indicator *AAR* the improvement in the Grassland group with -26 % is a little bit better.

Of the 14 grassland ecosystem types being part of and displayed in Annex A, the target (-50 % AAE) can be met for only 8 of them under OPT_hv scenario (Table 44). For Mediterranean tall perennial dry grassland (R1E), Mediterranean annual-rich dry grassland (R1F), Mountain hay meadow (R23), Boreal and arctic acidophilous alpine grassland (R42), Temperate acidophilous alpine grassland (R43) and Arctic-alpine calcareous grassland (R44) the objective is not attainable. The total area of those ecosystem types comprises to roughly 10 % of the total receptor area across the European UNECE region. However, the absolute AAE for those ecosystem types is except for R1F (with a total ecosystem area of ~2.000 km^2 i.e. 0,03% of the total receptor area) with values of <1 kg ha^{-1}a^{-1} quite small.

1.4.2 Ex-post analysis evaluating exceedance of harmonized minimum $CL_{emp}N$ data

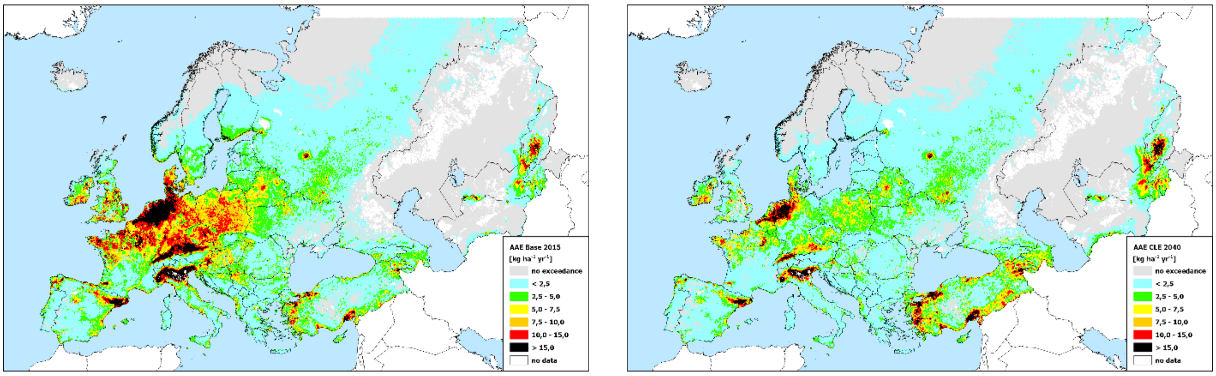
In this chapter the harmonized European minimum $CL_{emp}N$ data (chapter 1.2.1) was evaluated. The harmonized minimum $CL_{emp}N$ data was also used for the optimization runs by CIAM.

Similar to the assessments for the NFC reported $CL_{emp}N$ data (chapter 1.4.1) for each of the above-mentioned scenarios (chapter 1.4) the indicators AAE [kg ha^{-1} a^{-1}] and AAR [%] (area, where the projected deposition is above the Critical Load) were evaluated. Also, for each of the scenarios the relative changes of those indicators under the projections in comparison to the Baseline scenario (Base 2015) were calculated to assess, if the 50% reduction goal for risks for biodiversits is achievable. The following figures and tables show the results of the evaluation for different levels of information and aggregation:

- UNECE wide modelled exceedance of harmonised minimum $CL_{emp}N$ – coloured areas indicate area weighted AAE; grey areas indicate no remaining risk for biodiversity (Figure 6)
- Regional AAE [kg ha^{-1} a^{-1}] and AAR [%] of harmonized minimum $CL_{emp}N$ for EU-27 (all EU countries), EECCA (Eastern European, Caucasian and Central Asian countries and Turkey), WB (West-Balkan countries), Non-EU (European countries not in the EU nor WB or EECCA) (Table 5)
- Regional relative change in AAE [%] and AAR [%] of harmonized minimum $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 (Table 6)
- Country specific AAE [kg ha^{-1} a^{-1}] and AAR [%] of harmonized minimum $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 (Table 45)
- Country specific relative change in AAE [%] and AAR [%] of harmonized minimum $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 (Table 46)
- EUNIS level-1 specific AAE [kg ha^{-1} a^{-1}] and AAR [%] of harmonized minimum $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 (Table 7)

- EUNIS level-1 relative change in AAE [%] and AAR [%] of harmonized minimum $CL_{emp}N$ (min) under the projections for 2040 in comparison to the baseline scenario 2015 (Table 8)
- EUNIS level-3 specific AAE [kg ha^{-1} a^{-1}] and AAR [%] of harmonized minimum $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 for grassland ecosystems (R) (Table 47)
- EUNIS level-3 relative change in AAE [%] and AAR [%] of harmonized minimum $CL_{emp}N$ under the projections for 2040 in comparison to the baseline scenario 2015 for grassland ecosystems (R) (Table 48)

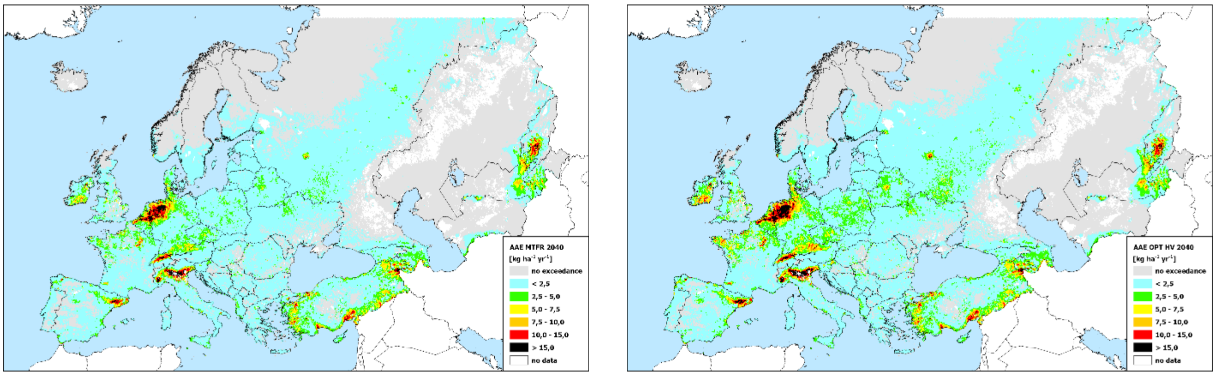
Figure 6 **Modelled exceedance of harmonized minimum $CL_{emp}N$ under five different scenarios (grey areas indicate no remaining risk for biodiversity): A: under the Base 2015 scenario; B: under the CLE scenario; C: under the OPTscenario; D: under the OPT_hv scenario; E: under the MTFR 2024 scenario**


A: Exceedance of $CL_{emp}N$ (min) under Base 2015 scenario

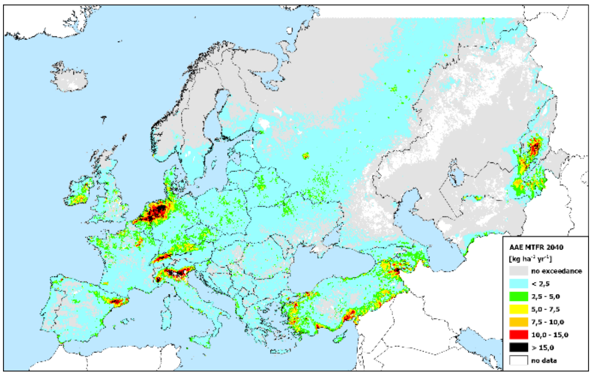
B: Exceedance of $CL_{emp}N$ (min) under the CLE scenario

C: Exceedance of $CL_{emp}N$ (min) under the OPT scenario

D: Exceedance of $CL_{emp}N$ (min) under the OPT_hv scenario



E: Exceed. of $CL_{emp}N$ (min) under the MTFR 2040 scenario



Source: own illustration, CCE/UBA

The assessments show that under the OPT_hv 2040 scenario for EU-27-, non-EU- and WB-countries for both indicators (AAE [kg ha^{-1} a^{-1}] and AAR [%]) the attainability of 50 % reduction compared to the Baseline 2015 scenario seems feasible (Table 6). For the OPT 2040 scenario the attainability is with 75% reduction comfortably possible for AAE but not for the reduction of the AAR with 43% reduction. Table 6 also shows, that for the EECCA region including Turkey improvements of > 50 % is not possible neither for the AAR nor for AAE, not even under the MTFR scenario. Looking into single countries of this group largest improvements of > 50 % are feasible for AAE only in Belarus, Moldova, Russia and Ukraine. A reduction of >50% in AAR is only possible for Moldova and Ukraine. For Turkey the improvements are smaller than 20 % for AAE and10 % for AAR. For Armenia, Tadjikistan and Turkmenistan even an increase of AAE is projected (Table 46).

For the EU-27 region the goal of -50 % reduction of AAE under the OPT_hv scenario is not achievable for Cyprus, Hungary, Malta and The Netherlands. In all other EU countries, as well as in all European non-EU countries and in all West-Balkan countries the emission reduction under OPT_hv will lead to the overall attainability of the goal to reduce AAE by at least 50 % (Table 46). However, the reduction of the AAR in Europe (EU-27, non-EU and WB), i.e. the area with deposition above the Critical Load is predicted to be less successful, with 17 out of 40 countries in South-, West- and Central-Europe falling behind the envisage 50% reduction. For the OPT 2040 scenario the overall results are quite similar only, a little bit less successful though, with only Slovenia (only AAR) and Albania (both indicators) additionally falling below the -50%-target.

Evaluating the risks for biodiversity on the level of ecosystem groups (aggregated across all ecosystem types and areas falling into the group), it is shown, that for the *Marine habitats (M)* and the terrestrial Groups of *Grasslands and lands dominated by forbs, mosses, or lichens (R)* and *Heathland, scrub and tundra (S)* the attainability of -50 % AAE under OPT_hv seems impossible (Table 8). The calculated reduction under OPT_hv 2040 is at -23% for marine habitats, at -38 % for Grasslands and at -48% for Heathlands across the European UNECE domain. Those ecosystem groups cover 30% of the total receptor area (19% Grasslands, 6% Heathlands and 5% Marine habitats). For the OPT 2040 scenario the predicted reduction in AAE is even smaller for Grasslands (-20%) and Heathlands (-29%) and also for the Surface Water ecosystems -50% in AAE is not attainable. For Marine Habitats under OPT 2040 there is even an increase in AAE projected.

Of the 14 grassland ecosystem types being part of and displayed in Annex A, the target (-50 % AAE) can be met for only 5 of them under OPT_hv 2040 scenario (Table 48). For Mediterranean closely grazed dry grassland (R1D), Mediterranean tall perennial dry grassland (R1E), Mediterranean annual-rich dry grassland (R1F), Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta (R1M), Oceanic to subcontinental inland sand grassland on dry acid and neutral soils (R1P), Mountain hay meadow (R23), Boreal and arctic acidophilous alpine grassland (R42), Temperate acidophilous alpine grassland (R43) and Arctic-alpine calcareous grassland (R44) the objective is not attainable. However, the absolute AAE for those ecosystem types is with values between 0,1 and 1,9 kg $ha^{-1}a^{-1}$ relatively small. Also, except for R42 for them there are improvements of AAE between -10% and -49% projected. The total area of those nine ecosystem types comprises to roughly 10 % of the total receptor area across the European UNECE region, with the largest share of 7% belonging to R1E.

Table 5 AAE [kg ha^{-1} a^{-1}] and AAR [%] evaluating regional specific assessment of exceedance of harmonized minimum $CL_{emp}N$ for different scenarios for 2040

	receptor area		Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	% of total country area	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
EU-27	2.115.145	51,0	2,3	60,3	0,7	38,2	0,6	34,0	0,5	30,1	0,3	24,3
Non-EU	354.560	45,9	0,9	22,4	0,4	12,8	0,3	11,1	0,3	10,5	0,2	8,4
WB countries	116.298	56,0	1,8	52,4	0,8	32,3	0,5	25,5	0,3	19,1	0,2	14,0
EECCA countries & Turkey	5.216.576	22,8	0,1	25,0	0,3	25,7	0,2	22,3	0,1	19,5	0,1	15,7

Table 6 Relative change in AAE and AAR of exceedance of harmonized minimum $CL_{emp}N$ under the different scenarios for 2040 in comparison to the baseline scenario 2015

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]
EU-27	-69,2	-36,7	-75,6	-43,6	-80,4	-50,1	-87,7	-59,7
Non-EU	-58,3	-42,9	-67,9	-50,6	-69,4	-53,2	-76,5	-62,4
WB countries	-56,9	-38,3	-69,5	-51,3	-80,6	-63,5	-86,8	-73,3
EECCA countries & Turkey	79,5	3,0	19,0	-10,5	-38,1	-22,0	-44,9	-37,3

Table 7 AAE [kg ha^{-1} a^{-1}] and AAR [%] for EUNIS Level-1 ecosystem classes evaluating exceedance of harmonized minimum $CL_{emp}N$ for different scenarios for 2040

	receptor area	Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
Inland surface waters (C)	2.029	0,3	20,0	0,2	11,0	0,2	9,8	0,1	9,4	0,1	7,6
Marine habitats (M)	366.206	0,0	1,5	0,1	1,9	0,1	1,6	0,0	1,3	0,0	1,1
Coastal habitats (N)	5.384	0,6	17,0	0,3	11,4	0,2	8,1	0,2	5,5	0,1	4,5
Wetlands(Q)	463.866	0,1	7,2	0,1	5,3	0,1	4,3	0,0	4,1	0,0	2,9
Grasslands and lands dominated by forbs, mosses, or lichens (R)	1.433.579	0,7	27,8	0,7	26,6	0,6	23,1	0,4	19,7	0,4	17,5
Heathland, scrub, and tundra (S)	448.142	1,5	37,8	1,2	35,0	1,1	33,5	0,8	30,5	0,7	28,2
Forest and other wooded land (T)	5.083.372	0,5	41,2	0,3	32,6	0,2	28,4	0,1	24,9	0,1	19,2

Table 8 **Relative change in AAE and AAR for EUNIS Level-1 ecosystem classes of harmonized minimum $CL_{emp}N$ under the different scenarios for 2040 in comparison to the baseline scenario 2015**

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]
Inland surface waters(C)	-32,1	-44,7	-43,1	-50,7	-53,8	-52,9	-62,0	-62,1
Marine habitats (M)	101,2	22,4	27,4	4,0	-23,0	-16,3	-33,9	-25,2
Coastal habitats (N)	-44,8	-33,1	-59,7	-52,3	-73,2	-67,6	-79,8	-73,2
Wetlands (Q)	-43,1	-26,8	-57,7	-39,8	-61,5	-43,2	-78,3	-59,3
Grasslands and lands domina-ted by forbs, mosses, or lichens (R)	3,0	-4,1	-20,3	-17,0	-38,4	-29,1	-46,9	-37,2
Heathland, scrub, and tundra (S)	-17,9	-7,3	-29,1	-11,5	-48,4	-19,4	-55,6	-25,3
Forest and other wooded land (T)	-53,7	-20,9	-68,1	-31,1	-81,4	-39,7	-85,9	-53,3

1.5 Discussion and conclusion

Different UNECE-wide datasets of $CL_{emp}N$ displaying different sensitivity of biodiversity have been produced by CCE ($CL_{emp}N$ (min)) and National Focal Centres to the ICP Modelling & Mapping. The CCE harmonized data sets ($CL_{emp}N$ (min), chapter 1.2.1) have been provided to CIAM for Integrated Assessment modelling. The NFC data has been integrated by CCE in a second UNECE wide dataset ($CL_{emp}N$ (NFC), chapter 1.2.2). Both CCE datasets, the harmonized minimum $CL_{emp}N$ and the dataset reflecting the results of the Call for data, have been evaluated within the ex-post assessment.

Overall, the assessed 2040 deposition scenarios indicate that total values of AAE are generally very low for most countries. However, as an aggregated, area-weighted indicator, AAE is not well suited to represent regional variability or localised exceedance patterns, particularly when applied to large and heterogeneous assessment units. In spatially extensive countries, Critical Load exceedances occurring in limited parts of the territory may be diluted by large areas with low or no exceedance, resulting in low national AAE values that provide only a coarse indication of remaining ecosystem pressure.

The AAR indicator complements this information by addressing a different aspect of Critical Load exceedance. It quantifies the absolute area and/or relative share of the total receptor area within a reporting unit where exceedances persist, thereby characterising the spatial extent of potentially affected ecosystems. This indicator does not reflect exceedance intensity, but provides transparent information on how widespread remaining exceedances are at country and regional scales.

Considered together, AAE and AAR describe complementary dimensions of Critical Load exceedance. While AAE summarises the overall magnitude of exceedances, AAR reflects their spatial coverage. The combined use of both indicators therefore supports a more robust and balanced assessment of the potential impacts of air pollution on ecosystems and biodiversity.

1.5.1 Sensitivity of ecosystems in different approaches

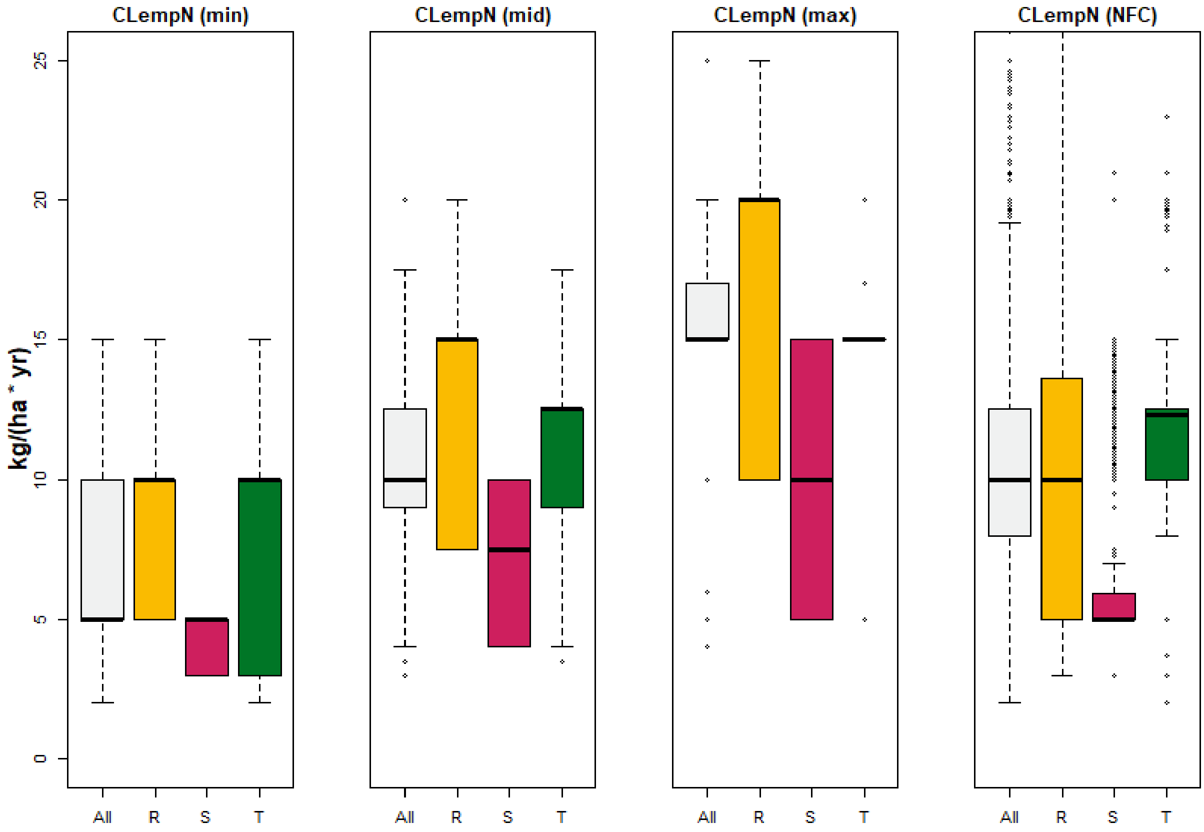
The sensitivity of the different $CL_{emp}N$ data set is displayed by the grey boxes in Figure 7. The most sensitive harmonized dataset is reflecting the minimum ends of the $CL_{emp}N$ ranges. The second most sensitive harmonized dataset is the one reflecting the NFC choice by averaging them and by filling the gaps with the NFC choices of the $CL_{emp}N$ ranges (chapter 1.2.2.2). The least sensitivity is displayed with dataset using the upper ends of the $CL_{emp}N$ ranges. Figure 7 shows also the sensitivities of four different ecosystem groups:

- Grasslands and lands dominated by forbs, mosses or lichens (yellow)
- Heathland, scrub and tundra (magenta)
- Forest and other wooded land (green)
- Whole data set (grey)

It shows that regularly the heathland, scrub and tundra ecosystems are the most sensitive habitats.

Figure 7 **Distribution of the different $CL_{emp}N$ values summarized by four habitat groups**

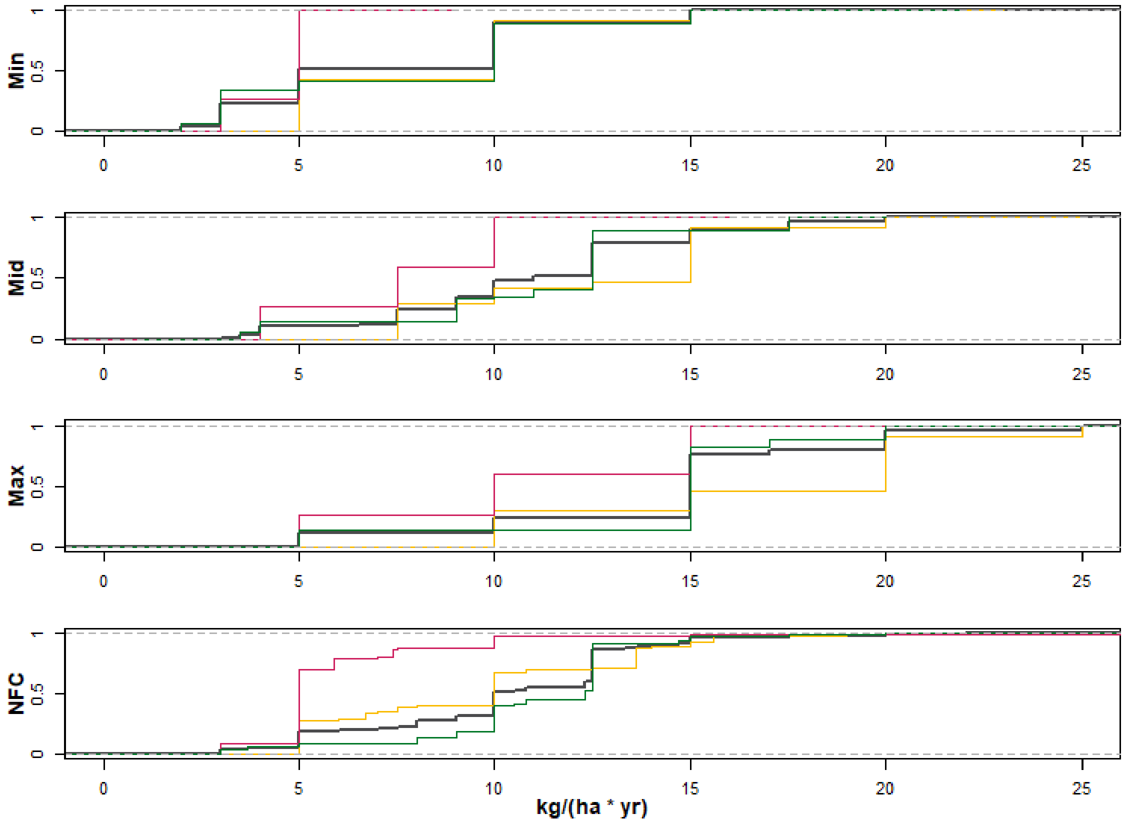
Grey: all habitats; olive: Grasslands and lands dominated by forbs, mosses or lichens; purle: Heathland, scrub and tundra; green: Forest and other wooded land;



Source: UBA, CCE, own source

The four different Critical Load datasets were additionally analysed using the cumulative distribution function (CDF) (see. Figure 8) and the same color coding as in Figure 7. This analysis shows that the data exhibit pronounced stepwise gradients between Critical Load classes, which is an expected consequence of the underlying data construction. It further indicates that the analysed values are clustered rather than evenly distributed across the full range. This means that even small changes (in the receptor or $CL_{emp}N$ table) can lead to large changes in the distribution percentile (e.g. from 5 to 10 kg ha^{-1} a^{-1}). Least pronounced jumps are observable in th NFC dataset with a larger variety of values.

Figure 8 Cumulative distribution function for the $CL_{emp}N$ parameters



Source: UBA, CCE, own source

1.5.2 Influence of different scenarios on reduction of risks for biodiversity

For both datasets the results of the ex-post assessment point out clearly that with the OPT_hv 2040 scenario the protection of biodiversity is projected to be more far-reaching than under the OPT 2040 scenario. On the regional level (EU-27, non-EU, WB), the relative reduction of risks for biodiversity expressed through reduction of AAE compared to the Baseline 2015 is roughly 5-10% larger with OPT_hv 2040 than with OPT 2040. A much greater difference is predicted for the EECCA countries. While the OPT scenario anticipates an increase in AAE compared to 2015, the OPT_hv scenario anticipates a decline of 30% (NFC) and 38% (min).

The evaluation at the ecosystem group level is similar. Particularly for grasslands (R), heathlands (S) and forests (T), the OPT-hv 2040 scenario brings about much more far-reaching improvements than the OPT scenario. This applies both to the AAE indicator and to the reduction in areas affected by exceedances.

1.5.3 Comparison of the influence of $CL_{emp}N$ (min) and $CL_{emp}N$ (NFC) on the prediction of risks for biodiversity

Comparing the results of the ex-post assessment with $CL_{emp}N$ (NFC) and $CL_{emp}N$ (min) differences of those two datasets have to be taken into account. The NFC reported $CL_{emp}N$ data is mainly based on national receptor (i.e. ecosystem) distribution. Compared to the harmonised receptor map (chapter 3) it is assumed that the national scientific expertise of receptor distribution is more accurate than the UNECE wide modelling approach implemented by the CCE. Also, the knowledge and scientific basis for the assignment of $CL_{emp}N$ to the national receptor maps is assumed to be more accurate than with the harmonised approach of the CCE described in chapter 1.2.1). For some countries the report of national $CL_{emp}N$ data result in a higher sensitivity of ecosystems compared to the $CL_{amp}N$ (min) data provided by the CCE (e.g. Finland, Sweden, Norway). For example, in the Norwegian report (annex C.10) a larger share of the senisitive ecosystem *Dark Taiga coniferous forest* (3 kg ha^{-1} a^{-1}) is assumed. On average, those assumptions result in more precautionary national data on average across the entire country compared to the harmonized CCE data (minimum). Therefore, the projected reduction in AAE or AAR under both scenarios (OPT_hv 2040 and OPT 2040) for Norway is smaller with the national data. This is because deposition must be reduced proportionally more for more sensitive target values.

This greater sensitivity is also evident at the level of the grassland ecosystem group (R). In the national datasets, particularly in Spain, stricter assumptions were made on average regarding the sensitivity of grassland ecosystems, and greater coverage was assumed. Overall, these different assumptions mean that the national data under the OPT_hv 2040 and OPT 2040 scenarios appear to show lower improvements in biodiversity risks than the harmonized minimum data from the CCE.

Conversely, in some countries, the opposite is true. In Germany, the Netherlands, and Poland, for example, the sensitivity of ecosystems is slightly reduced by the national data provided. As a result, the projected improvements that can be achieved through the scenarios are greater with the national data. In the Netherlands e.g. the application of the CCE minimum values means that the targeted 50% reduction in risks to biodiversity (AAE) cannot be achieved under the OPT_hv 2040 scenario (only -36%). With national data, on the other hand, an improvement of 52% would be feasible.

For all detailed country results it is referred here to the tables in annexes D.1and D.2.

2 Mapping SMB-/Steady State Critical Loads and extension of the Background Database

2.1 Introduction and background

Maintaining and further developing the methods used for modelling Critical Loads for eutrophication and acidification is a core element of the mandate of the Coordination Centre for Effects (CCE) and underpins a wide range of its activities. In line with this general objective, the 2024–2025 workplan for the implementation of the Convention (ECE/EB.AIR/2023/1[3]) assigns the CCE the task of investigating the potential for updating the Background Database (BGDB) for modelled Critical Loads (item 1.1.1.25).

In addition to methodological updates, such as the integration of the revised receptor map (chapter 3), an important focus of this work has been the exploration of options to extend the spatial coverage of the BGDB. The envisaged extension aims to include the EECCA countries and Turkey, thereby aligning the spatial extent of the modelled Critical Loads with that of the $CL_{emp}N$ described in chapter 1 of this report.

The following chapter summarises the progress achieved to date and outlines the current status of this ongoing work.

2.2 Modelling approach

The fundamental assumptions underlying the steady-state / SMB modelling of Critical Loads, as well as the core structure of the existing modelling framework, were retained from the established approach. A detailed description of this framework is provided in Reinds et al. (2021).

However, in addition to several targeted updates to key input datasets, the extension of the spatial domain required selected adaptations within the modelling framework. The most substantial updates concerned the following input data components:

- Receptor map
- Soil map
- Meterological data

2.2.1 Receptor map

In 2023, the CCE published a harmonised and updated receptor map for the UNECE region, including the EECCA countries and Turkey. This new receptor map and the characteristics of the underlying database are described in detail in Gebhardt (2023), with selected key features summarised in chapter 3 of this report. This update was required as the previously used receptor map, based on Cinderby et al. (2007), was outdated and did not cover the extended spatial domain, in particular the EECCA region was missing.

The integration of the new receptor map into the modelling framework was comparatively straightforward relative to other components of the update. The most relevant changes arise from the revised spatial distribution of ecosystem receptors.

Changes in receptor distribution have implications for the modelling of nitrogen and base cation uptake. At the current stage of the update, any resulting differences in uptake are solely

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[3] https://unece.org/sites/default/files/2023-10/ECE_EB.AIR_2023_1%20%28E%29.pdf

attributable to the revised receptor distribution, while the underlying modelling approach – based on tree species cover and EFISCEN data (Schelhaas et al., 2006) – remains unchanged.

2.2.2 Soil map

In the previous modelling framework, soil information was based on the European Soil Database v2 (European Commission and the European Soil Bureau Network, 2004). For the current update, the Harmonized World Soil Database (HWSD) version 2.0 (FAO & IIASA, 2023) was adopted, as it provides more recent information and covers the full spatial extent of the area under consideration, including the EECCA region and Turkey.

The HWSD combines spatially explicit soil mapping units with a comprehensive reference database containing associated soil attributes. While the technical preparation of the spatial soil layers was straightforward, the derivation of soil parameters required by the Critical Load modelling framework involved substantial additional processing.

In total, more than 29,000 soil mapping units representing 175 distinct soil types are included in the dataset. For these soil types, key parameters relevant for Critical Load calculations – such as texture classes, weathering rate classes, and selected chemical properties (e.g. pH, organic carbon and nitrogen content, carbonate content) – were extracted and harmonised to ensure consistency with the existing modelling framework.

2.2.3 Meteorological data

In the previous modelling framework, meteorological input data were derived from multiple sources. One key dataset was based on the E-OBS ensemble product, which provides daily meteorological variables on a regular grid over large parts of Europe (Cornes et al., 2018) and has been used, together with elevation data, to support the estimation of soil water percolation via the METHYD model.

While updated versions of the E-OBS dataset are available, their spatial coverage does not extend to the full assessment domain required for the current update, in particular the EECCA region and Turkey. As a consequence, E-OBS data could not be consistently applied across the enlarged modelling domain.

To ensure spatial consistency, the focus was therefore placed on the Climatic Research Unit (CRU) dataset (Harris et al., 2014), which is available via the Centre for Environmental Data Analysis and provides global, gridded time series of monthly climatic variables. The CRU dataset was already partly integrated in the original modelling framework, where selected parameters were aggregated to annual values for further processing. In addition to these variables, the CRU dataset offers a broader range of climatic parameters with global coverage that are relevant for soil water balance calculations.

However, some meteorological variables required by the original METHYD-based approach – most notably daily wind speed – are not available within the CRU dataset. Since soil water percolation is a key input to the steady-state / SMB Critical Load modelling framework, this limitation necessitated an adaptation of the percolation calculation method.

In the updated framework, soil water percolation is therefore estimated using a simplified water balance approach (Allen et al., 1998), where percolation is derived from precipitation, potential evapotranspiration, and a soil water deficit term. Soil water holding capacity is estimated from soil texture and organic matter content using empirical relationships following Saxton and Rawls (2006). This approach ensures methodological consistency across the extended spatial domain while retaining the key functional dependencies required for Critical Load calculations.

2.3 Summary and outlook

The work described in this chapter 2 documents substantial progress towards extending the spatial domain of the Critical Load modelling framework while maintaining methodological consistency with the established approach. Key input datasets, including receptor information, soil data and meteorological boundary conditions, have been updated and harmonised to support assessments beyond the previously covered area.

At the same time, the extension of the modelling domain has revealed several technical and methodological challenges, particularly with respect to data availability, consistency across the datasets and the integration of heterogeneous input sources. Addressing these challenges required targeted adaptations of the modelling framework and significant development effort, underlining the complexity of transferring an established modelling system to a substantially enlarged assessment domain.

The next steps will focus on the full implementation of the updated input datasets and the corresponding adaptation and consolidation of the modelling code. While the exact timing of final model results cannot yet be specified, the work completed so far provides a robust foundation for further development. However, the data is not ready yet, to be provided for assessments under the current process of revising the Gothenburgh Protocol. Nevertheless, building on this progress, the extended modelling framework is expected to enable more comprehensive Critical Load assessments for the full UNECE region, including the EECCA countries and Turkey, in future work cycles.

3 Harmonized receptor map (published 2023)

In 2023 an updated and harmonized land cover map for large parts of the Geneva Air Pollution Convention (CLRTAP), including Europe and seven countries in Eastern Europe, the Caucasus, and Central Asia (EECCA) was created (Gebhardt, 2023). This map replaces outdated land cover information from the 1990s and 2000s and is designed to support the calculation of Critical Loads (CL) for terrestrial ecosystems. The new harmonized land cover map provides the following improvements over previous map products:

- Higher thematic detail (especially at EUNIS Level 3)
- Updated land cover status (2018–2020 reference years)
- Expanded spatial coverage (Europe + EECCA)
- Higher internal consistency through unified translation rules

A central achievement of the project is that the new harmonized receptor map supports the EUNIS classification systems (up to Level 3). The final outputs significantly improve the thematic resolution, spatial consistency, and ecological relevance of land cover data available to European environmental modelling and policy processes.

3.1 Receptor map at EUNIS level 1 & 2

A major outcome is the creation of a region-wide EUNIS Level 2 land cover map with a uniform 100 × 100 m resolution. This was achieved through a combination of:

- CORINE Land Cover 2018 and Ecosystem Type Map v3.1 (ETM) for countries covered by CLC (EEA, 2018)
- Copernicus Global Land Cover 2019 for EECCA countries and non-CLC regions (Buchhorn et al., 2020)
- Newly developed crosswalk rules that translate these datasets systematically into EUNIS Level 1 and Level 2 classes

The resulting map provides consistent pan-regional classification across continental Europe and the EECCA region, covering all major ecosystems including forests, grasslands, wetlands, agricultural systems, coastal zones, and artificial surfaces.

This is the first time a harmonized EUNIS level 2 map has been produced for such a large and ecologically diverse region. It offers a significantly improved foundation for Critical Load calculations, which rely on correct identification of ecosystem types and sensitivity.

3.2 Receptor map at EUNIS level 3

The most important scientific and technical result is the generation of a fully model-derived EUNIS level 3 habitat map. This map includes 218 EUNIS cover classes, of which 204 are EUNIS level 3 habitats—a substantial expansion compared with earlier European maps.

Methodological achievements are:

- Use of >700,000 precisely classified vegetation plots from the European Vegetation Archive (EVA)

- Extraction of environmental features from:
  - Global Potential Natural Vegetation (GPNV) (Hengl, 2018)
  - Harmonized World Soil Database (HWSD) (FAO et al., 2009)
  - A Random Forest modelling framework trained separately for each EUNIS Level 2 group
  - Stratified sampling (60% training, 40% validation)
  - Achieved class accuracies between 60% and over 90%

The final habitat map is a major advancement because it introduces high-resolution habitat information that cannot be derived from satellite imagery alone. Vegetation plot–based modelling added ecological information and significantly increased thematic precision.

This dataset now allows Critical Load calculations to incorporate detailed differentiations among forest communities, grassland types, shrublands, wetlands, and coastal habitats—leading to more accurate modelling of ecosystem sensitivity and pollutant impacts.

3.3 Map update in 2024: Regional subdivion of the freshwater lakes class

The existing receptor class "Permanent oligotrophic lakes, ponds, and pools" (EUNIS C11) is being subdivided into three new categories based on geographical zones: "Alpine and sub-Arctic clear-water lakes," "Boreal clear-water lakes," and "Atlantic soft-water bodies."

This subdivision uses the “Environmental Zones 2018 - Version 1.0, June 2020” map, which divides the regions into the following zones:

1. Alpine North (ALN),
2. Boreal (BOR),
3. Nemoral (NEM),
4. Atlantic North (ATN),
5. Alpine South (ALS),
6. Continental (CON),
7. Atlantic Central (ATC),
8. Pannonian (PAN),
9. Lusitanian (LUS),
10. Anatolian (ANA),
11. Mediterranean Mountains (MDM),
12. Mediterranean North (MDN),
13. Mediterranean South (MDS),
14. Macaronesia (MAC),
15. Arctic (ARC).

The class “Permanent oligotrophic lakes, ponds, and pools” on the current receptor map was divided into these target categories:

- Receptor map = 3102 & Environmental zones 2018 = 5 Alpine South (ALS) --> 310201 „Alpine and sub-Arctic clear-water lakes“
- Receptor map = 3102 & Environmental zones 2018 = 15 Arctic (ARC) --> 310201 „Alpine and sub-Arctic clear-water lakes“

- Receptor map = 3102 & Environmental zones 2018 = 2 Boreal (BOR) --> 310202 „Boreal clear-water lakes“
- Receptor map = 3102 & Environmental zones 2018 = 4 Atlantic North (ATN) --> 310203 „Atlantic soft-water bodies“
- Receptor map = 3102 & Environmental zones 2018 = 7 Atlantic Central (ATC) --> 310203 „Atlantic soft-water bodies“

The new classes “Alpine and sub-Arctic clear-water lakes,” “Boreal clear-water lakes,” and “Atlantic soft-water bodies” were created with updated codes (Table 9). The updated receptor map is called *eoss_europe_eecca_eunis_level3_r100_2018_v2.01.tif*.

Table 9 The class key has been amended as follow

EUNIS C1	EUNIS C2	EUNIS C3	EUNIS G1	EUNIS G2	EUNIS G3	EUNIS LABEL
C	C1	C11b	3000	3100	3102	Permanent oligotrophic lakes, ponds and pools
C	C1	C11b1	3000	3100	310201	Alpine and sub-Arctic clear-water lakes
C	C1	C11b2	3000	3100	310202	Boreal clear-water lakes
C	C1	C11b3	3000	3100	310203	Atlantic soft-water bodies

Sources:
https://sdi.eea.europa.eu/catalogue/idp/api/records/6ef007ab-1fcd-4c4f-bc96-14e8afbcb688
https://sdi.eea.europa.eu/datastore/public?path=/eea_r_3035_1_km_env-zones_p_2018_v01_r00/

3.4 Conclusion and Outlook

The project successfully established a new harmonized land cover dataset for Europe and EECCA+, offering high-resolution EUNIS level 2 and 3 habitat map. The combination of remote sensing products, environmental modelling and a large vegetation plot database represents a major methodological advancement. The framework is scalable, updatable, and suitable for future extensions. In order to increase accuracy of EUNIS level 3 mapping (current class accuracies between 60% and over 90%), the modelling framework can be further refined by:

- Incorporating additional vegetation plots from EVA and national databases
- Adding more detailed environmental predictors (e.g., climate downscaling, improved soil profiles, topographic indices)
- Testing alternative machine-learning algorithms and ensemble models

Such improvements could reduce confusion between similar habitat types (e.g., forest subclasses, grassland communities) and increase spatial precision.

Together, this new harmonized receptor map significantly enhances the scientific basis for ecosystem protection, pollutant impact assessment and environmental policy implementation across the CLRTAP region. The map is compatible with the EMEP grid. A detailed description about the map is available in the report from (Gebhardt, 2023). The the map data itself is available from the CCE (CCE@uba.de).

4 Mapping and assessing ammonia Critical Levels

4.1 Introduction

In chapter 3.2.3 of the Mapping Manual (CCE, 2024b) Critical Levels for ammonia (NH3) for vegetation are defined. The values were recently revised, following the recommendations of a joint workshop of experts researching the effects of NH3 was held in Dessau (DE) in March 2022. The overarching question was whether new information is available to confirm or modify the Critical Levels earlier proposed by the UNECE in 2009. Participants involved in research and recent studies concerning the issue were invited. In the run-up to the workshop, a comprehensive synthesis of the literature from the last ten years was compiled and discussed with the workshop participants. Scientists dealing with research on effects of ammonia on vegetation and ecosystems and those involved in the monitoring of ammonia in the environment presented their recent research.

As a key finding the participants of the workshop agreed that ammonia should be better respected in the future environmental legislation. They also confirmed the validity of annual UNECE Critical Levels of 1 µg m^{-3} for lichens and bryophytes including ecosystems, where lichens and bryophytes are key part of the ecosystem integrity and of 3 µg m^{-3} for vascular plants, including ecosystems, where lichens and bryophytes are not key part of the ecosystem integrity. Critical Levels account for both direct (e. g. toxic) and indirect effects (e. g. species composition). The literature review and the findings of the workshop are published in UBA Texte | 31/ 2023 (Franzaring, 2023), Review of internationally proposed critical levels for ammonia.

After the update of the Manual chapter 3.2.3 an assessment exercise was implemented in the workplan 2024/2025 (1.1.1.24, Critical Levels of NH3: map exceedance data). This was also supported by the key-findings of the Saltsjöbaden-7 Workshop, to quantify impacts of NH_3 on sensitive vegetation (Engleryd et al., 2023). During the ongoing revision of the Gothenburg Protocol, it was recommended to use mapped ammonia Critical Levels for ex-post-analysis with modelled EMEP NH_3 concentration data to support the policy making process scientifically.

The key questions for the workplan task and for this chapter were, how the critical levels could be attributed to the European receptor map in a senseful ecosystem-specific way and how a statistical distribution of compliance and exceedance of Critical Levels across Europe would look like?

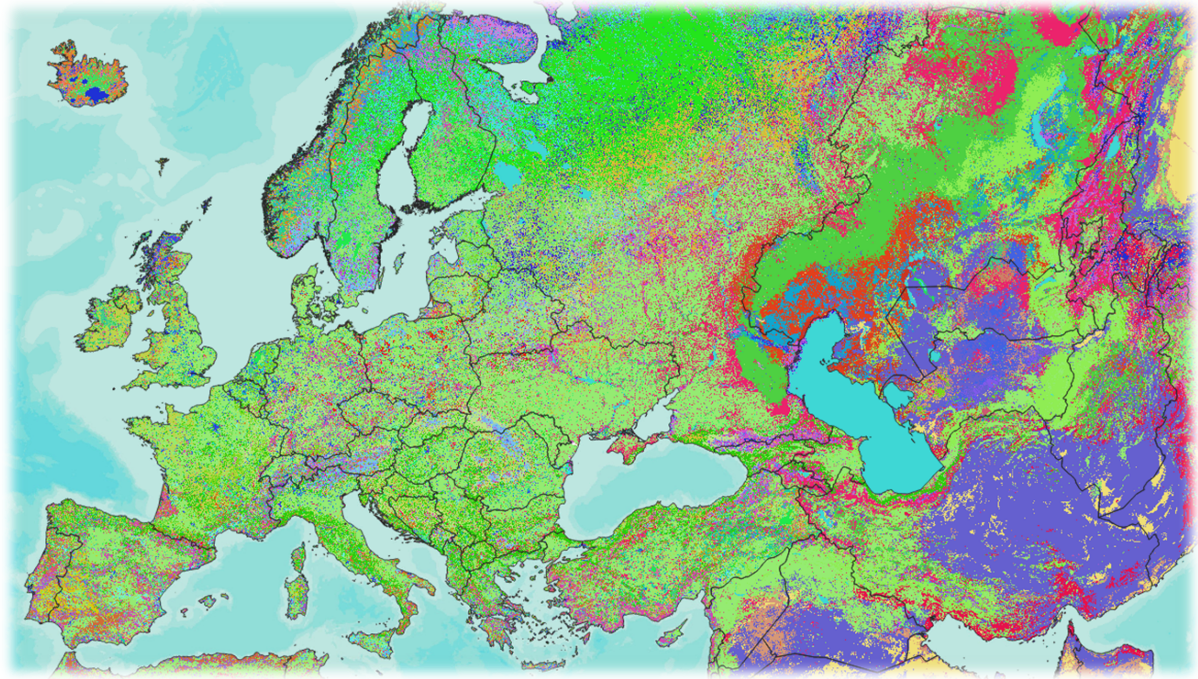
4.2 Methods

For the implementation and attribution of Critical Levels to the ecosystem types of the receptor map, the factsheets of the EEA database for EUNIS class definition and classification (EEA, 2025) were examined for the EUNIS classes at level 3. If lichens or bryophytes were found among the indicator species in the factsheets of the EUNIS classes, a critical level of 1 µg m^{-3} was assigned. If only vascular plants were found, these habitats were assigned with a Critical Level of 3 µg m^{-3}. Based on expert judgement EUNIS Class U ecosystems of “Inland habitats with no or little soil and mostly with sparse vegetation” were assigned a Critical Level of 1 µg m^{-3}completely, without checking the species lists of the EUNIS class factsheets and assuming lichens and bryophytes being present always. In contrast EUNIS Class C (Inland surface water habitats) was excluded from this assignment. Details are listed in “Annex 6: Assignment of Ammonia Critical Level to the EUNIS classes of the receptor map at Level 3”. For the former EUNIS class D, now Q „Wetlands“, no factsheets were available via EEA web app. Therefore, the information of the

EUNIS habitat classification published in 2020 (Chytry, 2020) was screened to assign values to the new EUNIS class Q. In addition, for EUNIS class Q ecosystems the review of the typical species according to the Habitat Directive was evaluated to search for lichens and bryophytes being among the indicator species of a habitat type (EIONET, 2018). Details of that assignment are listed in "Annex 7: Assignment of Sensitivity to Ammonia for Wetlands (EUNIS class Q) with the help of descriptions of typical species according to the habitats of the EU Habitats Directive"

Based on the information gathered in Annex 5 and Annex 6 the assigned values were mapped to the recently updated UNECE Receptor Map (Gebhardt, 2023). For mapping, statistical evaluation and exceedance calculations, the same methodological principles as applied in the Critical Load approach (e.g. chapter 1.2)were followed.

Figure 9 **Receptor map for ECE, WB and EECCA countries (221 EUNIS classes at level 3 were applied. With the receptor map a full coverage of semi-natural ecosystems on the EMEP grid of 0.1x0.1 degree is achieved.)**



Source: own illustration, CCE/UBA

After the mapping, an exceedance calculation was done with EMEP MSC West modelled NH_3 concentration data of the scenario runs which were provided for the process of ex-post evaluation during the revision of the Gothenburg Protocol (MSC-West et al., 2025).

This methodology and results were discussed and developed at informal online meetings 5th June 2024 and 19th June 2025 with interested representatives form ICP Modelling & Mapping and ICP Vegetation and at the 41st ICP Modelling & Mapping Task Force Meeting in Helsinki in February 2025.

4.3 Results

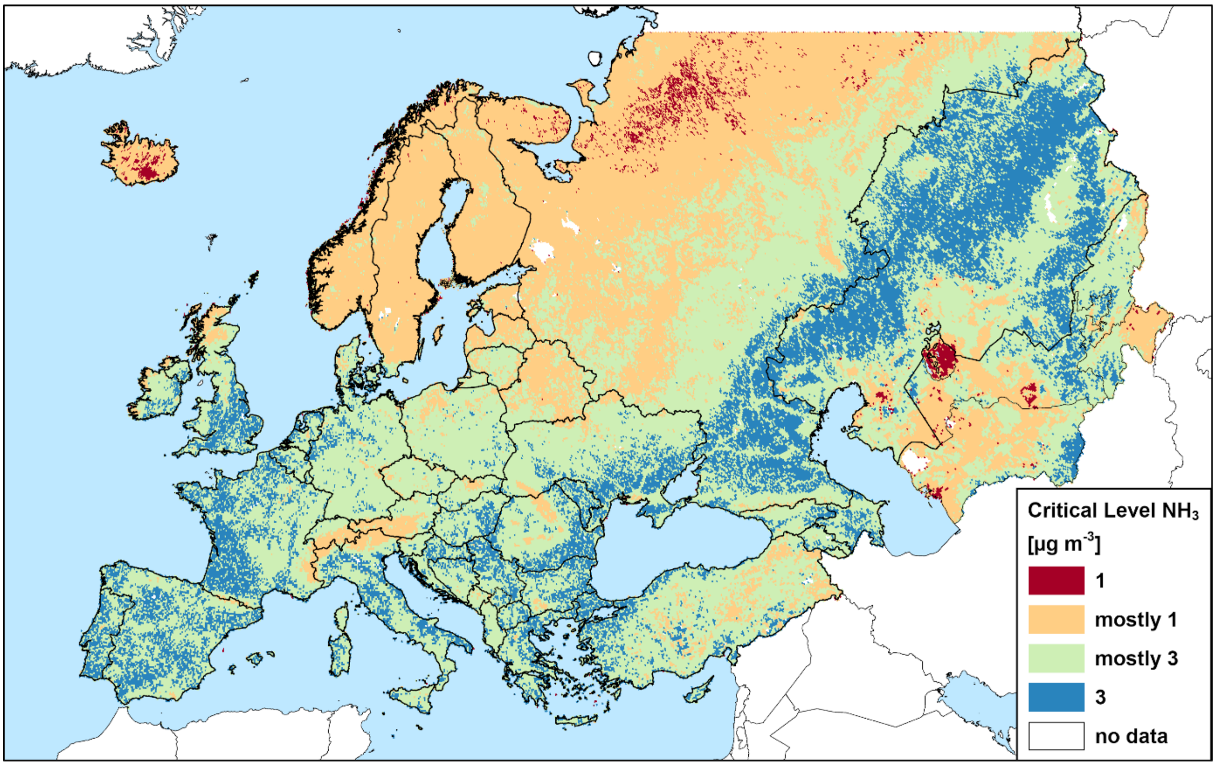
4.3.1 Mapping of Critical Level of ammonia

For documentation and mapping issues a table was structured with all relevant ecosystems at EUNIS class level 3 according to the recently updated UNECE Receptor Map (Gebhardt, 2023)..

The table, including the decision about which Critical Level was assigned and the relevant links to the EEA EUNIS habitat type factsheet database and EIONET habitat sheet, is published in Annex 6: Assignment of Ammonia Critical Level to the EUNIS classes of the receptor map at Level 3.

As a result, 68 ecosystems from the 221 were found to be highly sensitive to NH_3 (1µg m^{-3}), which is equivalent to 40,1 % of the total receptor area of 11.411.127 km^2. The rest of the receptor area (59,9 %) got a value of 3 µg m^{-3} assigned.

Figure 10 Assignment of NH_3 Critical Levels of 1 or 3 µg m^{-3} to the receptor map



Source: own illustration, CCE/UBA

Due to the EMEP grid cell resolution and the presence of several ecosystems in one cell a decision was made to proceed with grid cells not solely showing either sensitive or not sensitive ecosystems. Therefore, two extra categories for NH_3 Critical Levels on the map are described: “mostly 1” showing more than 50 % of the receptor area in a grid cell have a value of 1 µg m^{-3} and “mostly 3” showing more than 50 % of the receptor area in a grid cell have a value of 3 µg m^{-3}.

4.3.2 NH_3 concentration scenario data for ex-post evaluation to support the revision of the Gothenburg Protocol

By comparing the mapped critical levels with NH3 concentration data, estimates can be made of the risk of ecosystems being affected. In order to fulfill work package activity 1.1.1.24 and the requirements for ex-post analyses for the revision of the Gothenburg Protocol, the mapped critical levels were then compared mathematically with modeled NH3 concentrations from MSC-West. For this purpose, the data provided uniformly for all evaluation questions for the ex-post analysis of MSC-West was used and downloaded for a total of five different scenarios:

- 2015 baseline scenario (2015 Base)

- 2040 current legislation (CLE)
- 2040 maximum technical feasible reduction (MTFR)
- 2040 optimised to 50 % reduction in mortality risk from $PM_{2.5}$ (OPT)
- 2040 health & vegetation 50 % reduction in mortality risk and 40 % reduction in the risks of biodiversity loss (OPT_hv)

More details of the emission scenario are described in the 5th version of TFIAM policy brief (TFIAM & CIAM, 2025) and in the EMEP Status report (MSC-West et al., 2025).

4.3.3 Exceedance of Critical Levels for ammonia (NH_3)

To calculate the Exceedance of Critical Levels for ammonia the modelled and gridded values of ammonia concentration (µg m^{-3}) for the different scenario runs for the revision of the Gothenburg Protocol were intersected with the area and receptor related Critica Levels (µg m^{-3}). The following maps (Figure 11, Figure 12) and tables (Table 10, Table 11) show the results of this intersection. The approach presents the AAE for NH_3. In practice, exceedances are calculated individually for all receptor areas within a grid cell using the same grid-cell-specific modelled NH_3 concentration. The resulting exceedances are then accumulated and related to the total receptor area within the grid cell, yielding an area-weighted AAE expressed in concentration units (µg m^{-3}).

The results of this large-scale assessment show, that in all scenarios a large share of the overall receptor area (> 90 %) remains critically unaffected of ammonia concentration, thus modelled concentration remains below Critical Levels. Then, between 4 % to 6 % of the receptor area is affected only by minor exceedance of the Critical Levels below 1 µg m^{-3}. Only the small rest of the receptor area is confronted with ammonia concentrations, so that Critical Levels are exceeded by more than 1 µg m^{-3}. The resulting AAE on the overall receptor area varies in a very low range between 0,08 and 0,18 µg m^{-3} (Table 12).

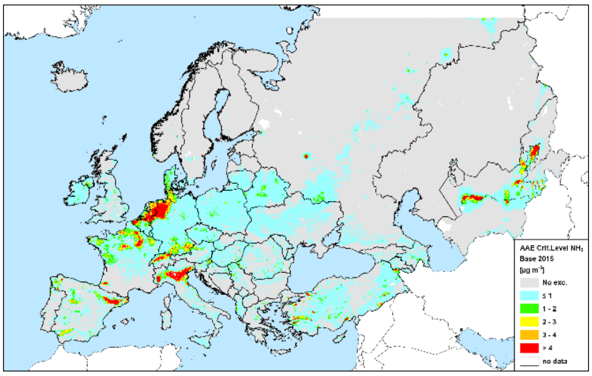
Interestingly, there is no large difference between the Baseline scenario 2015 and the projections for 2040. Remarkable is the observation that the AAE is highest with 0,18 µg m^{-3} under the assumptions for the 2040 Current Legislation scenario, with the affected receptor area above Critical Levels being the highest with 9,7 %. In contrast under the 2040 MTFR scenario the AAE is smallest with 0,08 µg m^{-3} and the affected ecosystem area with exceedance of Critical Levels smallest with 5,4 %.

In terms of AAE, the opt scenario is very similar to the baseline scenario, the opt_hv scenario reduces the AAE a bit. Comparing the share of non-affected ecosystems the opt and opt_hv scenario are very similar to the baseline scenario.

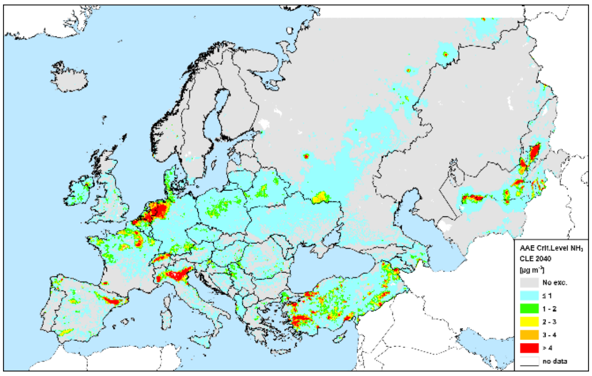
The visual comparison of the maps (Figure 11) and the analysis of Table 13 show, that ammonia and thus exceedance of Critical Levels is going down from the baseline 2015 to the projections for 2040 slightly in Western and Central Europe (EU-27, non-EU) whereas an increase of concentration and exceedance is recorded (depending on the scenario) in West-Balkan- and EECCA-countries as well as in Turkey. For the full country table please consult annex D.3.

Figure 11 **Average Accumulated Exceedance (AAE) for NH_3 Critical Level [µg m^{-3}] with the: A: 2015 baseline scenario; B: 2040 current legislation scenario (CLE); C: OPT 2040 scenario to reduce 50 % in mortality risk; D: OPT_hv 2040 scenario to reduce 50 % in mortality risk in the risks for biodiversity loss; E: 2040 MTFR scenario**

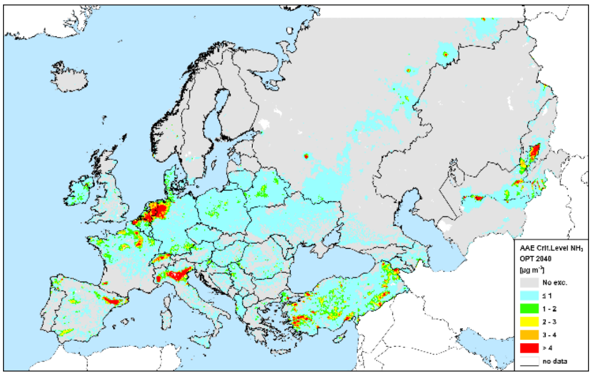
A: Exceedance of Critical Levels with 2015 base scenario



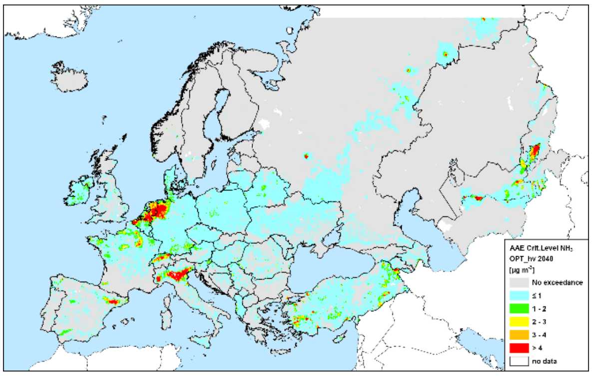
B: Exceedance of Critical Levels with 2040 CLE scenario



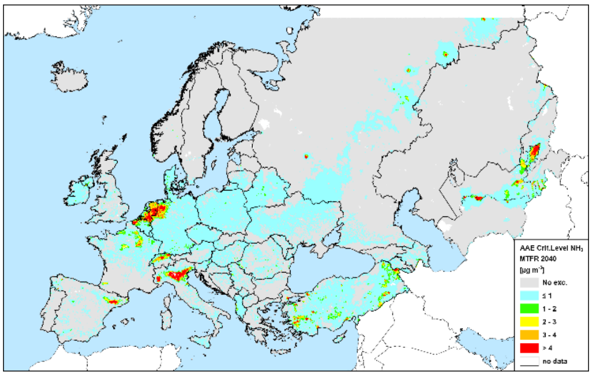
C: Exceedance of Critical Levels with OPT 2040 scenario



D: Exceed. of Critical Levels with 2040 OPT_hv scenario



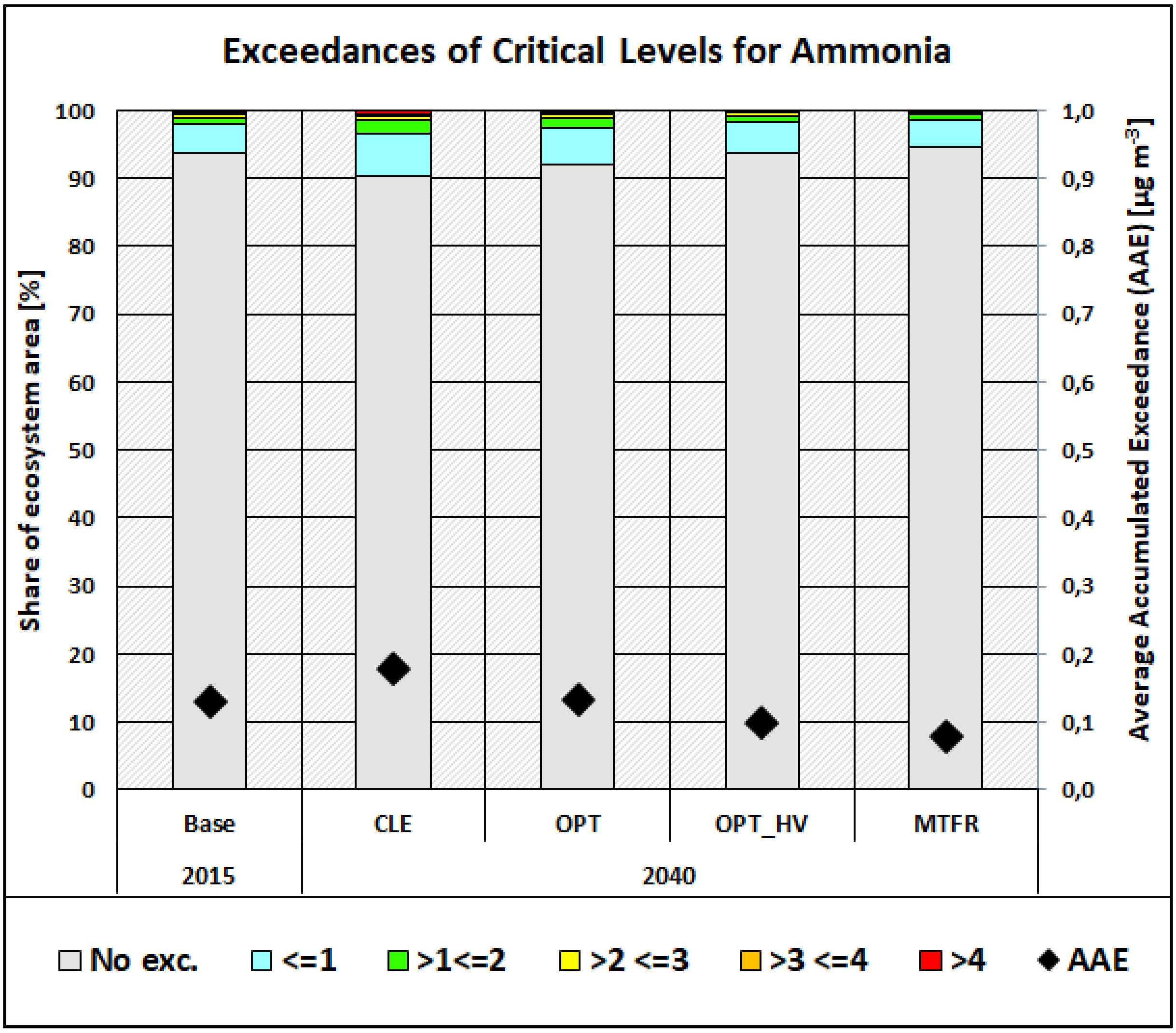
E: Exceedance of Critical Levels with 2040 MTFR scenario



Legend for maps A to E:

Source: own illustration, CCE/UBA

Figure 12 Bar charts showing the share [%] of ecosystem area with and without exceedance of Critical Levels for ammonia for the different scenarios (left y-axis); diamonds showing the overall AAE [µg m^{-3}] statistics (right y-axis)



Source: own illustration, CCE/UBA

Table 10 Share of receptor area [%] with or without exceedance of Critical Levels for ammonia

Exceedane [µg m^{-3}]	Base 2015	CLE 2040	Opt 2040	Opt_hv 2040	MTFR 2040
0	93,7	90,3	92,1	93,7	94,6
<=1	4,2	6,3	5,3	4,5	4,0
>1<=2	1,1	1,9	1,5	1,1	0,8
>2 <=3	0,4	0,7	0,5	0,3	0,3
>3 <=4	0,2	0,3	0,2	0,2	0,2
>4	0,4	0,5	0,3	0,2	0,2

Table 11 Receptor area [km²] affected through exceedance of Critical Levels for ammonia under the five scenarios for the revision of the Gothenburg Protocol

Exceedane [µg m⁻³]	Base 2015	CLE 2040	Opt 2040	Opt_hv 2040	MTFR 2040
0	10.687.413	10.304.280	10.513.024	10.690.186	10.791.374
<=1	479.651	718.578	604.704	513.303	455.695
>1<=2	128.299	211.680	167.752	121.292	90.323
>2 <=3	50.620	81.519	59.649	37.516	32.603
>3 <=4	24.621	37.081	27.234	20.652	18.960
>4	40.523	57.990	38.764	28.178	22.172

Table 12 AAE on the receptor area aross the CLRTAP domain under the five different scenarios for the revision of the Gothenburg Protocol

AAE [µg m⁻³]	Base 2015	CLE 2040	Opt 2040	Opt_hv 2040	MTFR 2040
AAE [µg m⁻³]	0,131	0,179	0,132	0,100	0,080

Table 13 Relative change in AAE and AAR of exceedance of Critical Levels for ammonia under the different scenarios for 2040 in comparison to the baseline scenario 2015

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
EU-27	-1,1	11,4	-17,1	-2,6	-31,1	-18,0	-54,1	-44,2
Non-EU	14,5	22,3	-17,0	-9,0	-18,0	-9,4	-39,3	-37,5
WB countries	169,0	166,4	99,3	123,1	14,7	38,8	-15,6	0,0
EECCA countries & Turkey	156,8	95,7	67,7	52,5	5,6	18,1	5,1	18,5

4.4 Discussion

The assignment of Critical Levels to ecosystem classes with the help of the EUNIS class specific species lists provided by the EEA to our knowledge is the first attempt to provide a database for broadscale mapping ecosystem sensitivity towards atmospheric ammonia concentration. The following alignment of EUNIS class specific information on NH_3 sensitivity with the UNECE receptor map provides a good and consistent way for mapping Critical Levels for ammonia across the European part of UNECE including the EECCA region. It follows the same approach for the mapping of $CL_{emp}N$ based on the uniform and harmonized method. However, uncertainties lay within the receptor map itself, e.g. national databases of ecosystem distribution are sometimes far more accurate. Also, it offers only information EUNIS level 3, whereas ecosystem variability and thus sensitivity go further down to EUNIS level 4. The assignment of Critical Levels was also only down on EUNIS level 3 and thus the sensitivity attribution was not possible to be done on the finest resolution and with the most accurate knowledge about sensitive species being representative for the ecosystems.

Applying the Critical Level map, the results of the effects assessment with EMEP modelled concentration data show, that ammonia concentration and thus risks for ecosystems across the CLRTAP domain is only slightly influenced by the scenario development for the revision of the Gothenburg Protocol. The risks for effects on ecosystems through ammonia concentration remain unchanged in the same order of magnitude.

The level of exceedance, with AAE around 0,1 µg $m^{-3}$and affected receptor area with concentration above Critical Levels of around 5-10 % is fairly low. However, those results have to be interpreted with great care. Note that the EMEP MSC-W model calculations have a resolution of 0.1x0.1 degree, and are only representative of regional background conditions. In reality ammonia is highly variable within the atmosphere with high concentration close to source regions or point sources and very low concentrations in background regions (far from sources). In order to capture hot spot areas, model results on much higher resolution would be necessary (e.g. through uEMEP downscaling), but that would require knowledge about the emissions (or the activity data) on a very fine resolution. Since ammonia is a short-lived gas, regional background concentrations would underestimate concentrations for source areas severely, and possibly overestimate background conditions. Therefore, exceedances of critical levels are in general expected to be underestimated for the source areas.

European scale fine resolution ammonia emissions (or activity data) are not available. However, several countries (e.g. the Netherlands, Denmark and the UK) have developed such fine resolution ammonia emission data. In order to investigate the importance of model and emission resolution for the calculation of exceedances of ammonia CLs, a next step could be to intercompare exceedance calculations using model results based on high resolution emission inventories and the ammonia emissions reported to EMEP, while at the same time checking their consistency (e.g. by aggregating the fine resolution emission data to the EMEP emissions on 0.1 x 0.1 degree.).

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A Annex 1: $CL_{emp}N$ Table for the harmonized UNECE-wide approach

Table 14 Attribution of $CL_{emp}N$ to EUNIS classes (Level 3)

51 $CL_{emp}N$ ecosystem types (Bobbink et al., 2022) were attributed to 62 EUNIS classes at Level 3; displayed in **bold** those 52 rows with a match in the receptor map; ID 12-14 have the same EUNIS code, resulting in a list of 50 EUNIS classes from the receptor map for which a CLempN could be as-signed

ID	Ecosystem type	EUNIS_group	EUNIS_code	$CL_{emp}N$
1	Atlantic upper-mid salt marshes	MA	MA223	10-20
2	**Atlantic mid-low salt marshes**	**MA**	**MA224**	**10-20**
3	Atlantic pioneer salt marshes	MA	MA225	20-30
4	**Shifting coastal dunes**	**N**	**N13**	**10-20**
5	**Shifting coastal dunes**	**N**	**N14**	**10-20**
6	**Coastal dune grasslands (grey dunes)**	**N**	**N15**	**5-15**
7	Coastal dune heaths	N	N18	10-15
8	Coastal dune heaths	N	N19	10-15
9	**Moist and wet dune slacks**	**N**	**N1H**	**5-15**
10	Dune-slack pools (freshwater aquatic communities of permanent Atlantic and Baltic or Mediterranean and Black Sea dune-slack water bodies)	N	N1H1	10-20
11	**Dune-slack pools (freshwater aquatic communities of permanent Atlantic and Baltic or Mediterranean and Black Sea dune-slack water bodies)**	**N**	**N1J1**	**10-20**
12	**Permanent oligotrophic lakes, ponds and pools (including soft-water lakes)**	**C**	**C1.1**	**2-10**
13	**Alpine and sub-Arctic clear water lakes**	**C**	**C1.1**	**2-4**
14	**Boreal clear water lakes**	**C**	**C1.1**	**3-6**
15	**Atlantic soft water bodies**	**C**	**C1.2**	**5-10**
16	Permanent dystrophic lakes, ponds and pools	C	C1.4	5-10
17	**Raised and blanket bogs**	**Q**	**Q1**	**5-10**
18	**Valley mires, poor fens and transition mires**	**Q**	**Q2**	**5-15**
19	**Palsa and polygon mires**	**Q**	**Q3**	**3-10**
20	**Rich fens**	**Q**	**Q41**	**15-25**
21	**Rich fens**	**Q**	**Q42**	**15-25**
22	Rich fens	Q	Q43	15-25
23	**Rich fens**	**Q**	**Q44**	**15-25**

ID	Ecosystem type	EUNIS_group	EUNIS_code	$CL_{emp}N$
24	Arctic-alpine rich fens	Q	Q45	15-25
25	Semi-dry Perennial calcareous grassland (basic meadow steppe)	R	R1A	10-20
26	Mediterranean closely grazed dry grasslands	R	R1D	5-15
27	Mediterranean tall perennial dry grassland	R	R1E	5-15
28	Mediterranean annual-rich dry grassland	R	R1F	5-15
29	Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta	R	R1M	6-10
30	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils	R	R1P	5-15
31	Inland sanddrift and dune with siliceous grassland	R	R1Q	5-15
32	Low and medium altitude hay meadows	R	R22	10-20
33	Mountain hay meadows	R	R23	10-15
34	Moist or wet mesotrophic to eutrophic hay meadow	R	R35	15-25
35	Temperate and boreal moist and wet oligotrophic grasslands	R	R37	10-20
36	Moss and lichen dominated mountain summits	R	R42	5-10
37	Temperate acidophilous alpine grasslands	R	R43	5-10
38	Arctic-alpine calcareous grassland	R	R44	5-10
39	Tundra	S	S1	3-5
40	Arctic, alpine and subalpine scrub habitats	S	S2	5-10
41	Lowland to montane temperate and submediterranean Juniperus scrub	S	S31	5-15
42	Northern wet heath ‘U’ Calluna-dominated wet heath (upland)	S	S411	5 - 15
43	Northern wet heath ‘L’ Erica tetralix-dominated wet heath (lowland)	S	S411	5 - 15
44	Dry heaths	S	S42	5 -15
45	Maquis, arborescent matorral and thermo-Mediterranean scrub	S	S5	5-15
46	Garrigue	S	S6	5-15
47	Broadleaved deciduous forest	T	T1	10-15
48	Fagus forest on non-acid and acid soils	T	T17	10-15
49	Fagus forest on non-acid and acid soils	T	T18	10-15

ID	Ecosystem type	EUNIS_group	EUNIS_code	$CL_{emp}N$
50	Mediterranean Fagus forest on acid soils	T	T18	10-15
51	**Acidophilous Quercus forest**	**T**	**T1B**	**10-15**
52	**Carpinus and Quercus mesic deciduous forest**	**T**	**T1E**	**15-20**
53	Mediterranean evergreen	T	T21	10-15
54	**Coniferous forests**	**T**	**T3**	**3-15**
55	**Temperate mountain Picea forest**	**T**	**T31**	**10-15**
56	**Temperate mountain Abies forest**	**T**	**T32**	**10-15**
57	**Mediterranean mountain Abies forest**	**T**	**T33**	**10-15**
58	**Temperate continental Pinus sylvestris forest**	**T**	**T35**	**5-15**
59	**Mediterranean montane**	**T**	**T37**	**5-17**
60	**Mediterranean lowland to submontane Pinus forest**	**T**	**T3A**	**5-17**
61	**Dark taiga**	**T**	**T3F**	**3-5**
62	**Pinus sylvestris light taiga**	**T**	**T3G**	**2-5**

B Annex 2: NFC Response to the Call for Data 2023/24

B.1 Description of the goals

The aim of the CfD 2023/2024 was to apply the new values on $CL_{emp}N$ to the national receptor maps and provide the results as plain text files so that the national data can be included by CCE in the European database for $CL_{emp}N$[4].

B.2 Summary on the data delivery

The following 13 countries delivered reports and data:

Table 15 **Statistics for $CL_{emp}N$ (in [kg/(ha yr)]) delivered by the NFC within the CfD 2023/24**

	CLempN (min)	CLempN (mean)	CLempN (max)	Valid records
AT	5,0	7,9	15,0	10.894
BE(FL)	6,0	18,2	34,0	71.423
BE(WA)	9,0	18,2	20,0	27.763
BG	3,6	17,1	37,9	17
CH	4,0	9,1	20,0	17.532
CZ	7,5	11,3	17,5	7.574
DE	7,5	12,1	20,0	1.187.305
ES	5,0	7,8	15,0	269.212
FI	2,0	4,7	15,0	29.032
IT	2,0	8,5	15,0	366.119
NL	5,7	14,0	25,0	168.355
NO	2,0	4,5	10,0	166.332
PL	7,5	10,5	20,0	256.860
SE	3,0	3,9	20,0	7.982
UK	5,0	8,5	10,0	37.242

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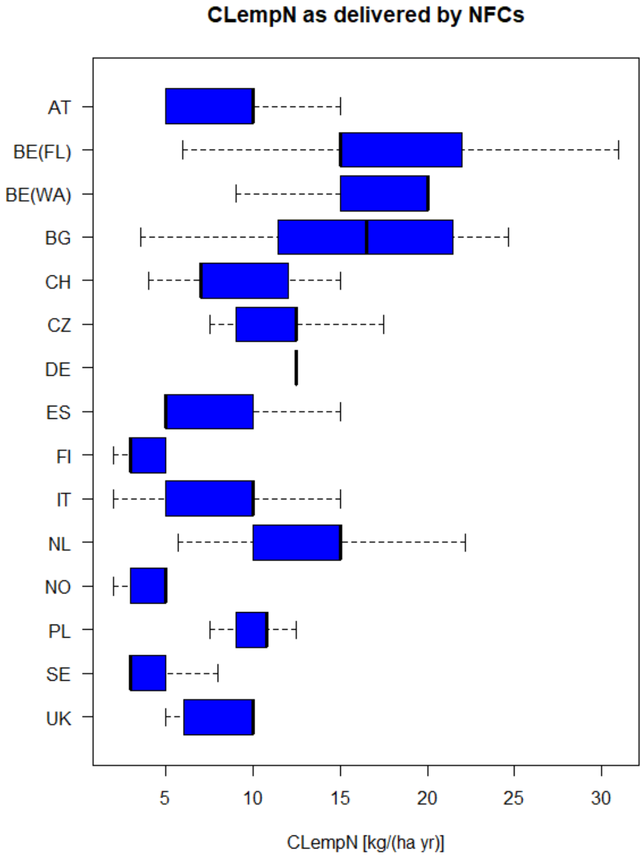
[4] https://www.umweltbundesamt.de/en/call-for-data

Figure 13 Distribution of the data delivered by the NFC within the CfD 2023/24



Source: UBA, CCE, own source

Due to the variety of different NFC approaches, the integration of the NFC data into a single database UNECE wide database built up by CCE (chapter 1.2.1) comes with some challenges. These effects arose, for example, from a lack of spatial coverage, missing data for certain parts of the country and rounding errors in the transmitted location coordinates.

Furthermore, several NFC did not only report CL data and CL choices for those EUNIS codes which are described in Bobbink et al. (2022) but provided data also for other EUNIS classes and/or sub-units of the existing codes or in the old EUNIS codes format.

B.3 Table reflecting the NFC choice of the $CL_{emp}N$ range used for the harmonized mapping approach

For those EUNIS classes described in Bobbink et al. (2022), where NFC data was available, the arithmetic average (not area weighted) of all attributed national data choices was calculated and then applied across the whole domain of the receptor map in a harmonized way. The calculated average values based on NFC choices are displayed in Table 16 in comparison to the original average values of the original range.

Table 16 **Comparison of mid-point $CL_{emp}N$ after Bobbink et al. (2022) with arithmetic average of NFC reported $CL_{emp}N$**

ID	Ecosystem type	EUNIS group	EUNIS code	$CL_{emp}N$ mid-point	$CL_{emp}N$ NFC choice[1]
1	Atlantic upper-mid salt marshes	MA	MA223	15	12,5
2	Atlantic mid-low salt marshes	MA	MA224	15	12,5
3	Atlantic pioneer salt marshes	MA	MA225	25	
4	Shifting coastal dunes	N	N13	15	10,0
5	Shifting coastal dunes	N	N14	15	10,0
6	Coastal dune grasslands (grey dunes)	N	N15	10	5,0
7	Coastal dune heaths	N	N18	12,5	
8	Coastal dune heaths	N	N19	12,5	
9	Moist and wet dune slacks	N	N1H	10	5,0
10	Dune-slack pools (freshwater aquatic communities of permanent Atlantic and Baltic or Mediterranean and Black Sea dune-slack water bodies)	N	N1H1	15	
11	Dune-slack pools (freshwater aquatic communities of permanent Atlantic and Baltic or Mediterranean and Black Sea dune-slack water bodies)	N	N1J1	15	
12	Permanent oligotrophic lakes, ponds and pools (including soft-water lakes)	C	C1.1	6	2,0
13	Alpine and sub-Arctic clear water lakes	C	C1.1	3	3,0
14	Boreal clear water lakes	C	C1.1	4,5	3,0
15	Atlantic soft water bodies	C	C1.2	7,5	
16	Permanent dystrophic lakes, ponds and pools	C	C1.4	7,5	5,0
17	Raised and blanket bogs	Q	Q1	7,5	6,3
18	Valley mires, poor fens and transition mires	Q	Q2	10	8,0
19	Palsa and polygon mires	Q	Q3	6,5	4,0
20	Rich fens	Q	Q41	20	14,2
21	Rich fens	Q	Q42	20	13,3
22	Rich fens	Q	Q43	20	19,0
23	Rich fens	Q	Q44	20	15,0
24	Arctic-alpine rich fens	Q	Q45	20	15,0

ID	Ecosystem type	EUNIS group	EUNIS code	$CL_{emp}N$ mid-point	$CL_{emp}N$ NFC choice[1]
25	Semi-dry Perennial calcareous grassland (basic meadow steppe)	R	R1A	15	12,5
26	Mediterranean closely grazed dry grasslands	R	R1D	10	5,0
27	Mediterranean tall perennial dry grassland	R	R1E	10	5,0
28	Mediterranean annual-rich dry grassland	R	R1F	10	5,0
29	Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta	R	R1M	8	6,4
30	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils	R	R1P	10	6,0
31	Inland sanddrift and dune with siliceous grassland	R	R1Q	10	6,7
32	Low and medium altitude hay meadows	R	R22	15	11,0
33	Mountain hay meadows	R	R23	12,5	11,4
34	Moist or wet mesotrophic to eutrophic hay meadow	R	R35	20	16,7
35	Temperate and boreal moist and wet oligotrophic grasslands	R	R37	15	11,7
36	Moss and lichen dominated mountain summits	R	R42	7,5	5,0
37	Temperate acidophilous alpine grasslands	R	R43	7,5	7,1
38	Arctic-alpine calcareous grassland	R	R44	7,5	7,5
39	Tundra	S	S1	4	
40	Arctic, alpine and subalpine scrub habitats	S	S2	7,5	6,4
41	Lowland to montane temperate and submediterranean Juniperus scrub	S	S31	10	5,0
42	Northern wet heath ‘U’ Calluna-dominated wet heath (upland)	S	S411	10	5,0
43	Northern wet heath ‘L’ Erica tetralix-dominated wet heath (lowland)	S	S411	10	5,0
44	Dry heaths	S	S42	10	7,5
45	Maquis, arborescent matorral and thermo- Mediterranean scrub	S	S5	10	5,0

ID	Ecosystem type	EUNIS group	EUNIS code	$CL_{emp}N$ mid-point	$CL_{emp}N$ NFC choice[1]
46	Garrigue	S	S6	10	
47	Broadleaved deciduous forest	T	T1	12,5	11,6
48	Fagus forest on non-acid and acid soils	T	T17	12,5	11,0
49	Fagus forest on non-acid and acid soils	T	T18	12,5	12,5
50	Mediterranean Fagus forest on acid soils	T	T18	12,5	10,0
51	Acidophilous Quercus forest	T	T1B	12,5	11,0
52	Carpinus and Quercus mesic deciduous forest	T	T1E	17,5	15,5
53	Mediterranean evergreen	T	T21	12,5	10,0
54	Coniferous forests	T	T3	9	9,7
55	Temperate mountain Picea forest	T	T31	12,5	11,0
56	Temperate mountain Abies forest	T	T32	12,5	10,6
57	Mediterranean mountain Abies forest	T	T33	12,5	10,0
58	Temperate continental Pinus sylvestris forest	T	T35	10	9,4
59	Mediterranean montane	T	T37	11	5,0
60	Mediterranean lowland to submontane Pinus forest	T	T3A	11	5,0
61	Dark taiga	T	T3F	4	3,0
62	Pinus sylvestris light taiga	T	T3G	3,5	2,0

[1] empty cells denote, that there was no national data available in any of the national datasets; for gap filling, the minimum value of the original $CL_{emp}N$ range was used for the mapping

C Annex 3: Country Reports CfD 23/24 $CL_{emp}N$

C.1 Austria

National Focal Centre
Thomas Dirnböck, Karl Knaebel **Umweltbundesamt – Perspektiven für Umwelt & Gesellschaft**

Explanatory notes

The empirical Critical Loads (CL_{emp}) for nitrogen from Bobbink and Hettelingh (Bobbink & Hettelingh, 2011) were updated on the basis of a comprehensive review and the involve-ment of a large number of experts Bobbink, Loran and Tomassen, 2022 (Bobbink et al., 2022). This new assessment is based on the current EUNIS habitat classification. A link be-tween the old and new EUNIS codes did not previously exist and was added for this project in order to link the new CL_{emp} values to the habitat map of Austria. The empirical Critical Loads were then defined for the sensitive ecosystem types occurring in Austria. As in previous years, the minimum value of the range speci-fied in Bobbink, Loran and Tomassen from 2022 (Bobbink et al., 2022) was used - with a few exceptions. Note that in Austria, empirical Critical Loads are only used for non-forest eco-systems. Details on the categorisation can be found in Table 17.

Table 17 Updated CL_{emp} values used in Austria

EUNIS 2012			EUNIS 2022					CL_{emp}N for Austria		
Code	**Habitat/Ecosystem Type**	**CL_{emp} AT (min-max)[1]**	**EUNIS-Code 2022**	**CL_{emp} min[2]**	**CL_{emp} max[2]**	**Uncertainty[2]**	**Effects[2]**	**EUNIS-Code 2022 used for CL_{emp}[3]**	**CL_{emp} AT[3]**	**Note**
D1	Raised and blanked bogs	5 (5 – 10)	Q1	5	10	##	Increase in vascular plants; decrease in bryophytes; altered growth and species composition of bryophytes; increased N in peat and peat water	Q1	5	Minimum value
D1.1	Raised bogs	5 (5 – 10)	n.a.					Q1	5	CL_{emp} of Q1
D1.2	Blanket bogs	5 (5 – 10)	n.a.					Q1	5	CL_{emp} of Q1
D2	Valley mires, poor fens and transition mires	10 (10 – 15)	Q2	5	15	##	Increase in sedges and vascular plants; negative effects on bryophytes	Q2	5	Minimum value
D2.3	Transition mires and quaking bogs	10 (10 – 15)	n.a.					Q2	5	CL_{emp} of Q2
D4	Base-rich fens and calcareous spring mires	15 (15 – 30)	Q4					Q4	15	No new CL_{emp} assessment
D4.1	Rich fens, including eutrophic tall-herb fens and calcareous flushes and soaks	15 (15 – 30)	Q4.1	15	25	#	Increase in tall vascular plants (especially graminoids); decrease in bryophytes	Q4.1	15	Minimum value
D4.2	Basic mountain flushes and streamsides, with a rich arctic-montane flora	15 (15 – 25)	Q4.2	15	25	#	Increase in tall vascular plants (especially graminoids); decrease in bryophytes	Q4.2	15	Minimum value
D4.22	Alpine riverine [Carex maritima] ([Carex incurva])	15 (15 – 25)	n.a.					Q4.2	15	No new CL_{emp} assessment; Q4.2 value

EUNIS 2012			**EUNIS 2022**					**$CL_{emp}N$ for Austria**		
E1	Dry grasslands	15 (15-25)	R1					R1	10	no new CL_{emp} assessment; minimum value of subgroups
E1.1	Inland sand and rock with open vegetation	15 (15-25)	R1.1; R1.6; R1.8					R1	10	no new CL_{emp} assessment; R1 value
E1.12	Euro-Siberian pioneer calcareous sand swards	15 (15-25)	R1.3					R1	10	R1 value
E1.2	Perennial calcareous grassland and basic steppes	15 (15-25)	R1A	10	20	##	Increase in tall grasses; decline in diversity; change in species composition; increased mineralisation; N leaching; surface acidification	R1	10	Minimum value
E1.22	Arid subcontinental steppic grassland ([Festucion valesiacae])	15 (15-25)	R1B1					R1	10	R1 value
E1.23	Meso-xerophile subcontinental meadow-steppes ([Cirsio-Brachypodion])	15 (15-25)	R1B2					R1	10	R1 value
E1.24	Central alpine arid grassland ([Stipo-Poion])	15 (15-25)	R1B3					R1	10	R1 value
E1.26	Sub-Atlantic semi-dry calcareous grassland	15 (15-25)	R1A3					R1	10	R1 value
E1.27	Sub-Atlantic very dry calcareous grassland	15 (15-25)	R1A4					R1	10	R1 value
E1.29	Pale fescue grassland	15 (15-25)	R1B5					R1	10	R1 value
E1.2B	Serpentine steppes	15 (15-25)	R1B6					R1	10	R1 value

EUNIS 2012			**EUNIS 2022**					**$CL_{emp}N$ for Austria**		
E1.2C	Pannonic loess steppic grassland	15 (15-25)	R1B7					R1	10	R1 value
E1.7	Closed non-Mediterranean dry acid and neutral grassland	10 (10-15)	R1M	6	10	##	Increase in graminoids; decline of typical species; decrease in total species richness	R1M	6	Minimum value
E1.76	Dry sub-continental acid steppic grasslands	10 (10-15)	R1M6					R1M	6	R1M value
E1.9	Open non-Mediterranean dry acid and neutral grassland, including inland dune grassland	15 (15-25)	R1P, R1Q	5	15	(#)		R1P, R1Q	5	Minimum value
E1.99	Pannonic inland dunes	15 (15-25)	R1Q7					R1Q	5	R1Q value
E1.D	Unmanaged xeric grassland	15 (15-25)	R1					R1	10	R1 value
E2.2	Low and medium altitude hay meadows	20 (20-30)	R22	10	20	(#)	Increase in tall grasses; decrease in diversity; decline of typical species	R2.2	10	Minimum value
E2.3	Mountain hay meadows	20 (10-20)	R23	10	15	#	Increase in nitrophilous graminoids; changes in diversity; decline of typical species	R2.3	10	Minimum value
E3.5	Moist or wet oligotrophic grassland	15 (15-25)	R37	10	20	#	Increase in tall graminoids; decreased diversity; decrease in bryophytes	R3.7	10	Minimum value
E4	Alpine and subalpine grasslands	5 (5-10)	R4					R4	5	R4.4 value
E4.3	Acid alpine and subalpine grassland	5 (5-10)	R4.3	5	10	#	Changes in species composition; increase in plant production	R4.3	5	Minimum value

EUNIS 2012			**EUNIS 2022**					**CL_{emp}N for Austria**		
F2	Arctic, alpine and subalpine scrub	5 (5-15)	S2	5	10	#	Decline in lichens; bryophytes and evergreen shrubs	S2	5	Minimum value
F2.2	Evergreen alpine and subalpine heath and scrub	5 (5-15)	S22					S2.2	5	S2 value
F2.3	Subalpine deciduous scrub	15 (5-15)	S25					S2.5	10	maximum S2 value (mostly meso/eutrophic habitats)
F2.4	Conifer scrub close to the tree limit	5 (5-15)	S26					S2.6	10	maximum S2 value (mostly meso/eutrophic habitats)
F4.2	Dry heaths	10 (10-20)	S42	5	15	##	Transition from heather to grass dominance; decline in lichens; changes in plant biochemistry; increased sensitivity to abiotic stress	S4.2	10	Minimum value (mainly not managed)

[1] latest CL_{emp} value used in Austria according to Bobbink and Hettelingh (2011)

[2] ## reliable; # quite reliable and (#) expert judgement

[3] EUNIS Code used to set new CL_{emp} value

[4] new CL_{emp} value used in Austria

C.2 Belgium (Flanders)

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C.2.1 Introduction

Newly derived Critical Loads for N deposition for the main Flemish habitats and regionally protected ecosystem types were recently published in 2 advises from the Research Institute for Nature and Forest (Vanden Borre, De Keersmaeker, et al., 2024; Vanden Borre, Neirynck, et al., 2024). Although these Critical Loads are not yet the given standard in Flanders (Belgium) and the values are not implemented in the Nitrogen Decree (Decree of 26 January 2024 on the Integrated Approach to Nitrogen, published in the Belgian Official Journal on 22 February 2024), it was eventually decided to answer the recent call for data on empirical Critical Loads. A procedure to accept the new list based on the most recent UN report (Bobbink et al., 2022) is currently running at several administrative courts.

C.2.2 Methods

Critical Loads for Natura 2000 habitats in Flanders have been identified using an integrated method of an empirical and modelling approach, which is currently applied in the Netherlands (Wamelink et al., 2023). This approach was adopted because of the high similarity in natural habitats occurring in Northern Belgium. Also, the presence of a large border area, which is exposed to high transboundary nitrogen exchange due to agricultural activities, justified this choice. Moreover, the use of unique values instead of ranges of Critical Loads is more convenient to judge assess whether the Critical Load for a given habitat has been exceeded or not. Unlike the previous time (Hens & Neirynck, 2013), the Dutch Critical Loads were not simply copied (with some adaptations) to the Flemish habitats, but the integrated method was applied in its entirety to the Flemish habitats, leading to some differences between Dutch and Flemish Critical Loads for specific subtypes of habitats. The report of Bobbink et al. 2022 (Bobbink et al., 2022) defined the upper and lower limits within which the Critical Load had to fall.

The mapping of empirical Critical Loads was based on the most recent version of the Flemish vegetation map (De Saeger S. et al., 2023). 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 using polygons. Its land cover classes along with vegetation types are defined by an extensive list of legend units. Each polygon consists of up to 5 units, from which the unit with the lowest Critical Load was selected in the mapping. The classification for the CL vegetation map was done by classifying the relevant polygons (ecords) into 64 ecosystem types, according to the instructions by the CCE. In addition to this existing list, we also submitted Critical Loads from 8 protected ecosystem types, occurring in Flanders (Table 18).

Table 18 Supplementary table of additional vegetation types, which were also included in the current Flemish submission.

ID	Ecosystem type	EUNIS_group	EUNIS_code	$CL_{emp}N$ (eq $ha^{-1}a^{-1}$)
65	Charophyte submerged carpets in mesotrophic waterbodies	C	C1.25	2142
66	Permanent eutrophic lakes, ponds and pools	C	C1.3	2142
67	Atlantic and Baltic coastal dune scrub	N	N1A	1428-1928
68	Atlantic and Baltic moist and wet dune slack	N	N1H	1428
69	Tall-sedge bed	Q	Q53	1713
70	Shady woodland edge fringes, Nitro-hygrophilous communities of usually large-leaved herbs developing along the shaded side of wooded stands and hedges	R	R553	1856
71	Xero-thermophile scrub communities of Western Europe and western Central Europe	R	S3512	1428
72	Salix fen scrub	S	S92	1499-2142

C.2.3 Results

The total Flemish Eco Area amounted to 837.9 km^2, representing 6.2 % of the total Flemish surface area (Table 19). Forests (T) are the prevailing ecosystem types, covering 55 % of the total Eco area. The median Critical Load from all ecords is 1071 eq ha^{-1} a^{-1}. The EUNIS group C (inland surface water habitats) had the lowest median Cl (500 eq ha^{-1} a^{-1}), followed by heatlands (S), which median Critical Load amounted to 714 eq ha^{-1} a^{-1} (Figure 14).

Figure 14 Box-plots of empirical Critical Load values from the 7 EUNIS classes, based on the selected ecords (in eq ha^{-1} a^{-1}, n = 71423)

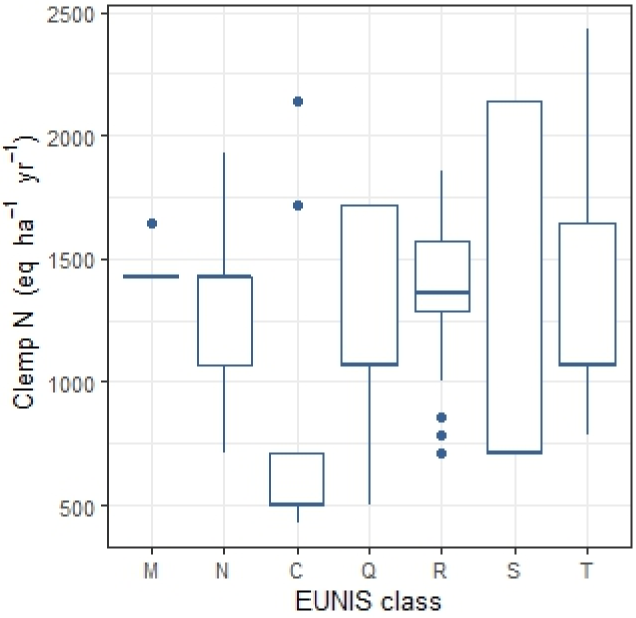

Table 19 Surface area from the occurring EUNIS classes and corresponding median empirical Critical Load in Flanders.

EUNIS class	surface (ha)	CL_{emp} (eq a^{-1} yr^{-1})
M	274	1428
N	2278	1428
C	2794	500
Q	1547	1071
R	18758	1356
S	11697	714
T	46444	1071
All	83792	1071

C.3 Belgium (Wallonia)

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C.3.1 Regional Data Produced

Critical loads data have been produced for forests (coniferous, deciduous, mixed forests) and natural vegetation in Wallonia. Natura 2000 ecosystems are included in mapping of natural vegetation ecosystems.

C.3.2 Mapping procedure Wallonia

From Walloon Land Cover Map, 27.344 forest ecosystems area (>1 ha) were extracted and overlaid with thematic maps in order to calculate critical loads parameters. From Corine Land Cover 2006, four natural ecosystem types (representing 136 ecosystems area) were extracted and assigned to a theoretical value according to ecosystem type.

C.3.3 Calculation methods & results Wallonia

Forest soils

Since 2010, the Walloon region has been monitoring forest ecosystems and calculating critical loads using steady-state methods for eutrophication and acidification.

From then on, critical load values are calculated for each type of soil and each forest species.

In the absence of empirical data for Walloon forest ecosystems, the critical load values obtained via SMB model were used. If the calculated value is not included in the range of empirical values proposed for the ecosystems classified according to EUNIS T1E and T3 by table 5.1 from Manual on Methodologies and criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks, and Trends (CCE, 2024b), then the critical load is set at the minimum or maximum value of the interval.

For mixed forests (mixture of deciduous and coniferous trees), the EUNIS G4 code has not been transposed into the EUNIS 2022 code, no interval of empirical values is proposed. For these ecosystems, empirical N critical loads of 15 kg N ha^{-1} yr^{-1} is applied which corresponds to the maximum value for conifers (EUNIS T3) and the minimum value for deciduous trees (T1E).

We observe that the critical load values calculated by the steady state (CL_{nut}) method (Figure 15) are higher than the empirical values proposed by table 5.1. Therefore, the value for deciduous forests is 20 kg N ha^{-1} yr^{-1} and for coniferous 15 kg N ha^{-1} yr^{-1} (Figure 16).

Are the criteria/indicators that were chosen to define the empirical critical load adequate? For forests, is it relevant to use the change in ground vegetation as indicators, rather than the health of the trees?

Natural vegetations

For Walloon ecosystems, considering the lack of accurate input data, we use critical values established in Flanders with SMB method (Meykens & Vereecken, 2001). The critical loads for N to natural vegetations are reported in Table 20.

A transposition of the EUNIS 2012 codes into EUNIS 2022 codes was attempted.

Table 20 Critical loads for natural vegetations in Wallonia

Ecosystem type	EUNIS code 2012	EUNIS code 2022	CL nut = CLempN
Natural grassland	E1	R1A	1286
Moors and heathland	F4.2	S42	643
Inland marshes	D5	R5	786
Peat bogs-Fens	D2	Q2	786

As the critical load values calculated according to the Steady-state methodology fall within the intervals proposed by table 5.1, the CL_{nut} Value was retained. For the EUNIS D5/R5 code no empirical values are proposed.

Figure 15 Critical loads of nutrient nitrogen for forests, CLNut(N)- Steady State model

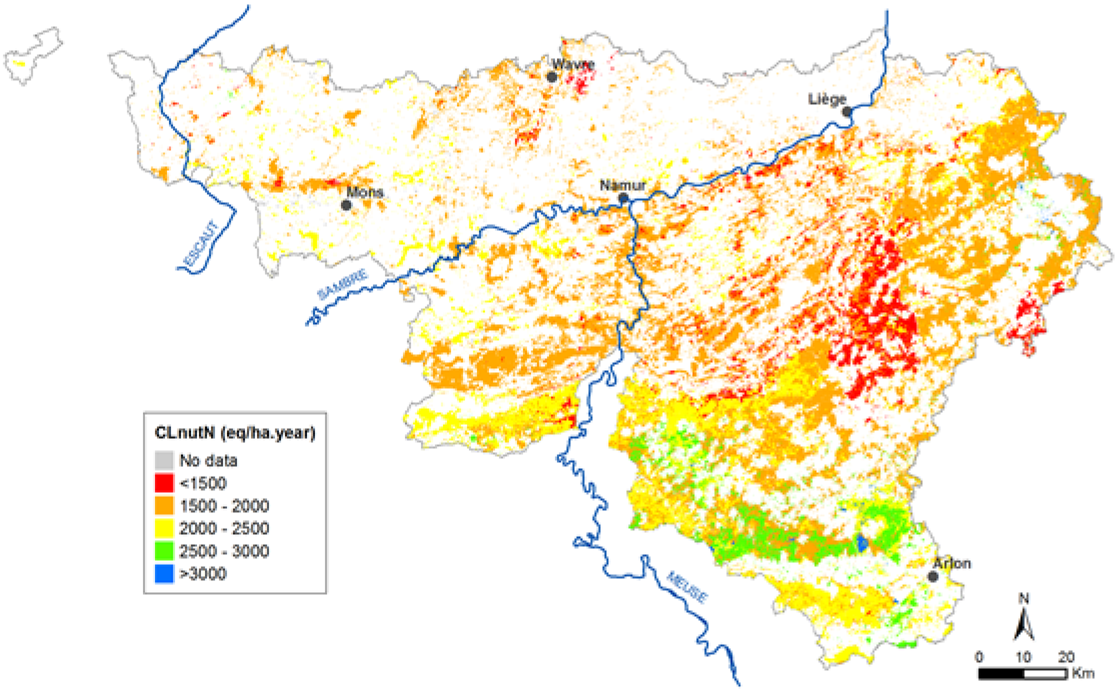
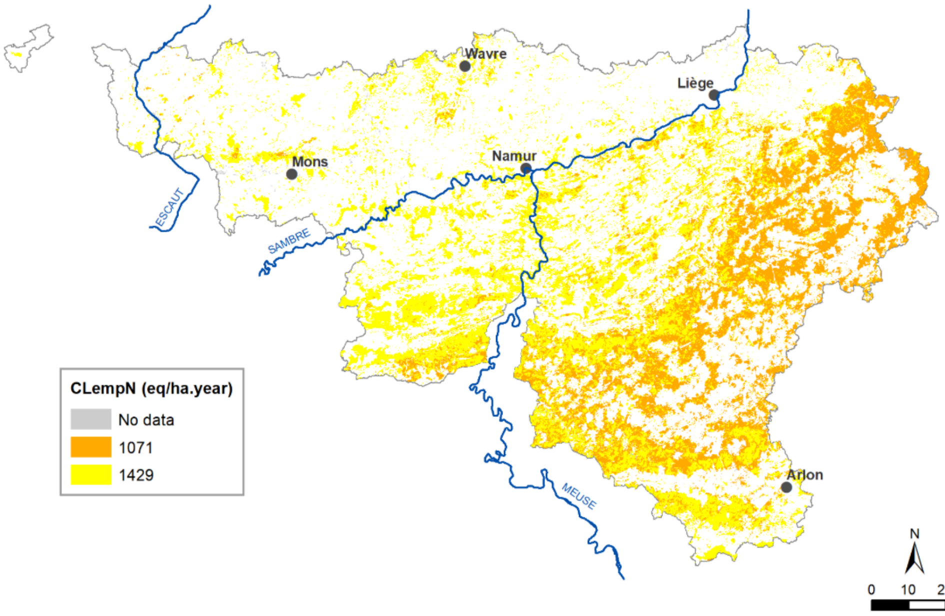


Figure 16 Critical loads of nitrogen for forests, $CL_{emp}N$



C.4 Bulgaria

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The comparison of the amount of precipitation under the assembly of tree vegetation in the forest plantations and in the experimental sample sites covered by other types of vegetation shows that the largest amounts of precipitation were measured in the sites 7310 (902.30 mm) and 7187 (796.98 mm).

The average annual pH values of the precipitation ranged from 5.29 (site 7257) to 5.99 (site 7415). It is established that acid precipitation is recorded in sample sites 7257 (5.29), 7470 (5.35) and 7184 (5.50).

The highest value for the annual inorganic nitrogen-containing deposits (2705.04 $eq.ha^{-1}.yr^{-1}$) was found for the shrub vegetation in the 7310 site, while the main share of the deposits is being due to the input of nitrate deposits (2485.82 $eq.ha^{-1}.yr^{-1}$).

The highest sulfate deposits which income with precipitation were found for wetland site C677275 and for the shrub ecosystem in site 7257, 531.82 and 531.50 $eq.ha^{-1}.yr^{-1}$, respectively. The amounts recorded in the agricultural sites C677101 (496.78 $eq.ha^{-1}.yr^{-1}$), C677494 (484.98 $eq.ha^{-1}.yr^{-1}$) and 7187 (448.49 $eq.ha^{-1}.yr^{-1}$) are also high.

The highest total amount of acidifying deposits of nitrogen and sulfur compounds was found for experimental site 7310 characterized by shrub vegetation cover (3059.22 $eq.ha^{-1}.yr^{-1}$), which is mainly due to the reported high amount of inorganic nitrogen-containing deposits and the most-large amounts of precipitation.

Deposited basic cations with precipitation are one of the main components of the balance equation in the positive-sign Steady State Mass Balance critical loads method, contributing significantly to increasing the tolerance of different types of ecosystems to acid deposition as they neutralize it.

Regarding the annual deposition of basic cations, it is found that the most neutralizing ions are deposited in the site 7187 covered by meadow vegetation (3207.23 $eq.ha^{-1}.yr^{-1}$). High values were also recorded for the meadow vegetation in the site 7295 (2793.33 $eq.ha^{-1}.yr^{-1}$) and in the agricultural area 7494 (2638.30 $eq.ha^{-1}.yr^{-1}$). The lowest values of the deposition of basic ions were found in 2004 (313.99 $eq.ha^{-1}.yr^{-1}$) and for the spruce forest ecosystem in 2005 (348.97 $eq.ha^{-1}.yr^{-1}$).

High values are reported for lead and cadmium deposits in the studied forest sites. In terms of cadmium deposits, the highest amounts were found for meadow vegetation in site 7295 (938.30 $g.ha^{-1}.yr^{-1}$). The values for lead deposits found for shrub ecosystem in 7310 (902.30 $g.ha^{-1}.yr^{-1}$) are high, followed by those for meadow ecosystem in site 7187 (796.98 $g.ha^{-1}.yr^{-1}$). The lowest deposits of the two heavy metals, lead and cadmium, are observed in grassland site 7176 and in 2004.

In half of the investigated sample areas, it was found that the deposits of basic cations were in greater quantities and successfully compensated the acid deposits coming with the precipitation. The ratio of basic and acidic deposits is unfavorable in the four forest ecosystems, in the grasslands of 7469 and 7176, in the agricultural areas of 7423 and 7187, as well as in the shrub ecosystem in 7310, for which higher levels of acidifying deposits were reported, compared to those of alkalizing deposits.

C.5 Czech Republik

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C.5.1 Introduction

This document gives an overview of the response by the Czech Republic to the Call for Data (CfD) 2023 on empirical Critical Loads, which has been agreed at the 38th meeting of the ICP Modelling and Mapping Task Force along with the 29th meeting of the Coordination Centre for Effects on 3–5 May 2022. The submitted data represent the updated national critical load database and contain “$CL_{eut}N$”.

C.5.2 Methods and data

We used a new updated 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 empirical Critical Loads $CL_{emp}N$, according to Bobbink et al. (Bobbink et al., 2022), were used and updated only for the EUNIS habitats, where the empirical Critical Load for eutrophication by nitrogen was lower than $CL_{nut}N$ (computed by the SMB method). Concurrently, we updated the $CL_{emp}N$ and EUNIS codes.

C.5.3 Critical loads of eutrophication *(CL_{eut})*

The table CL_{eut} contains $CL_{eut}N$ values. The minimum values between $CL_{nut}N$ (computed by the SMB method) and $CL_{emp}N$ is reported.

C.5.4 Critical load of nutrient nitrogen $CL_{nut}N$

The critical load of nutrient nitrogen was calculated as follows:

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

f_{de} … denitrification fraction

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

Equation 1

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

The submitted values of acceptable N concentration were calculated as:

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

$N_{le(acc)}$ … 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 $m^3 \cdot ha^{-1} \cdot yr^{-1}$)

Equation 2

C.5.5 The empirical critical load of nitrogen $CL_{emp}N$:

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 et al., 2022) (Table 21).

Table 21 Mean values of Updated Critical Loads for selected EUNIS habitats

Habitat	EUNIS	old $CL_{emp}N$ [eq/ha/yr]	old $CL_{emp}N$ [kg/ha/yr]	updated $CL_{emp}N$ [kg/ha/yr]	updated $CL_{emp}N$ [eq/ha/yr]	$CL_{eut}N$* [eq/ha/yr]
Dry grasslands	E1	1249.5	17.5	**15**	**1071**	478
Alpine and subalpine grasslands	E4	535.5	7.5	7.5	535.5	536
Beech woodland	T1-7/ T1-8	1071	15	**12.5**	**892.5**	894
Thermophilous deciduous woodland, Acidophilous oak-dominated woodland	T1-9, T1-B	1071	15	**12.5**	**892.5**	888
Ravine and slope woodland	T1-F	1249.5	17.5	17.5	1249.5	1039
Highly artificial broadleaved deciduous forestry plantations	T1-H	1071	15	**12.5**	**892.5**	891
Highly artificial broadleaved deciduous forestry plantations and Picea abies reforestation and Native pine plantations	T1-H/ T3-27/ T3-M2	1071	15	**12.5**	**892.5**	768
Hercynian subalpine spruce forests	T3-13	892.5	12.5	12.5	892.5	798

Habitat	EUNIS	old $CL_{emp}N$ [eq/ha/yr]	old $CL_{emp}N$ [kg/ha/yr]	updated $CL_{emp}N$ [kg/ha/yr]	updated $CL_{emp}N$ [eq/ha/yr]	$CL_{eut}N$* [eq/ha/yr]
Pice abies reforestation	T3-27	714	10	**9**	**642.6**	613
Temperate continental Pinus sylvestris forest	T3-5	714	10	10	714	553
* mean value from submitted updated data for a particular EUNIS habitat						

C.6 Finland

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C.6.1 Introduction

In response to the Call for Data for 2023 empirical critical loads of nitrogen were evaluated for non-marine protected areas in Finland. In total critical loads were assessed for 40710 km2 corresponding to 12 % of the land and freshwater area of Finland. This includes 14300 km2 protected as a Special Area of Conservation (SAC) under the Habitats Directive and 20970 km2 protected also as a Special Protection Area (SPA) under the Birds Directive. Compared to the previous submissions of empirical critical loads for nitrogen (Holmberg et al., 2015; Holmberg et al., 2011) the habitat classification was updated from the earlier CORINE-based approach and newer values of the empirical critical loads were utilized (Bobbink et al., 2022).

C.6.2 Mapping of ecosystem types

The information on habitats within protected areas was derived from the Protected area compartment information system (SAKTI) of Parks and Wildlife Finland (under Metsähallitus) and the Nature 2000 site register maintained by the Finnish Environment Institute. Sites were classified into EUNIS habitats at level 3 based on information available in SAKTI (Finnish Environment Institute & Metsähallitus, 2020) – primarily based on crosswalks from Habitats directive Annex I habitat types, and utilizing other site information such as soil type, site fertility, main tree species, and bog and mire type to resolve classes for non-unique crosswalks. A total of 44 EUNIS level 3 habitat types were identified on the protected areas and they accounted for 94 % of the area of non-marine protected areas (43788 km2). The habitats' critical loads were evaluated within the 0.10°×0.05° grid separately for each protection category and EUNIS habitat type within each cell.

C.6.3 Empirical critical loads for nutrient Nitrogen

The last update of the empirical critical loads for nutrient nitrogen were used as the basis for assigning critical loads for the habitats (Bobbink et al., 2022; CCE, 2024b). The lower value of the published range was used for all habitat types to account for the assumed sensitivity of northern ecosystems with lower productivity and shorter growing seasons (CCE, 2024b). Critical loads were available for 34 of the 44 EUNIS habitat classes covering over 87 % of the non-marine protected areas (40710 km^2).

C.6.4 Changes in deposition and exceedance

Empirical critical loads of nitrogen for the protected areas in Finland were compared to modelled historical deposition estimates (EMEP, 2024). Dry depositions were assigned based on the ecosystem category in the deposition models which are assigned to matching EUNIS classes at level 1. Compared with earlier estimates (Holmberg et al., 2011) there can be small differences in the deposition estimates previously used, but mainly any differences would be due to the updated critical loads (Bobbink et al., 2022) and the use of habitat classifications available for the protected areas as opposed to the CORINE based habitat assignment used previously (Holmberg et al., 2011).

Largest reduction in areas with exceedances of critical loads have occurred in the past 20 years (Table 22). However, still approximately 10 % of protected coniferous forests (T3F, T3G, T3J, T3K) and raised bogs (Q11) had nitrogen deposition exceeding their critical loads in 2020, as well as 3 % of lakes (mainly the oligotrophic (C1.1) and dystrophic lakes (C1.4)). For coniferous forests currently legislated emission reductions would not guarantee that critical loads are not exceeded by 2040 (for emission scenarios according to van Caspel et al. (2024).

Table 22 Habitat area, $CL_{emp}N$ and area exceedances for protected areas in Finland

EUNIS code	Area km²	$CL_{emp}N$ kg ha^{-1} a^{-1}	AE (1990) km²	AE (2005) km²	AE (2020) km²	AE (2040) km²	AAE (2020) kg ha^{-1} a^{-1}
C1	3272.3	3 – 5	543.1	342.5	111.2	12.8	0.02
N1	4.6	5 – 10	0.2	0.2	0.1		0.01
Q1	1301.0	5	739.8	575.4	127.1	0.2	0.06
Q2	10067.8	5	255.6	109.1	12.4		0.00
Q3	421.9	3	0.0				
Q4	384.0	15					
R2	9.3	10	2.5	0.1			
R3	22.0	10 – 15	0.0				
R4	368.8	5					
S2	6738.1	5					
S4	19.6	5	9.7	8.8	0.1		0.00
T1	5674.4	10 – 15	7.8	0.6			
T3	12426.2	2 – 3	3105.8	2997.7	1200.8	595.2	0.11
Total	**40709.8**		**4664.6**	**4034.4**	**1451.7**	**608.2**	**0.04**

Values summarized at EUNIS level 2. Empty fields indicate no exceedance. CLempN ranges show the variation of $CL_{emp}N$ among the EUNIS level 3 classes included. AE area with $CL_{emp}N$ exceeded. AE (2040) is for the January 2025 GP_WGE scenario for Current Legislation 2040. AAE: average accumulated exceedance; calculation includes areas not in exceedance.

C.7 Germany

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C.7.1 Introduction

In response to the 2023–2024 Call for Data on empirical Critical Loads for nitrogen ($CL_{emp}N$), as agreed at the 38th meeting of the ICP Modelling and Mapping Task Force and the 29th meeting of the Coordination Centre for Effects (3–5 May 2022), Germany submits an updated national dataset of empirical Critical Loads for nitrogen. The submission builds on the revised empirical Critical Load ranges published byBobbink et al. (2022), which were derived through an extensive expert review and are based on the current EUNIS habitat classification. These updated $CL_{emp}N$ ranges were assigned to German ecosystem types using the national receptor map which was also the basis for the data delivery for the CfD 2017/18. Where necessary, linkages between habitat classifications were applied to ensure consistency with the national habitat mapping.

As empirical Critical Loads are provided as ranges (e.g. 5–10 kg N ha^{-1} yr^{-1}), a single value is required for exceedance calculations and the preparation of spatial maps. The average value of the respective $CL_{emp}N$ range was therefore applied consistently across all ecosystem types, providing a pragmatic and reproducible solution without implying a preference for a particular interpretation of the range.

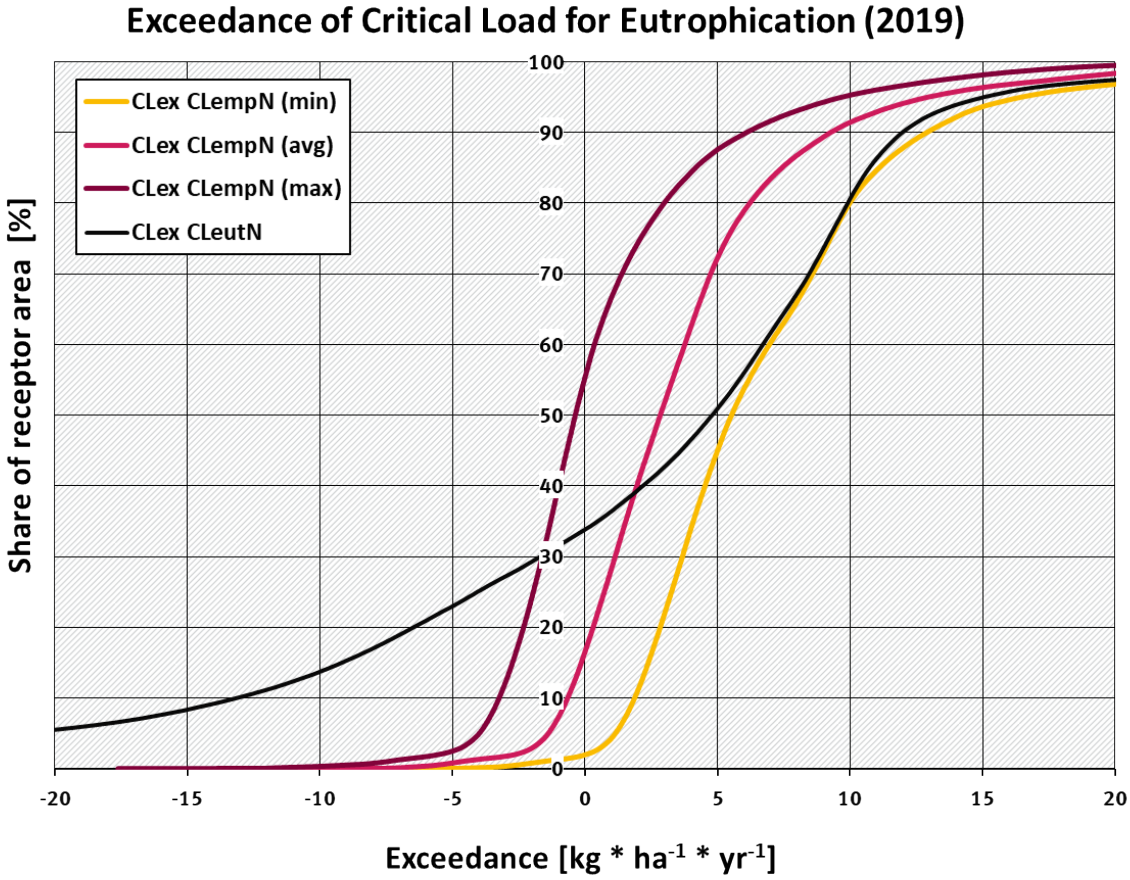
The German approach follows the methodology already applied by several other Parties in response to the Call for Data, aiming at a harmonised and transparent implementation of the updated empirical Critical Loads while reflecting national ecosystem characteristics. The submitted dataset provides a consistent basis for assessing nitrogen deposition exceedances and supporting effects-oriented analyses under the Convention.

C.7.2 Materials and methods

This exercised is based on the receptor map which was already the basis for the Steady-State/SMB Critical Loads delivered for the CfD 2017/18. This dataset covers about 106.975 km^2 of the area of Germany. An extensive description can be found in Schlutow et al. (2018). The original receptor map contains information about 210 different habitat types, which are directly linked to the NATURA 2000 classification sheme. The link between this information and the EUNIS classes listed in the $CL_{emp}N$ table was done by expert knowledge (201 matches) on basis of the BERN model (Schlutow et al., 2024). Only for about 10% of the receptor area no match could be made. Most missing links are in variations of Oak forests on acid sand (9190) and Central

European lichen-pine forests (91T0). The mid point of the $CL_{emp}N$ range was the assigned as final number. This was done after analyzing the impact of the different $CL_{emp}N$ values (min, mid, max) in contrast to the $CL_{eut}N$ (see Figure 17). The impact was assest by comparing the CL exceedance based on Nitrogen deposition in the year 2019 which was derived from the PINETI IV project (Kranenburg et al., 2024).

Figure 17 **CL exceedance in Germany**



C.7.3 Results and Outlook

The resulting dataset covers approximately 98.000 km^2 of Germany for which $CL_{emp}N$ values are available. The absolute and relative shares of the individual $CL_{emp}N$ values are presented in Table 23 $CL_{emp}N$ in the German dataset. The most frequent value is 12,5 [kg ha^{-1} yr^{-1}] accounting for around 74% of the total area.

As a next step, the German NFC plans to assess whether the assigned $CL_{emp}N$ values can be used to further strengthen the $CL_{eut}N$ dataset. This includes testing the use of the upper and lower bounds of the $CL_{emp}N$ range as empirically based thresholds to identify and potentially remove extreme modelled $CL_{eut}N$ values.

Table 23 CL$_{emp}$N in the German dataset

CLempN (mid) [kg ha^{-1} yr^{-1}]	Area [km^2]	Area [%]
7,5	837	0,9
8	232	0,2
10	2.1971	22,4
12,5	72.753	74,1
15	729	0,7
17,5	1.568	1,6
20	58	0,1
All	98.149	100,0

C.8 Italy

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C.8.1 Introduction

The Call for Data 2023-2024 on Empirical 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 was to review and update empirical Critical Loads ($CL_{emp}N$), The Italian NFC answered the call by applying the CL_{emp} ranges (Bobbink et al. 2022) to ecosystems according to the EUNIS classification at the 3rd level, using an EMEP grid of 0.1°x0.05°.

Previously, CLs had been produced using the SMB model, calculated over the national territory on the same grid, in response to the 2015 call for data.

We evaluated which of the two indicators was more protective for biodiversity, concluding that the empirical critical load safeguards a larger area.

C.8.2 Materials and methods

For the calculation of empirical critical loads, we used:

- The raster-format map of receptor ecosystems provided by the CCE
- The table of CL_{emp} ranges produced by Bobbink et al. (Bobbink et al., 2022)
- The EMEP grid (0.1°x0.05°)
- The Natura 2000 areas map

In a GIS environment, the receptor ecosystem map was converted from raster to vector format to allow for the clipping of ecosystems based on the EMEP grid cells and to calculate the surface area of each ecosystem within each cell.

Each ecosystem was assigned the minimum CL_{emp} value associated with it according to Table 24.

Table 24 CL_{emp} range value for EUNIS class 3° liv

EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max		EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max
2103	Atlantic and Baltic shifting coastal dune	10	20		6502	Submediterranean pseudomaquis	5	15
2104	Mediterranean, Macaronesian and Black Sea shifting coastal dune	10	20		6503	*Spartium junceum* scrub	5	15
2105	Atlantic and Baltic coastal dune grassland (grey dune)	5	15		6504	Thermomediterranean arid scrub	5	15
2117	Atlantic and Baltic moist and wet dune slack	5	15		6601	Western basiphilous garrigue	5	15
2118	Mediterranean and Black Sea moist and wet dune slack	10	20		6602	Western acidophilous garrigue	5	15
3102	Permanent oligotrophic lakes, ponds and pools	2	10		6603	Eastern garrigue	5	15
4101	Raised bogs	5	10		6604	Macaronesian garrigue	5	15
4102	Blanket bogs	5	10		6605	Mediterranean gypsum scrub	5	15
4202	Poor fens and soft-water spring mires	5	15		6606	Mediterranean halo-nitrophilous scrub	5	15

EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max		EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max
4203	Apennine acidic fens	5	15		6607	Aralo-Caspian semi-desert	5	15
4204	Intermediate fen and soft-water spring mire	5	15		6608	Semi-desert sand dune with sparse scrub	5	15
4205	Non-calcareous quaking mire	5	15		7101	Temperate *Salix* and *Populus* riparian forest	10	15
4300	Palsa and polygon mires	3	10		7102	*Alnus glutinosa-Alnus incana* forest on riparian and mineral soils	10	15
4401	Alkaline, calcareous, carbonate-rich small-sedge spring fen	15	25		7103	Temperate hardwood riparian forest	10	15
4402	Extremely rich moss-sedge fen	15	25		7104	Mediterranean and Macaronesian riparian forest	10	15
4404	Calcareous quaking mire	15	25		7106	Broadleaved mire forest on acid peat	10	15
4405	Arctic-alpine rich fen	15	25		7107	*Fagus* forest on non-acid soils	10	15
5113	Mediterranean closely grazed dry grassland	5	15		7108	*Fagus* forest on acid soils	10	15
5114	Mediterranean tall perennial dry grassland	5	15		7109	Temperate and submediterranean thermophilous deciduous forest	10	15

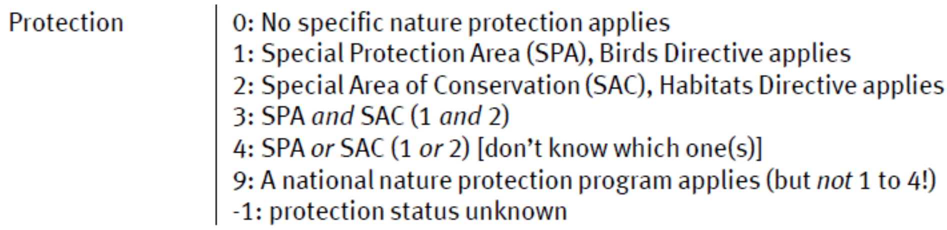
EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max		EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max
5115	Mediterranean annual-rich dry grassland	5	15		7110	Mediterranean thermophilous deciduous forest	10	15
5121	Lowland to montane, dry to mesic grassland usually dominated by *Nardus stricta*	6	10		7111	Acidophilous *Quercus* forest	10	15
5123	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils	5	15		7112	Temperate and boreal mountain *Betula* and *Populus tremula* forest on mineral soils	10	15
5124	Inland sanddrift and dune with siliceous grassland	5	15		7113	Southern European mountain *Betula* and *Populus tremula* forest on mineral soils	10	15
5202	Low and medium altitude hay meadow	10	20		7114	*Carpinus* and *Quercus* mesic deciduous forest	15	20
5203	Mountain hay meadow	10	15		7115	Ravine forest	10	15
5305	Moist or wet mesotrophic to eutrophic hay meadow	15	25		7117	Broadleaved deciduous plantation of non site-native trees	10	15
5307	Temperate and boreal moist or	10	20		7201	Mediterranean ever-	10	15

EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max		EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max
	wet oligotrophic grassland					green *Quercus* forest		
5402	Boreal and arctic acidophilous alpine grassland	5	10		7301	Temperate mountain *Picea* forest	10	15
5403	Temperate acidophilous alpine grassland	5	10		7302	Temperate mountain *Abies* forest	10	15
6101	Shrub tundra	3	5		7303	Mediterranean mountain *Abies* forest	10	15
6102	Moss and lichen tundra	3	5		7305	Temperate continental *Pinus sylvestris* forest	5	15
6201	Subarctic and alpine dwarf *Salix* scrub	5	10		7306	Temperate and submediterranean montane *Pinus sylvestris-Pinus nigra* forest	15	15
6202	Alpine and subalpine ericoid heath	5	10		7307	Mediterranean montane *Pinus sylvestris-Pinus nigra* forest	15	15
6203	Alpine and subalpine *Juniperus* scrub	5	10		7308	Mediterranean montane *Cedrus* forest	5	17
6205	Subalpine and subarctic deciduous scrub	5	10		7310	Mediterranean lowland to submontane *Pinus* forest	5	17

EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max		EUNIS G3	EUNIS LABEL	$CL_{emp}N$_min	$CL_{emp}N$_max
6206	Subalpine *Pinus mugo* scrub	5	10		7315	Dark taiga	3	5
6301	Lowland to montane temperate and submediterranean *Juniperus* scrub	5	15		7316	*Pinus sylvestris* light taiga	2	5
6401	Wet heath	5	15					
6402	Dry heath	5	15					
6501	Mediterranean maquis and arborescent matorral	5	15					

The 2020 update of the Natura 2000 areas map (https://gn.mase.gov.it/portale/home) was used to assign the protection code according to Table 25.

Table 25 Code corresponding to protection type

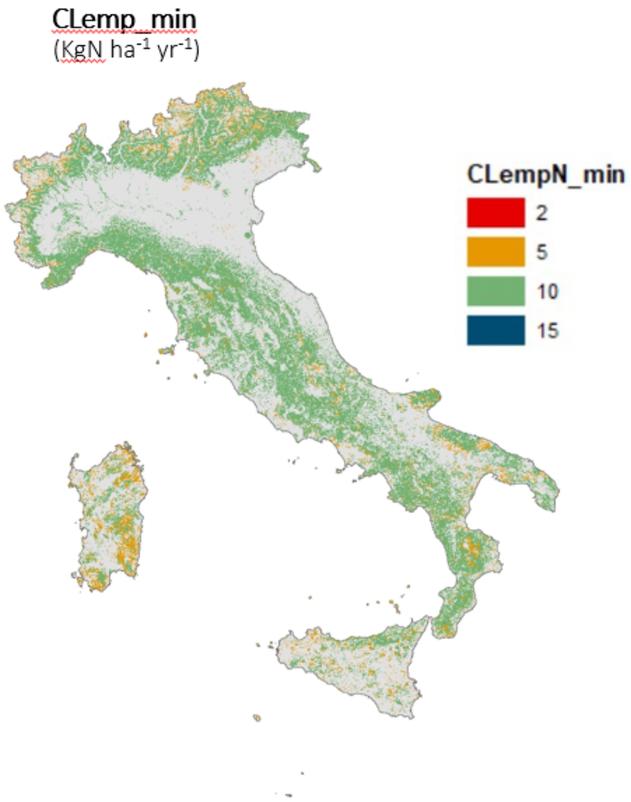


Protection	0: No specific nature protection applies 1: Special Protection Area (SPA), Birds Directive applies 2: Special Area of Conservation (SAC), Habitats Directive applies 3: SPA *and* SAC (1 *and* 2) 4: SPA *or* SAC (1 *or* 2) [don't know which one(s)] 9: A national nature protection program applies (but *not* 1 to 4!) -1: protection status unknown

In each grid cell, ecosystems with an area ≤ 0.01 m^2 were removed, as specified in the Call for Data.

Figure 18 shows the CL_{emp} minimum values to ensure the highest possible level of ecosystem protection.

Figure 18 Cl_{emp}_minimum value for receptor ecosistems map



To assess the extent of exceedances using CL_{emp} as a biodiversity protection parameter, deposition data for the years 2000 and 2019 were downloaded from the EMEP MSC-W website. Additionally, four scenarios produced by CIAM were used: the 2015 baseline, 2040 current legislation (CLE), 2040 maximum technically feasible reduction (MTFR), and 2040 optimized (OPT) (see Figure 19).

The scenarios are simulated for the five meteorological years between 2016-2020 in order to reduce the effects of meteorological variability.

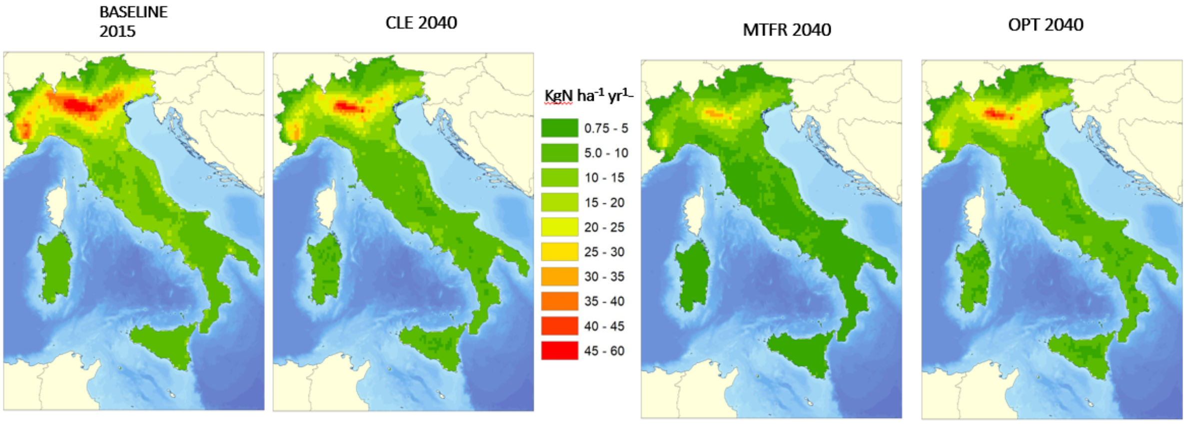
2015 Baseline represents the state of atmospheric depositions in 2015, based on actual emissions of pollutants such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), and ammonia (NH_3) up to that year. It includes observed levels of acid and nitrogen deposition, with impacts on terrestrial and aquatic ecosystems. This scenario serves as a reference point for assessing future changes in deposition based on different emission reduction policies.

2040 Current Legislation (CLE) projects future depositions assuming that all existing environmental regulations in various countries are fully implemented by 2040. It includes expected emission reductions under current national and international regulations (e.g., EU directives, the Gothenburg Protocol, air quality regulations). However, it does not account for additional measures beyond those already approved, meaning that some environmental impacts may still persist in certain regions.

2040 Maximum Technically Feasible Reduction (MTFR) represents the maximum possible emission reductions achievable using all available abatement technologies, regardless of economic costs. It involves the implementation of strict measures to minimize NO_x, SO_2, and NH_3 emissions, aiming to reduce acid and nitrogen deposition to the lowest possible levels. In this scenario, the risk of damage to ecosystems would be significantly reduced, but the cost of implementation could be very high.

2040 Optimized (OPT) is a balanced approach between emission reductions, economic costs, and environmental benefits. It relies on optimized reduction strategies to achieve the highest possible benefit at sustainable costs. It may include a mix of technological measures, stricter regulations, and possibly changes in energy consumption or agricultural practices. The goal is to maximize ecosystem protection while minimizing economic and social impacts.

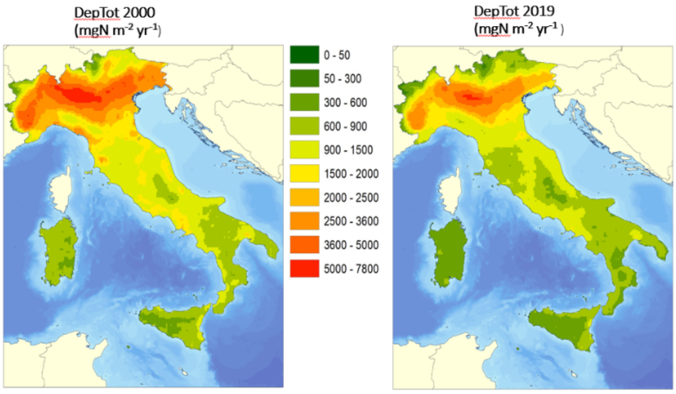
Figure 19 **CIAM Scenarios 2015 baseline, 2040 current legislation (CLE), 2040 maximum technically feasible reduction (MTFR), and 2040 optimized (OPT) scenario averaged over the five meteorological years between 2016-2020.**



C.8.3 Results

Below are the maps derived from GIS-based processing (IDW of total depositions for the years 2000 and 2019 (Figure 20), used as well as the scenarios developed by CIAM to calculate exceedances relative to CL_{emp} (Figure 21).

Figure 20 **Total deposition derived from EMEP MSC-W**



In general, the scenarios showed a decreasing trend in depositions, and consequently a declining of exceedances levels, is observed. However, exceedances persist in the Po Valley even under the most favourable and reductive scenario even though the % of land at risk of biodiversity loss is reduced from 58% in the 2015 baseline scenario to 0.7% in the 2040 MTFR scenario (see Figure 22).

Figure 21 **Exceedances calculated with respect to the CL_{emp} minimum value of the range under the different scenarios**

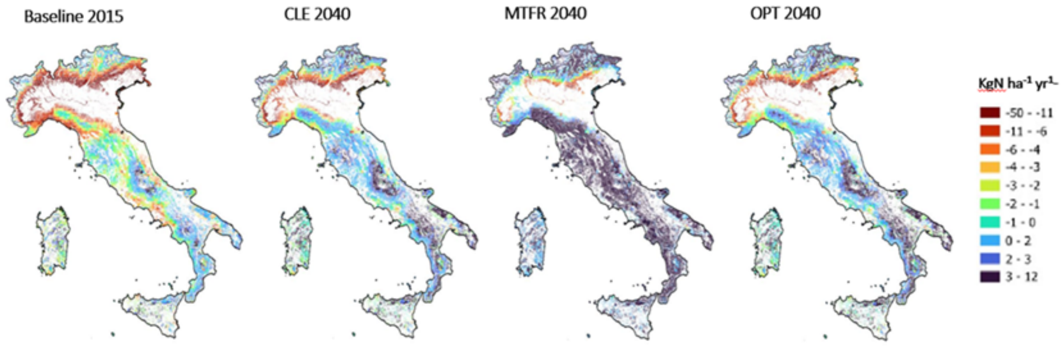
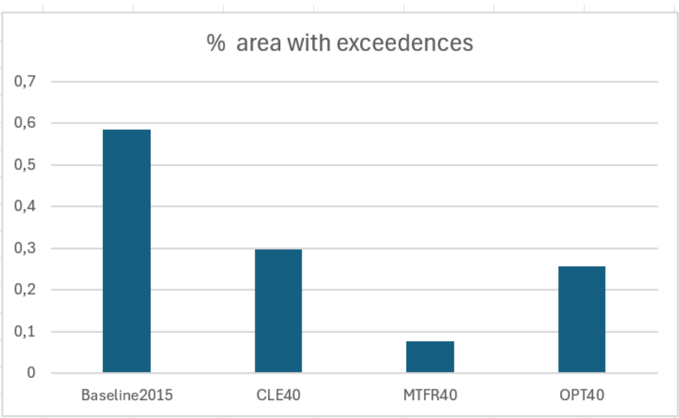


Figure 22 **% area exceedances calculated with respect to the CL_{emp} minimum value in 4 CIAM scenarios**



Basically, while the CLE scenario in 2040 records a 50% exceedences reduction compared to the 2015 baseline, the MTFR reach 87% reduction and the OPT scenario shows a 57% reduction. Figure 22 and Figure 23 show the exceedences reduction in the four scenarios tested for each EUNIS class. From the graph, the MTFR 2040 is the best scenario for quite every EUNIS ecosystems, while for some ecosystem the reduction is stronger (EUNIS N13, N14, N1J1, Q45, R, S5, S6, and all the T except T1E).

Figure 23 % area exceedances x eunis class, calculated with respect to the CLemp minimum value in 4 CIAM scenarios.

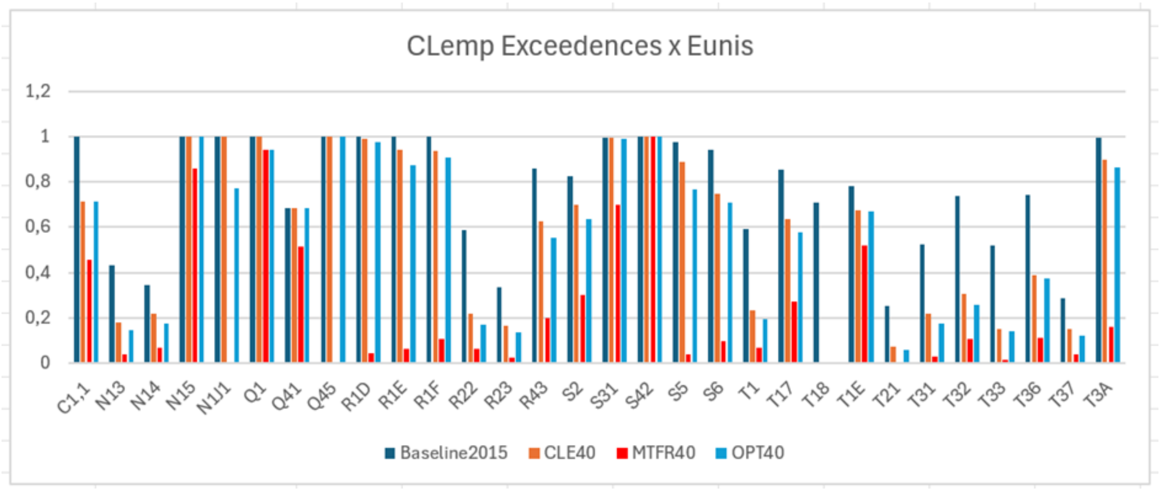


Table 26 EUNIS Code description

Eunis code	Description
C1.1	Permanent oligotrophic lakes, ponds and pools (including soft-water lakes)
N13	Shifting coastal dunes
N14	Shifting coastal dunes
N15	Coastal dune grasslands (grey dunes)
N1J1	Dune-slack pools (freshwater aquatic communities of permanent Atlantic and Baltic or Mediterranean and Black Sea dune-slack water bodies)
Q1	Raised and blanket bogs
Q41	Rich fens
Q45	Arctic-alpine rich fens
R1D	Mediterranean closely grazed dry grasslands
R1E	Mediterranean tall perennial dry grassland
R1F	Mediterranean annual-rich dry grassland
R22	Low and medium altitude hay meadows
R23	Mountain hay meadows
R43	Temperate acidophilous alpine grasslands
S2	Arctic, alpine and subalpine scrub habitats
S31	Lowland to montane temperate and submediterranean Juniperus scrub
S42	Dry heaths

Eunis code	Description
S5	Maquis, arborescent matorral and thermo- Mediterranean scrub
S6	Garrigue
T1	Broadleaved deciduous forest
T17	Fagus forest on non-acid and acid soils
T18	Fagus forest on non-acid and acid soils
T1E	Carpinus and Quercus mesic deciduous forest
T21	Mediterranean evergreen
T31	Temperate mountain Picea forest
T32	Temperate mountain Abies forest
T33	Mediterranean mountain Abies forest
T36	Temperate and sub-Mediterranean montane Pinus sylvestris-Pinus nigra forest
T37	Mediterranean montane Pinus sylvestris-Pinus nigra forest
T3A	Mediterranean lowland to submontane Pinus forest

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C.9.1 Introduction

Nitrogen deposition in the Netherlands is recognised as a large threat to protected nature areas (Autoriteit, 2024; Wamelink et al., 2013). Various policy measures are taken to reduce this threat (Reinds et al., 2024). Critical loads play an important role in these policies. In recent national legislation targets are set based on critical load exceedance in Natura 2000 areas:

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

These critical loads are an combination of empirical critical load ranges and modelling (Van Dobben et al., 2012). In 2022 new empirical critical loads were set for (semi)natural vegetations by Bobbink et al. (2022). This new information has been used in this study to calculate new critical load maps for CLTAP, using a methodology similar to the method used in 2022 (van Hinsberg & Reinds, 2022). The maps for Natura 2000 areas is the same as used in Dutch legislation. Outside Natura 2000 areas the information is based on nature targets of Dutch provinces (van Beek et al., 2018).

C.9.2 General methodology

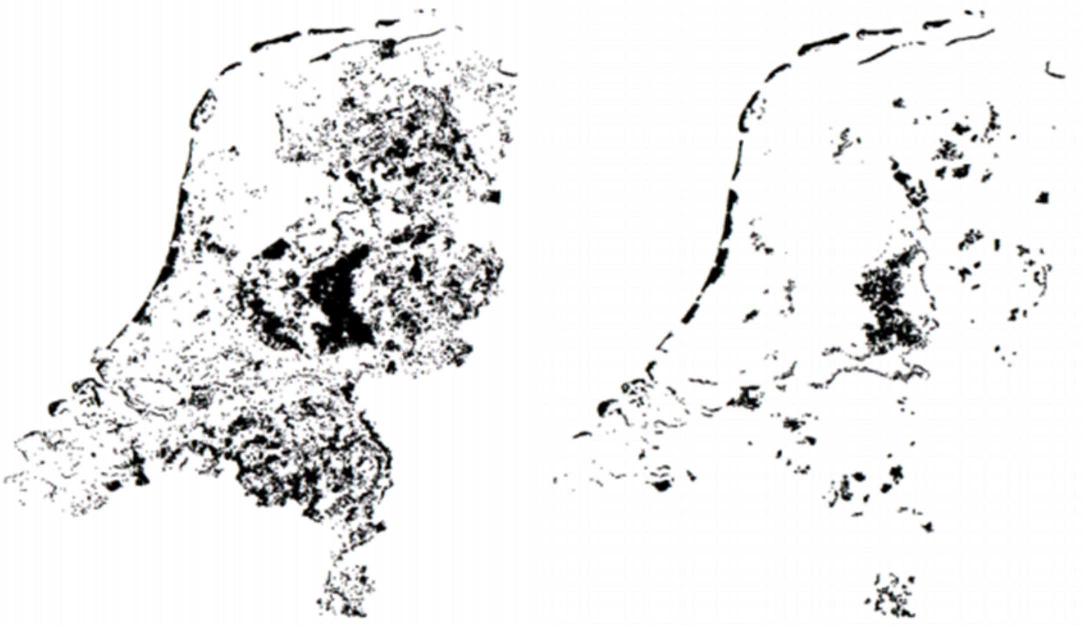
The Netherlands has a long history of using soil vegetation models for setting critical loads withing the empirical critical load ranges (CCE, 2017). The backbone of soil modelling has changed from SMB to SMART2 to VSD+. Limits of abiotic conditions were based on models (MOVE, PROPS) or empirically determined ranges, for various ecosystem types.

In this new update, critical loads were calculated for all terrestrial nature areas in the National Ecological Network (NEN; Figure 24, left) using the new European empirical critical load ranges.

Empirical critical load levels were calculated, separately, for protected habitats in Natura 2000 areas (Figure 24, right) and for nature management types in other nature areas (Figure 24, left).

Inside Natura 2000 areas critical loads were set using the information of Wamelink et al. (2023) together with maps of protected habitattypes. Outside Natura 2000 areas critical loads were calculated with VSD+ (Bonten L. et al., 2009) using the same methods as in van Hinsberg and Reinds (2022). Outside Natura 2000 areas the information is based on nature targets of Dutch provinces and their sensitivity (van Beek et al., 2018).

Figure 24 **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).**



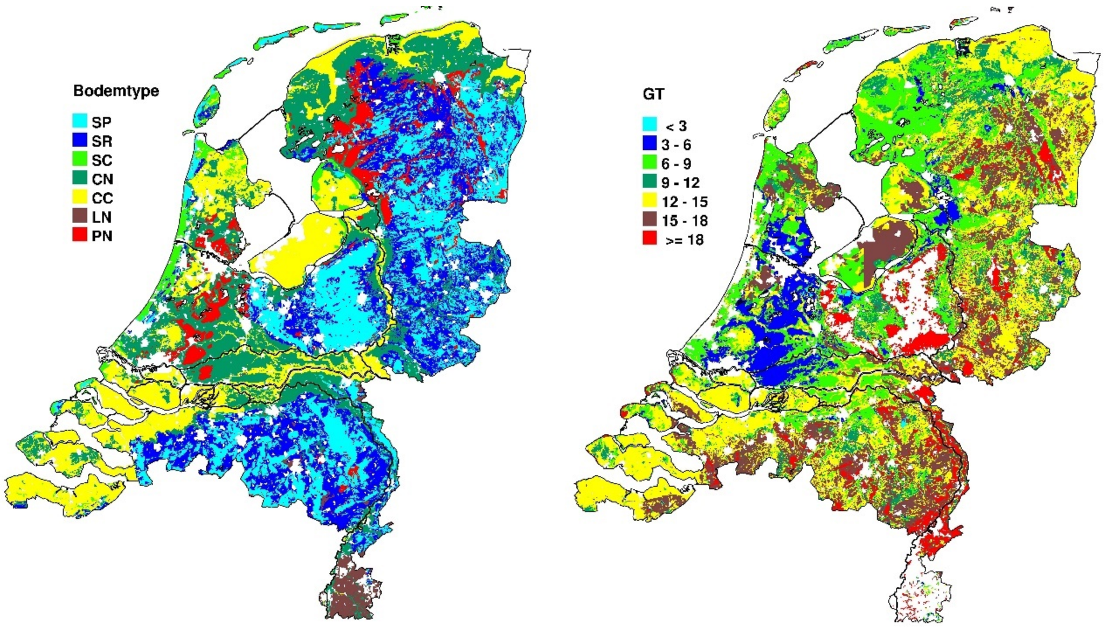
C.9.3 Input data

For 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. Within Natura 2000 areas (right) we used the habitat map and Wamelink et al. (2023) to map critical loads.

Outside Natura 2000 areas critical loads were calculates with VSD+, with an updated approach as compared to van Hinsberg and Reinds (2022), we now used a direct link between nature management types and habitat types to derive critical values instead of the more complex linking through plant associations used previously. The soil types for which VSD+ has been parametrised were mapped based on the updated version of the soil map 1:50000 (Steur & Heijink, 1991). Information on groundwater levels was derived from a the groundwater level map of the Netherlands (Van Heesen, 1970). 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 (Figure 25). Clay soils occur along the rivers, in the north and southwest 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 (Figure 25).

Figure 25 **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.**



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 (N_{avail}) were derived from indication values for trophic conditions. The trophic index was transformed into values of N_{avail}, using a regression with data from 2017 on N_{avail} and trophic index calculated for the same nature target types as used in the submission of 2017, according to:

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

Equation 3

With N_{avail} 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.

C.9.4 Critical load function

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

$$CL(N) = N_{availcrit} - N_{upt} - N_{lf} - N_{fix} - N_{seep}$$

Equation 4

With $N_{availcrit}$ = critical N availability, N_{upt} = N uptake, N_{lf} = total litterfall of N (above and below soil surface), N_{fix} = N fixation (set to zero), N_{seep} = N flux via upward seepage.

For each 250 x 250 metre grid, we compared the calculated $CL_{eut}N$ with the empirical critical range. When $CL_{eut}N$ was within this range, the calculated value was used. When $CL_{eut}N$ was outside the empirical critical loads we used the nearest empirical critical load for the given range. For CLN_{max}, we always used the value computed with Equation 4. For the acidification critical loads, a critical pH was used as the criterion, which means that $CL_{max}N$ is based on pH and thus differs from CLN_{max}, which is based on N availability. In the data submission, the lowest value of CLN_{max} (based on N_{avail}) and $CL_{max}N$ (based on pH) was used for $CL_{max}N$.

C.9.5 Results

Cumulative frequencies for $CL_{eut}N$ (Figure 26) show that $CL_{eut}N$ 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, $CL_{eut}N$ is determined by the empirical value, not the (higher) SMB value. Comparison with the previous submission (from 2021, using the 2012 empirical critical loads), shows that the distribution has shifted towards lower values (Figure 26 a), due to the lower empirical critical loads for especially heathland and forests and the new procedure to link nature management types to critical values (Figure 26 a, b, c).

Figure 26 Cumulative frequencies of $CL_{eut}N$ in eq ha^{-1} yr^{-1} for all vegetations (a) and for heathlands and forest seperately (b, c) for the 2021 and the current submission.

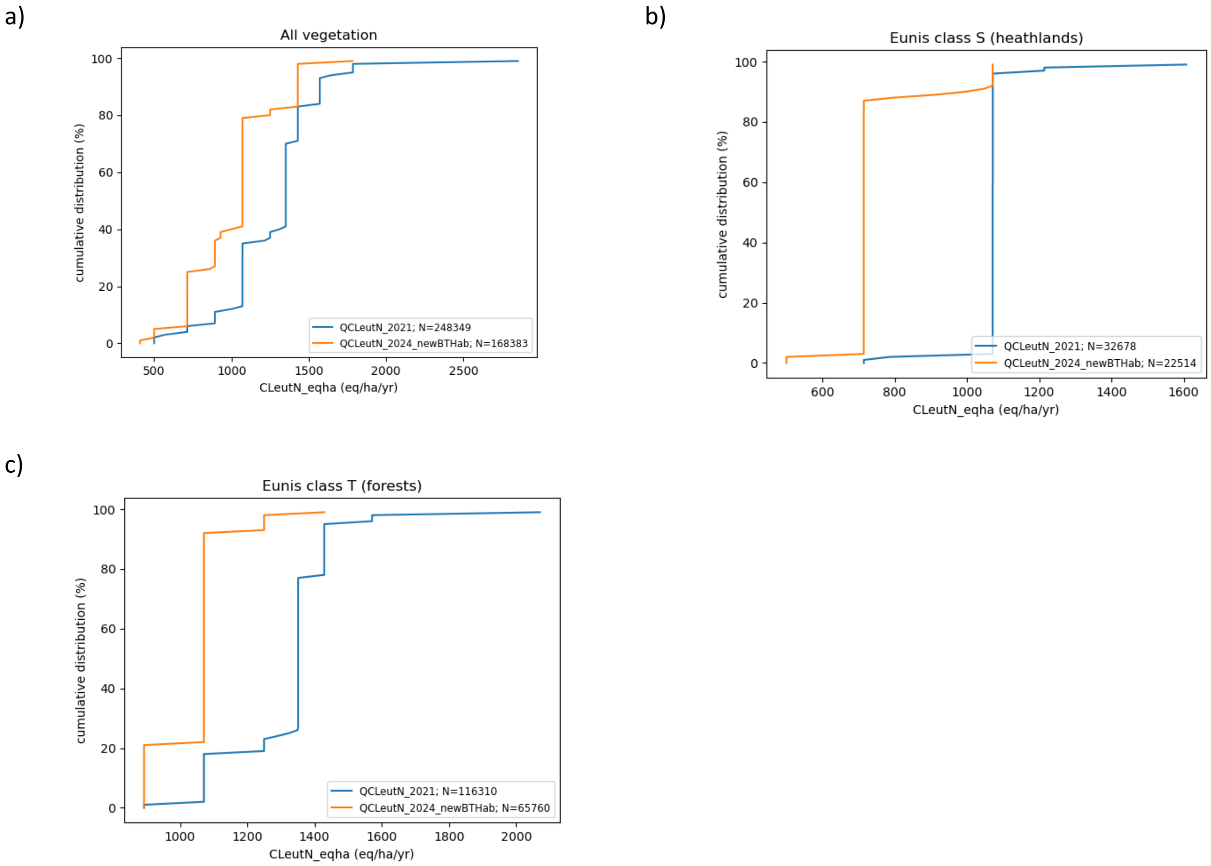
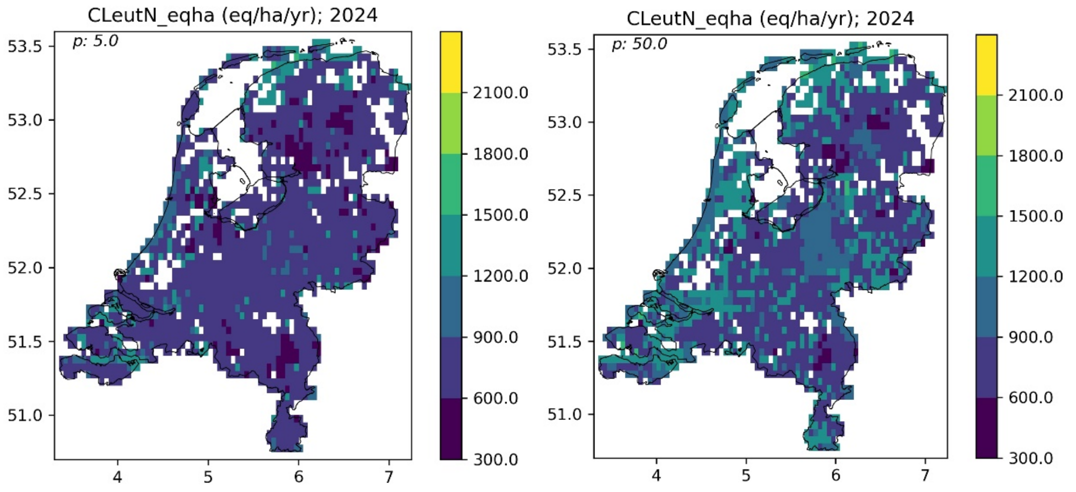


Figure 27 Maps of $CL_{eut}N$ on 0.05 × 0.05° resolution; 5 percentile (left) and median values (right) per grid cell.



The lowest $CL_{eut}N$ values can be found in raised bogs and dune areas (Figure 27), 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 26 (a)).

C.9.6 Assigning nature and habitat types to 250 x 250 metre grid cells

In this assessment of critical loads, we 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 $CL_{eut}N$ should not be used on a local scale.

C.9.7 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. For forests, the difference has become larger than in the previous submission due to the lower empirical critical loads that have been used. 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 (Van Dobben et al., 2012). As empirical values are broadly accepted, and the model results are considered a further specification, Wamelink et al. (2023) 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.

C.10 Norway

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C.10.1 Empirical critical loads for nutrient nitrogen

Here follows a description of the Norwegian national approach to implement the updated empirical critical loads ($CL_{emp}N$) for nutrient nitrogen provided by Bobbink et al. (Bobbink et al., 2022). The key findings from the application are discussed and obstacles and gaps in ecosystem types are identified.

C.10.2 The national approach

The approach to applying empirical critical loads for nutrient nitrogen in Norway has previously been described in CCE (2022). The empirical critical loads were then in accordance with Bobbink and Hettelingh (2011) but have now been updated in line with the revised empirical critical loads in Bobbink et al. (Bobbink et al., 2022). No changes have been made to the underlying land cover map or the general approach.

The $CL_{emp}N$ ranges provided in Bobbink et al. (Bobbink et al., 2022) are linked to EUNIS habitat types. In Norway a land cover map from Norut (Johansen, 2009) is used as basis for assigning the $CL_{emp}N$. This map uses a different habitat type classification than EUNIS. Hence, the Norut habitat types had to be translated into EUNIS classes. This was already done when the Norut map was first applied, but the EUNIS codes had to be updated according to the new EUNIS classification, and in some cases the translation had to be adjusted. Most of the Norut types can be directly translated to EUNIS classes. However, for a few of the habitat types the translation is not clear. In other cases, there is a EUNIS translation, but this EUNIS class lacks a suggested $CL_{emp}N$. In some cases, there were also issues with translating the previous EUNIS codes to the present. More details on the translation are given in Table 27.

In Bobbink and Hettelingh (2011) the same $CL_{emp}N$ range was given for the EUNIS classes C1.1. (Permanent oligotrophic lakes, ponds and pools) and C1.4 (Dystrophic lakes, ponds and pools), so all area with the Norut-type water was assigned the same $CL_{emp}N$. In Bobbink et al. (Bobbink et al., 2022), different ranges were given for these types of waters, and moreover the C1.1 class was split in alpine and boreal waters. Hence there was a need to define the water area according to these three types. First, the distinction between oligotrophic and dystrophic waters was made based on the concentration of total organic carbon (TOC). Second, the distinction between alpine and boreal waters was made for the oligotrophic waters using the biogeographical map, DAT-85-en, which has been developed by the European Environment agency (EEA, 2016).

To distinguish between oligotrophic and dystrophic waters, a threshold was set at 15 mg/l TOC, where waters above this were defined as dystrophic. This was in accordance with the threshold between humic and very humic waters given in the Norwegian guidance for classification under the Water Framework Directive (DirektoratsgruppenVanndirektivet, 2018). A statistical model was applied to assign gridded TOC concentration values to all of Norway. Two different datasets were used as input data: The 2019 national lake survey (de Wit et al., 2023; Hindar et al., 2020) and 2019 data from the annual trend lake monitoring (Vogt & Skancke, 2023). The former represents 758 lakes that are nationally distributed and with minimal impact from anthropogenic activities. The latter represents 78 acid-sensitive lakes, mainly located in southern Norway, which is the region most heavily impacted by acid deposition. The observed increase in surface water TOC concentrations in the last decades is to a large extent related to recovery from acid deposition (de Wit et al., 2016). Generalised additive modelling (GAM) was selected as statistical method. This method is suitable for spatial modelling as it flexibly describes different shapes of non-linear relations between variables. The GAM model was developed by first testing different variables and combinations of interactions. In the final model UTM coordinates were included as interactions and a cubic spline function was applied along with a Gamma-distribution with log-link. The model estimated TOC concentrations with a 1 x 1 km resolution. From this an average value was calculated for each grid cell in the 0.25°×0.125° longitude-latitude grid applied for the Norwegian critical loads for acidification of surface waters (for which the TOC model is also used). The waters in the Norut map were assigned a TOC concentration based on the TOC grid, and subsequently split into oligotrophic and dystrophic waters.

In most cases the $CL_{emp}N$ selected from the ranges provided in Bobbink et al. (Bobbink et al., 2022) were minimum values. This was selected due to the typically cold climate and nutrient poor soils in Norway, and it is also in line with the precursory principle. Any deviation from this is explained in Table 27.

After assigning $CL_{emp}N$ value to all the Norut habitat types, the resulting empirical critical loads map was overlaid by the 0.10°×0.05° longitude-latitude grid. Given the high detail of the Norut 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. $CL_{emp}N$ IDs from the provided excel file were added, with further details given inTable 27.

Empirical critical loads were not set for the land cover types “agriculture land”, “cities and urban areas” and “unclassified” in the Norut map although these areas were included in the total area for Norway. The two first are considered irrelevant while the latter is too uncertain.

Table 27 An overview of the translation of habitat types, selection of $CL_{emp}N$ and implication compared to the previous $CL_{emp}N$ for the different habitat types. ID refers to the excel file provided by CCE (clempn_export.xlsx)

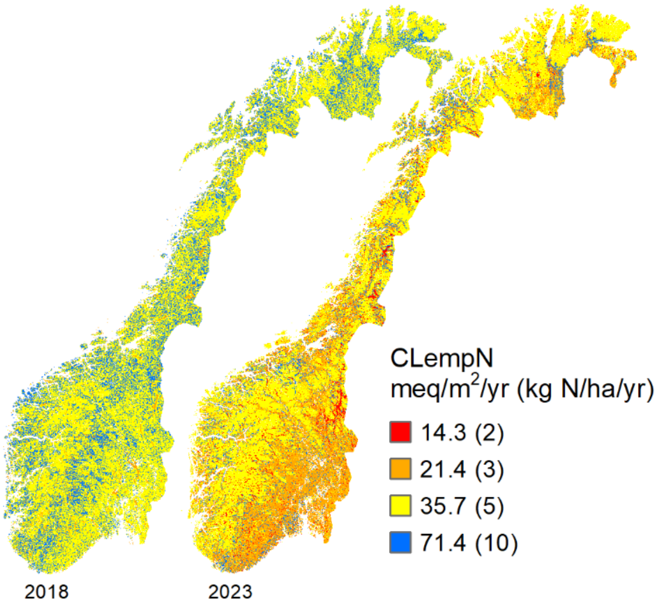
Norut type	EUNIS code applied (previously applied)	Comment habitat type translation	Comment $CL_{emp}N$ selection	Implications for $CL_{emp}N$
4-5 9 12+14+16	T1 (G1) Q1 (D1) S2 (F2)	Same translation as before, just new EUNIS code. ID applied according to EUNIS code	Minimum	No change in $CL_{emp}N$
3 10-11 18	T3G (G3.B) Q2 (D2) R1P (E1.9)	Same translation as before, just new EUNIS code. ID applied according to EUNIS code	Minimum	Lower $CL_{emp}N$
1	T3F (G3)	T3F is more specific than the previously applied G3. ID applied according to EUNIS code	Minimum	Lower $CL_{emp}N$
2	T3 (G4.2)	There was no new EUNIS class that corresponded to the previous G4.2. It represents a mixture of the two new categories T3F and T3G, so the more general class T3 was selected	Minimum	Lower $CL_{emp}N$
6-8	T1C15 (G1.918)	There was no $CL_{emp}N$ for this EUNIS class, so the ID 54 was chosen, according to the $CL_{emp}N$ selected	$CL_{emp}N$ was set according to EUNIS class T3, minimum	Lower $CL_{emp}N$
19-20	R411 (E4.11)	There was no $CL_{emp}N$ for this EUNIS class, so the ID 36 was chosen, according to the $CL_{emp}N$ selected	$CL_{emp}N$ was set according to EUNIS class R42, minimum	No change in $CL_{emp}N$
15	R42 (E4.2)	There is no new EUNIS code for the previous E4.2. In the excel file R42 is chosen for “Moss and lichen dominated mountain summits”, so we have set this, with the corresponding ID 36, in lack of a better option.	$CL_{emp}N$ was not set according to EUNIS class R42 (5 kg N/ha/yr). The actual Norut habitat type in question (lichen dominated) should not have a $CL_{emp}N$ too different from T3G (2 kg N/ha/yr), so the $CL_{emp}N$ was set to 3 kg N/ha/yr	Lower $CL_{emp}N$
13	R42 (E4.3)	EUNIS class R42 was selected as it corresponds to the previous E4.3, so ID 36 is chosen also for this.	This EUNIS class was not included in Bobbink et al., (2022), so the $CL_{emp}N$ was set as in Bobbink and Hettelingh (2011), which also corresponds with what is set to be R42 in the excel file, minimum	No change in $CL_{emp}N$

Norut type	EUNIS code applied (previously applied)	Comment habitat type translation	Comment $CL_{emp}N$ selection	Implications for $CL_{emp}N$
17	S411 (F4.11)	The Norut type matches both S411 and S42 (previously F4.2), but both have the same $CL_{emp}N$ range. In the excel file S411 is split in two. We have chosen ID 42 as the closest to the Norut type	Minimum	Lower $CL_{emp}N$
21	U4 (H4)	This EUNIS class was not in the excel file, so no ID was set	$CL_{emp}N$ set according to previous applications	No change in $CL_{emp}N$
22	C1.1	Same translation as before, but specified to ID 13	Minimum	Lower $CL_{emp}N$
22	C1.1	Same translation as before, but specified to ID 14	Minimum	No change in $CL_{emp}N$
22	C1.4	Same translation as before. ID applied according to EUNIS code	Minimum	Higher $CL_{emp}N$

C.10.3 Key findings from the update of the critical loads

The update of the $CL_{emp}N$ resulted in lower values for several of the habitat types. A comparison of the old and new empirical critical loads map for Norway is given in Figure 28.

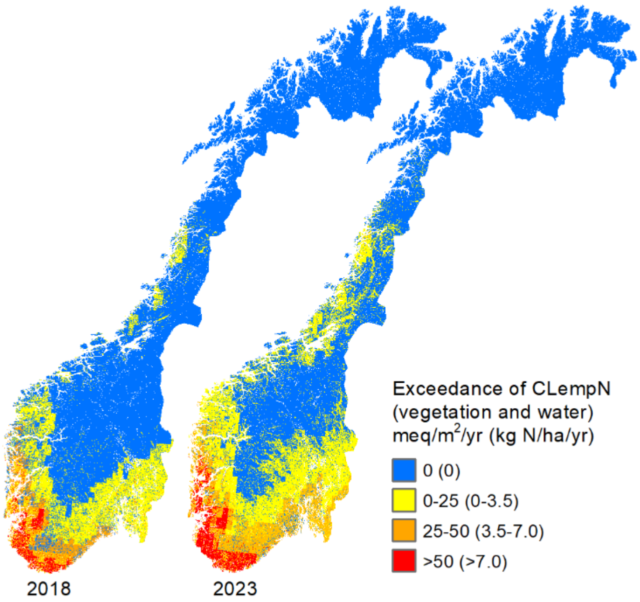
Figure 28 **Previous (2018) and most recently updated (2023) empirical critical loads for nutrient nitrogen for Norway.**



With the updated $CL_{emp}N$ four different values are now applied to the habitat types of Norway (2, 3, 5, or 10 kg N ha^{-1} yr^{-1}). This contrasts with the three different values that were previously applied (3, 5, or 10 kg N ha^{-1} yr^{-1}). Among the 21 different terrestrial habitat types in the Norut map, 11 were given lower $CL_{emp}N$ while for the remaining 10 classes the $CL_{emp}N$ remained unchanged. The new subdivision of water led to lower, unchanged, and higher $CL_{emp}N$ for alpine oligotrophic, boreal oligotrophic, and dystrophic waters, respectively. The regions with the lowest $CL_{emp}N$ values are now more clearly defined geographically. The two lowest critical loads levels are found mainly in the south-eastern region and along the coast, as well as in the middle region (Trøndelag) and in the north (Finnmarksvidda). Areas with the highest critical loads level are spread and constitute less contiguous areas.

To assess the effect from updated $CL_{emp}N$, exceedances were calculated using both the previous and the updated critical loads and the same deposition (average nitrogen deposition 2012-2016). The update led to an increased area with exceedance of critical loads, from 25% to 37% of the total area of Norway (Figure 29). The magnitude of the exceedances also increased with the updated critical loads. Increased exceedances were particularly evident in the south-eastern and in the middle regions, which agrees with the regional patterns described above for $CL_{emp}N$, but also in the south-western region where the nitrogen deposition is highest.

Figure 29 **Exceedance of empirical critical loads of nutrient nitrogen for the time period 2012-2016 using previous (2018) and most recently updated (2023) empirical critical loads for Norway.**



C.10.4 Obstacles and identified gaps in ecosystem types

Obstacles identified were related to the translation from the Norut habitat types to EUNIS classes and to EUNIS classes missing $CL_{emp}N$. These are described in detail inTable 27. In summary, there are no EUNIS classes corresponding to the previous G4.2 “Mixed taiga woodland with Betula” and E4.2 “Moss and lichen dominated mountain summits”. For the EUNIS classes T1C15, R411, and U4 there were no $CL_{emp}N$ provided.

C.11 Poland

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C.11.1 Introduction

In response to the CCE “call for data 2023-24”, the Polish NFC is submitting an updated database of empirical critical loads for nitrogen (CL2024). Previous dataset was submitted to the CCE in 2021 (CL2021).

C.11.2 Ecosystems database

Terrestrial ecosystem database, was based on CLC18 (Giós, 2019), and combined with spatial dataset of wetland and non-forest ecosystems (IMUZ, 2012). The revised EUNIS Habitat classification was used (Chytry, 2020) with linkage to previous version classes (Davies et al., 2004) with extension to 2nd level of 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 97128 km^2 of terrestrial ecosystems, with one or more habitats in each grid cell and contains 256872 records with ecosystems limit area set ≥0.5 ha (“EcoArea”≥ 5000 m^2). Forests cover 98.4 % of total ecosystems.

Table 28 **CL2024 Ecosystem database for Poland for $CL_{emp}N$ calculations**

EUNIS code 2020	EUNIS code 2004	EUNIS habitat name	Ecosystem Area		
			Total	Covered by Natura 2000	
			[km^2]	[km^2]	% of Total
Q1	D1	Raised and blanket bogs	47.4	39.8	84.1
Q2	D2	Valley mires, poor fens and transition mires	105.8	59.3	56.0
Q4	D4	Base-rich fens and calcareous spring mires	1038.5	764.2	73.6
Q45	D4.2	Arctic–alpine rich fen	3.1	1.8	56.9
R22	E2.2	Low and medium altitude hay meadow	245.9	211.5	86.0
R23	E2.3	Mountain hay meadow	57.5	55.2	96.0
R43	E4.3	Temperate acidophilous alpine grassland	21.3	21.3	100.0
S2	F2	Arctic, alpine and subalpine scrub	36.5	36.5	100.0
S42	F4.2	Dry heath	4.8	4.5	94.6
T1	G1	Broadleaved deciduous forests	15171.7	7906.9	52.1
T31	G3.1	Temperate mountain *Picea* forest	3786.1	2747.8	72.6
T35	G3.5	Temperate continental *Pinus sylvestris* forest	52205.4	35681.0	68.3
(T)	G4	Mixed forests	24404.0	11438.4	46.9
TOTAL			**97128.0**	**58968.0**	**60.7**

C.11.3 Empirical critical load for nitrogen update 2024

The CLempN were calculated as an average value of range provided by Bobbink et al (Bobbink et al., 2022) for ecosystems indicated in Table 28. Estimated values and comparison to CL2021 are shown in tables below.

Table 29 **General statistic for CL2021 vs CL2024**

Parameter [n=256872]	CL2021 [kgN×ha^{-1}×r^{-1}]	CL2024 [kgN×ha^{-1}×r^{-1}]	Difference [%]
Minimum	7.5	7.5	0
Maximum	22.5	20.0	-11
Average	12.1	11.2	-7
Median	12.5	11.3	-10
±SD	2.4	1.5	-36

Table 30 CL2021 vs CL2024 for EUNIS ecosystem types

CL2021		**CL2024**		**Difference**
EUNIS 2004	[kgN×ha^{-1}×r^{-1}]	EUNIS 2020	[kgN×ha^{-1}×r^{-1}]	%
D1	7.5	Q1	7.5	0.0
D2	12.5	Q2	10.0	-20.0
D4	22.5	Q4	20.0	-11.1
		Q45	20.0	
E2	10.0	R22	15.0	50.0
E4	7.5	R23	12.5	66.7
		R43	7.5	
F2	10.0	S2	10.0	0.0
F4	15.0	S4	10.0	-33.3
G1	15.0	T1	12.5	-16.7
G3	10.0	T3	12.5	25.0
		T35	10.0	
G4	12.5	(T)	11.25	-10.0
Average	**12.1**	**Average**	**11.2**	**-7.4**

The reduction of $CL_{emp}N$ limits resulted in a decrease in the average $CL_{emp}N$ for Poland by 8.1% (from 12.1 to 11.1 eq×ha-1×year-1). This effect at the level of the entire database results from the large share of broadleaf forests (T1) (a decrease in the average $CL_{emp}N$ by 16.7%). Decreases in the $CL_{emp}N$ in other ecosystems (non-forest) have a insignificant impact due to their small share in the total area. On the other hand, the average $CL_{emp}N$ for lowland (R22) and mountain meadow (R23) ecosystems increased (by 50 and 66.7%, respectively), but their small total area on the scale of the entire database did not affect the average value.

Figure 30 CDF of $CL_{emp}N$ for forest and non-forest ecosystems.

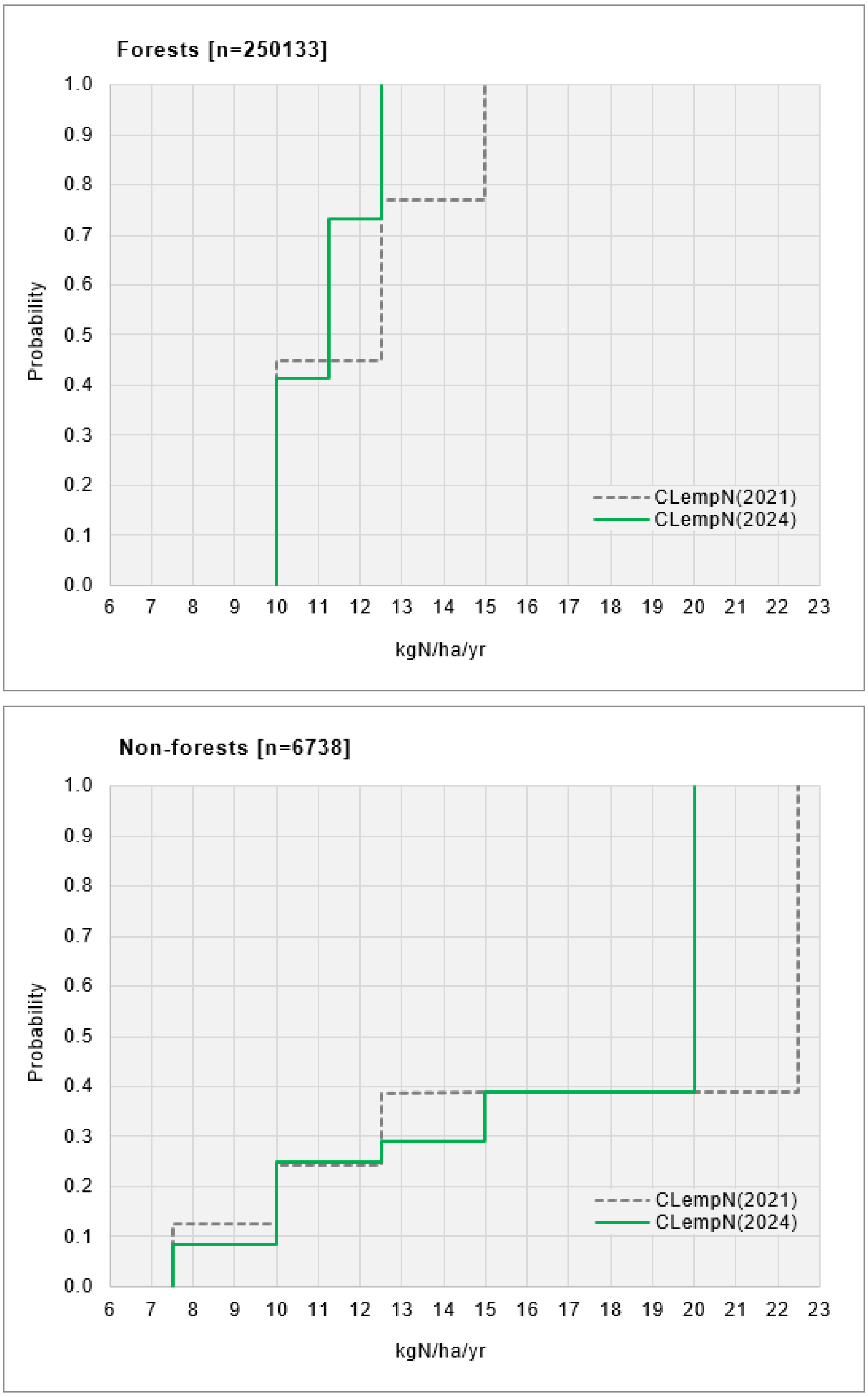
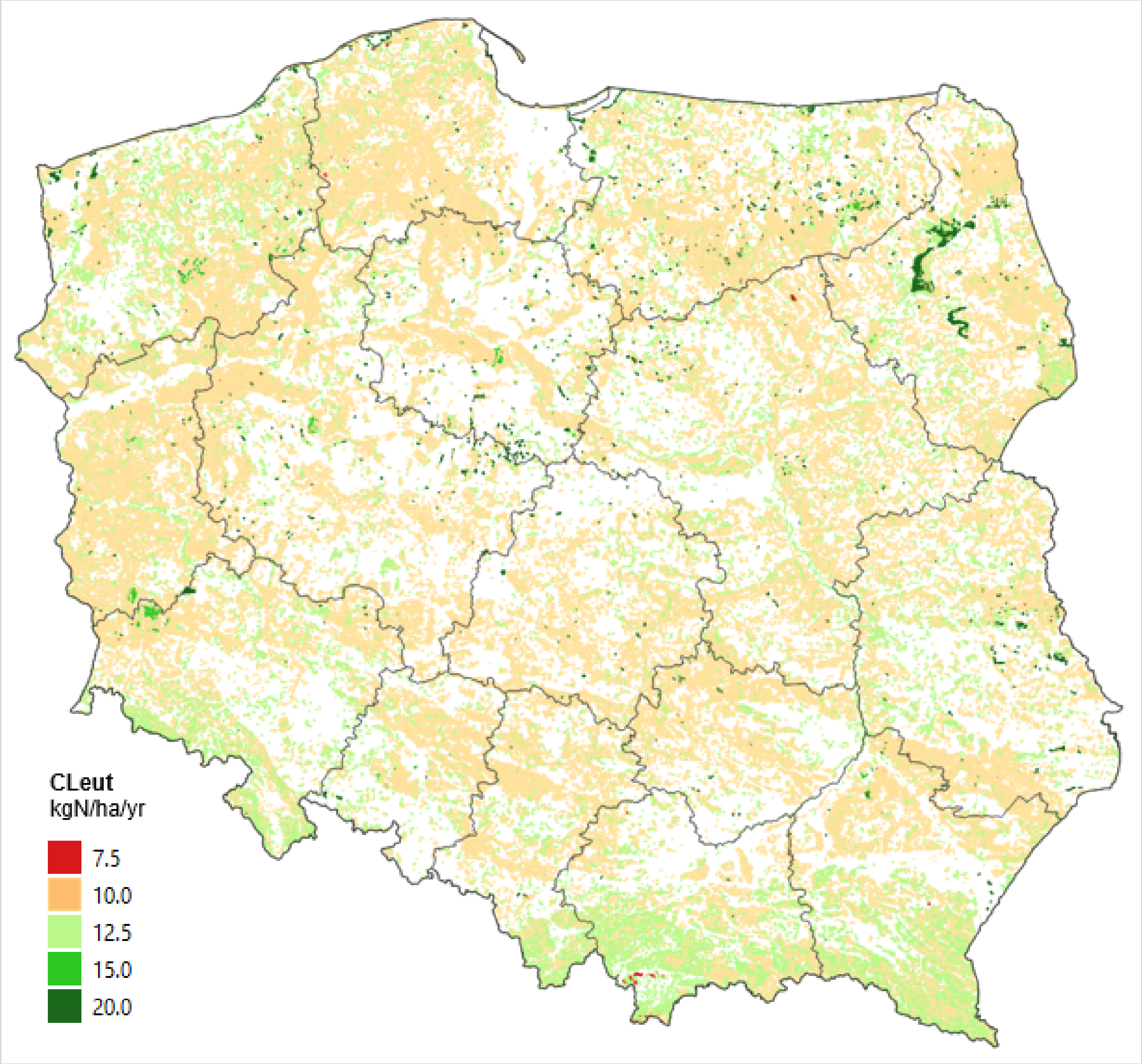


Figure 31 Spatial distribution of $CL_{emp}N$ for terrestrial ecosystems in Poland.



C.12 Spain

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C.12.1 Introduction

This report explains the methodology applied by the Spanish National Focal Centre to respond to the 2023 CCE Call for data (CfD 23/24) for the Empirical Critical Loads for Nitrogen ($CL_{emp}N$), as agreed during the 38th meeting of the ICP Modelling and Mapping Task Force, along with the 29th meeting of the Coordination Centre for Effects on 3–5 May 2022[5], and included in the 2024–2025 Workplan for the implementation of the Convention (item 1.1.1.22)[6].

As a result of this work, the national receptor map, within the EMEP grid[7], displays the spatial distribution of 123 different habitat types (118 categorized at level-3 of EUNIS classification and the rest of them at level 2) that cover 62% of the Spanish territory. $CL_{emp}N$ values was assigned to approximately 90% of this area.

The report presents an overview of the work done to prepare the national receptor map and to assign $CL_{emp}N$ values to the different classes of habitats. The submitted data are based on data and maps from national sources for cartography and on the revision by Bobbink et al. (Bobbink et al., 2022) for $CL_{emp}N$.

The assignation of $CL_{emp}N$ followed a step-by-step approach:

A. Identification and distribution of Spanish vegetation types within current EMEP grid (Peninsular Spain and Balearic Islands, excluding Canary Islands).

B. Categorization of vegetation units according to EUNIS classification.

C. Attribution of $CL_{emp}N$ values to the EUNIS classes.

D. Preparation of the national database with the identification and location of the habitats and their associated $CL_{emp}N$ following CfD 23/24 instructions.

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[5] ECE/EB.AIR/GE.1/2022/16–ECE/EB.AIR/WG.1/2022

[6] ECE/EB.AIR/2023/1

[7] Peninsular Spain and Balearic Islands

C.12.2 National Receptor Map and assignation of $CL_{emp}N$ values

A. Identification and distribution of Spanish vegetation types.

CIEMAT developed a national receptor map based on the National Forest Inventory[8] (NFI) and the Habitats Atlas of Spain (HAS)[9] [10]. The former was used as primary source to locate and identify forested formations, while the later was used to supply the information –primarily- on the rest of habitat types (coastal; grasslands and lands dominated by forbs, mosses or lichens; heathland, scrub and tundra habitats; wetlands and inland habitats with no or little soil and mostly with sparse vegetation).

The NFI (1:25.000[11] , mostly updated in 2023) provides, inter alia, detailed vector information for the entire Spanish territory about the structural type, main use, the degree of coverage and the main tree species mapped. The HAS displays the vegetation of Spain considering phytosociological associations at 1:50,000 scale in vector format. It is based on the habitat inventory of the Directive 92/43/CE, updated in 2005, which includes both habitats listed in Annex I of the Habitats Directive 92/43/CE and others not included.

B. Categorization of vegetation units according to EUNIS classification.

After habitats were properly identified and located, the next step was the assignation of the critical load value to each category according to the information provided in Bobbink et al. (Bobbink et al., 2022). Since the list of receptors from this source uses the EUNIS classification, it was necessary to establish equivalences between classifications used in the national sources (NFI and HAS) and EUNIS classification.

B.1 Habitat Atlas of Spain

To establish the association between HAS and EUNIS classifications, we used the following cartographical fields from HAS data: (i) CODUE (EU code for habitats included in the Annex I of the Habitats Directive), when present; (ii) ALLIANCE (phytosociological alliance to which each habitat belongs); and (iii) SPSALIANZA (species that define the alliance). There are existing crosswalks developed by the European Environment Agency[12] to establish direct relationships between CODUE codes and EUNIS classification for some habitats that provide unique or multiple relationship between CODUE and EUNIS categories. Therefore, data were subdivided into three sets depending on how the EUNIS category was assigned:

1. Habitats with CODUE in which the crosswalk establish an unequivocal relationship between CODUE and EUNIS categories. In these cases, the EUNIS category has been established in a direct way.

2. Habitats with CODUE in which the crosswalk establish more than one possible EUNIS category per CODUE. In this case, the EUNIS category of maximum similarity in terms of habitat-characteristic species or genera was assigned, among the possibilities showed by the crosswalk. A restriction by biogeographic region was included. Similarity was evaluated by

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[8] https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/mfe25_informacion_disp.html

[9] Atlas y Manual de los Hábitats Naturales y Seminaturales de España (miteco.gob.es)

[10] https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/atlas_manual_habitats_espanioles.html

[11] Andalucía and Comunidad Valenciana, at 1:50.000

[12] European Environment Agency (2021). EUNIS terrestrial habitat classification 2021_1 including crosswalks. https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification-1/eunis-terrestrial-habitat-classification-review-2021/eunis-terrestrial-habitat-classification-2021

the Sørensen index, comparing the set of diagnostic and dominant species in the EUNIS category with the species that define the alliance (SPSALIANZA). The Sørensen index (Sørensen, 1948) ranges from 0 to 1, and considers the number of species shared by both EUNIS and HAS categories (c), the total number of species constituting the alliance (b), and the number of diagnostic and dominant species in the EUNIS category. If a category is not assigned in this step, the same process is followed, but comparing at genus level instead of species level.

$$\text{Sørensen index (\%)} = \left(2c \;/\; (a+b) \right) * 100$$

Equation 5

3. When no CODUE was attributed to a habitat in the HAS database, we tried to assign a EUNIS category by expert judgement taking into account all the available and generated information: similarity in terms of habitat-characteristic species or genera (following the same species-genera staggered approach), biogeographical region, crosswalk information, habitat description, etc.

B.2 National Forest Inventory

This cartography comprises polygons representing different types of forests, indicating, inter alia, their biogeographical region (Alpine, Atlantic, or Mediterranean) and forest type (broadleaved, coniferous, or mixed), dominant tree species (up to three species or genus listed in order of cover percentage), characteristic tree formations (when relevant) and structural type.

We used characteristic tree formations and structural types in a first step of codification into EUNIS classification. Characteristic formations are specific arboreal communities (e.g., oak forests, pine forests, dehesas, etc.) of some forest formations. When they correspond directly to a single EUNIS habitat, a direct association was made. When a formation matched multiple EUNIS categories, the dominant tree species or genus (based on cover percentage) was used to narrow down the appropriate category, checking sequentially through up to three listed species. If no exact match was found, the most common EUNIS category in Spain for that formation is assigned. Structural types focus on vegetation structure rather than density and include gallery forests, mixed forests, afforestation, and riparian woodlands. For the forest formations with a characteristic structural type, the dominant tree species or genus was checked against EUNIS categories relevant to the forest type and biogeographic region, using a stepwise method starting with diagnostic species and, if necessary, dominant species. If no category could be assigned after this process, the habitat was classified at level 2 of the EUNIS system (T1, T2, T3) based on the dominant tree species.

C. Attribution of CLempN values to the EUNIS classes.

In Bobbink et al. (Bobbink et al., 2022) CLempN values are reported for habitats mostly at level 3 (but also some of them at level 2 and 4) of the EUNIS categories defined in 2021/2022[13] :

- Marine habitats (MA).
- Coastal habitats (N): N13, N14, N15, N18, N19, N1H, N1H1 y N1J1.
- Inland Surface waters (C).
- Mire, bog and fen (Q): Q1, Q2, Q3, Q41-Q44 y Q45.
- Grasslands and lands dominated by forbs, mosses or lichens (R): R1A, R1D, R1E, R1F, R1M, R1P, R1Q, R22, R23, R35, R37, earlier E4.2, R43 y R44.
- Heathland, scrub and tundra (S): S1, S2, S31, S411, S42, S5 y S6.
- Forest and other wooded land: T1, T17, T18, T1B, T1E, T21, T3, T31, T32, T33, T35, T37, T3A, T3F y T3G.

Since not all the habitats in the national receptor map were considered in this revision, and in order to assign values to the greatest number of national habitats using the available data, a similarity-based comparison of habitats was performed using the Sørensen index. The comparison was carried out between all EUNIS categories present in Spain (taking also into account the previous categorization of Spanish vegetation into EUNIS classification). When a habitat from the receptor map had neither a direct $CL_{emp}N$ assignment nor a possible assignment from a higher-level category (level 2 EUNIS) in Bobbink et al. (Bobbink et al., 2022), the $CL_{emp}N$ value from the most similar habitat was tried to assign, based on expert judgement and considering all available and generated information. Results of this assignation process are summarized in Table 31.

Table 31 Empirical critical loads assigned for Spanish habitats using EUNIS classification.

Habitat	Assignation ecosystem(s)[1]	Assignation procedure[2]	$CL_{emp}N$ (kg N ha^{-1} yr^{-1})
N11	N13, N14	S	10-20
N12	N13, N14	S	10-20
N13	N13	D	10-20
N14	N14	D	10-20
N15	N15	D	5-15
N16	N15	S	5-15
N1B	N15, S31	S	5-15
N1G	T3A	S	5-10
N1H	N1H	D	5-15

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[13] https://eunis.eea.europa.eu/habitats.jsp

Habitat	Assignation ecosystem(s)[1]	Assignation procedure[2]	$CL_{emp}N$ (kg N ha^{-1} yr^{-1})
N1J	N1H	S	5-15
N31		N	
N32		N	
N34		N	
Q21	Q2	G	5-15
Q22	Q2	G	5-15
Q23	Q2	G	5-15
Q24	Q2	G	5-15
Q25	Q2	G	5-15
Q41	Q41	D	15-25
Q43	Q43	D	15-25
Q51	Q41-Q44, Q45	S	15-25
Q52	Q41-Q44, Q45	S	15-25
Q53	Q41-Q44, Q45, R35	S	15-25
Q61	Q41-Q44, Q45	S	15-25
Q63	Q41-Q44, Q45	S	15-25
R12	R1P, R1D	S	5-15
R13	R1A	S	10-20
R18	R1A	S	10-20
R1A	R1A	D	10-20
R1D	R1D	D	5-15
R1E	R1E	D	5-15
R1F	R1F	D	5-15
R1G	R43	S	5-10
R1H	R44, S2	S	5-10
R1M	R1M	D	6-10
R1N	R43	S	5-10
R1P	R1P	D	5-15

Habitat	Assignation ecosystem(s)[1]	Assignation procedure[2]	$CL_{emp}N$ (kg N ha^{-1} yr^{-1})
R1R	R1D,R1E,R1F	S	5-15
R21	R22	S	10-20
R22	R22	D	10-20
R23	R23	D	10-15
R24	R22	S	10-20
R31	R37	S	10-20
R32	R35	S	15-25
R35	R35	D	15-25
R36	R35	S	15-25
R37	R37	D	10-20
R41	R44, S2	S	5-10
R43	R43	D	5-10
R44	R44	D	5-10
R55	R37	S	10-20
R56	R37	S	10-20
R57		N	
R61		N	
R71		N	
R73	R1D, R1F	S	5-15
S21	S2	G	5-10
S22	S2	G	5-10
S23	S2	G	5-10
S3		N	
S32	S31	S	5-15
S33	S2	S	5-10
S35	S5	S	5-15
S37		N	
S41	S411,S42	S	5-15

Habitat	Assignation ecosystem(s)[1]	Assignation procedure[2]	$CL_{emp}N$ (kg N ha^{-1} yr^{-1})
S42	S42	D	5-15
S5	S5	D	5-15
S51	S5	G	5-15
S54	S5	G	5-15
S61	S6	G	5-15
S62	S6	G	5-15
S65	S6	G	5-15
S66	S6	G	5-15
S71	S6	S	5-15
S73	S6	S	5-15
S91		N	
S93		N	
T1	T1	D	10-15
T11	T1	G	10-15
T12	T1	G	10-15
T13	T1E	S	15-20
T14	T1	G	10-15
T15	T1	G	10-15
T16	T1B	S	10-15
T17	T17	D	10-15
T18	T18	D	10-15
T19	T1E	S	15-20
T1A	T21	S	10-15
T1B	T1B	D	10-15
T1D	T18, T1B	S	10-15
T1E	T1E	D	15-20
T1F	T17	S	10-15
T1H		N	

Habitat	Assignation ecosystem(s)[1]	Assignation procedure[2]	$CL_{emp}N$ (kg N ha^{-1} yr^{-1})
T2		N	
T21	T21	D	10-15
T22	S5	S	5-15
T24	S5	S	5-15
T27	T1B	S	10-15
T29		N	
T3	T3	D	5-15
T32	T32	D	10-15
T33	T33	D	10-15
T34	T31	S	10-15
T36	T37	S	5-17
T37	T37	D	5-17
T3A	T3A	D	5-10
T3B		N	
T3C	T17	S	10-15
T3D	T3	G	5-15
T3J	T35	S	5-15
T3M		N	

[1] Ecosystem(s) used to assign $CL_{emp}N$ according to table 1 from Bobbink et al. (Bobbink et al., 2022)

[2] Assignation of empirical critical load ($CL_{emp}N$) from Bobbink et al. (Bobbink et al., 2022). $CL_{emp}N$ corresponds directly to the level-3 EUNIS category (D); corresponds to the upper level-2 EUNIS category (G); corresponds to a habitat (at EUNIS level-3) with similarity on dominant and diagnostic species (S); not assigned (N).

D. Preparation of the database with the identification and location of the habitats and their associated critical loads

Databases have been prepared according to the “Call for Data 2023/24: Instructions. Version 31 January 2024”14 proposed by the CCE. National receptor map was combined with the national map for protected areas15 and a CCE-provided grid for EMEP model to report all the information requested. Each reported record provides, inter alia, information about its identification, location, EUNIS code and the assigned $CL_{emp}N$ value (minimum value of the range).

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[14] https://www.umweltbundesamt.de/sites/default/files/medien/4038/dokumente/instructions_cfd_2023_update.pdf

[15] https://www.miteco.gob.es/es/cartografia-y-sig/ide/descargas/biodiversidad/enp.html

C.13 Sweden

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C.13.1 Summary

In February 2023, a Call for Data on empirical Critical Loads was issued by the Coordination Centrum for Effects under ICP Modelling and Mapping with a delivery deadline of March 2014. The aim of the call is to implement the recently reviewed and updated empirical Critical Load and to prepare a future item in the WGE/EMEP workplan 2024-2025 on applying next risk assessment including the $CL_{emp}N$.

This report describes empirical critical loads for nitrogen as a nutrient established at Swedish Natura 2000 (N2000) sites. A database with the results of the new calculations is submitted simultaneously.

Prior year 2014, most of the Swedish work related to critical loads of acidity and critical loads of nitrogen as a nutrient has been based on calculations for forest soils or for lakes. In response to the Call for Data 2012 – 2014, Sweden shifted the focus and for nitrogen as a nutrient started to use Empirical Critical Loads calculated for N2000 areas. We maintain that $CL_{emp}N$ is for Sweden the best available way to establish critical loads for nitrogen as a nutrient and this submission is a follow-up and an update of the 2014 submission.

The habitats of protected areas in general and N2000 areas are well documented. The National Focal Centre (NFC) has in co-operation with national experts reviewed 89 habitats represented at 3983 out of 4029 Swedish N2000 sites and established $CL_{emp}N$ for these. This was done either by assigning empirical critical loads values from the recently revised work of Bobbink et al. (Bobbink et al., 2022) according to habitats present at each site, or by modifying the values in Bobbink et al. (Bobbink et al., 2022) for Swedish conditions, and by updating $CL_{emp}N$ set in 2014 for habitats not specified in Bobbink et al. (Bobbink et al., 2022). The latter evaluation was performed by habitat experts at the Swedish Species Information Centre (ArtDatabanken). Furthermore, $CL_{emp}N$ was assessed for 56 individual plant species present at the Swedish N2000 sites. For each individual N2000 site the reported $CL_{emp}N$ is the minimum of habitat based or plant species based $CL_{emp}N$.

The exceedance of $CL_{emp}N$ follows geographical pattern with most critical loads exceedance in southwest Sweden. In this part of the country the majority of the N2000 sites has exceedance of $CL_{emp}N$ (deposititon year 2018). For the country, the $CL_{emp}N$ is exceeded at approximately 14 % of the N2000 sites area regardless of the $CL_{emp}N$ submition year (2014 or 2024 hereby) that is used for the exceedance calculation.

C.13.2 Introduction

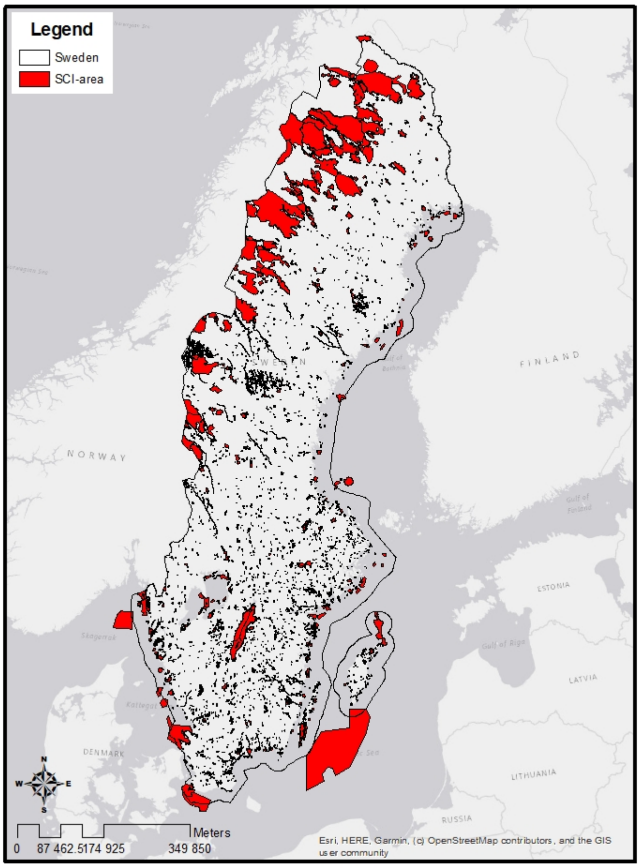
From the Swedish perspective the effects of air pollution and effects of climate change are high on the scientific and political agenda. The impact of air concentrations and deposition of N on ecosystems is of major concern. Exceedence of CL for nitrogen is widespread in the southern part of the country and further decline in nitrogen deposition is necessary to alleviate the situation. Therefore, Sweden welcomed the Call for Contribution issued by the CCE in February 2023.

C.13.3 Critical loads for N as a nutrient at Natura 2000 areas in Sweden

In the CfD 2012 – 2014, the Swedish NFC welcomed the encouragement to focus efforts on protected areas in general and on Natura 2000 areas specifically. As opposed to the productive forests which were used for calculations prior 2014, protected areas often are not managed and therefore land management does not have to be considered as major confounding factor. A further advantage of working with protected areas is that they often are more sensitive to nitrogen deposition than managed forest ecosystems. Therefore, the non-exceedance of critical loads implies that even managed forests in the same area are protected. The response to the current CfD 2023-2024 is a follow-up and an update of the response to the 2012 – 2014 CfD using the same methodology and the same areas we are focusing on. The habitats of protected areas are well documented. The NFC has in co-operation with national experts reviewed the empirical critical loads for N as a nutrient set for all habitat types present in the Swedish Natura 2000 sites in view of the updated empirical critical loads from Bobbink et al. (Bobbink et al., 2022).

The 4029 Natura 2000 protected areas in Sweden cover an area of approximately 6.6 million ha, according to the geospatial data. The N2000 area based on the geospatial data can (and does) differ from the officially reported N2000 area (7.7 m ha). As the gridded data submitted is made from the geospatial data, the areas reported are according to the geospatial reference material. Included in the 6.6 million ha there are Natura 2000 sites which consists of submerged marine habitats, habitats in caves, and sites with no reported habitats but with protection for birds or other animals. As these sites and associated habitats (five) are not considered relevant for setting $CL_{emp}N$, these have been removed. The remaining 5 million ha of Natura 2000 protected areas, approximately 11 % of the total area of Sweden (Figure 32), have set $CL_{emp}N$ in this submission.

Figure 32 Map of Swedish Sites of Community Importance (SCI) areas.



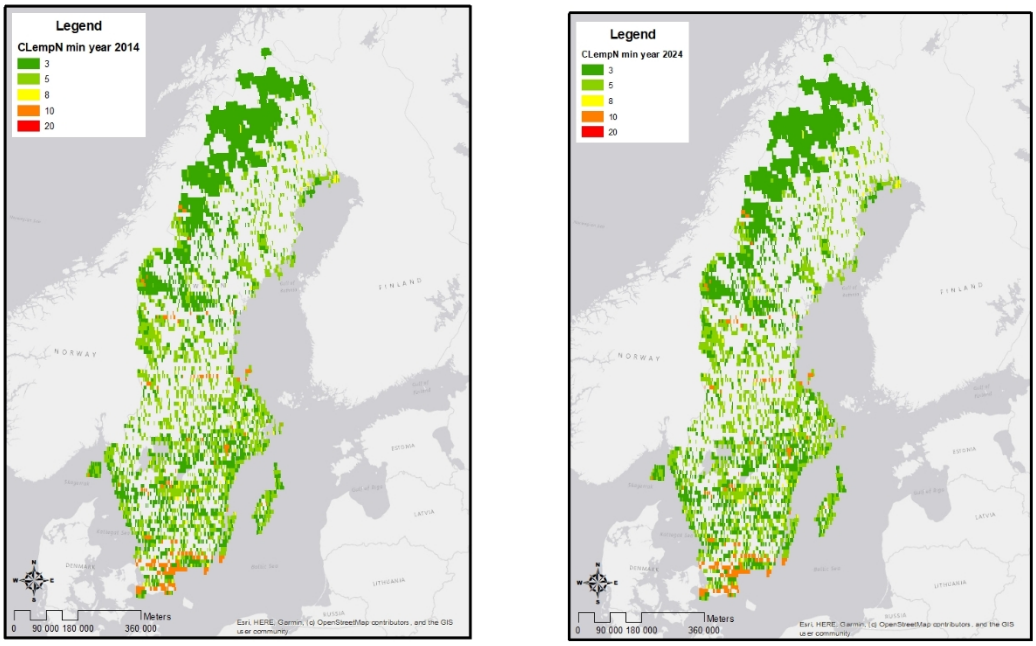
C.13.4 Empirical critical loads-habitats

There are a total of 89 habitat types included in the Swedish Natura 2000 sites. Our aim was to set empirical critical loads for nutrient N for each of these habitats with a starting point in the recently revised empirical critical loads by Bobbink et al. (Bobbink et al., 2022) combined with Swedish submission to the previous CfD (CCE, 2014).

Experts from the Swedish Species Information Centre (ArtDatabanken) reviewed the material for 87 habitat types (Table 32). Five habitats represented in the Swedish N2000 sites, caves and submerged marine habitats, were excluded from consideration as these were deemed irrelevant from the N deposition point of view (Table 32). Of the 40 habitat types included in Bobbink et al. (Bobbink et al., 2022) and present at Swedish N2000 sites, $CL_{emp}N$ were changed for 29 habitats since Bobbink and Hettelingh (Bobbink & Hettelingh, 2011), while at 11 habitat types $CL_{emp}N$ were unchanged. Compared to the 2014 Swedish submission (where $CL_{emp}N$ was set for 82 habitats), the $CL_{emp}N$ for the 2024 submission was set higher for four habitats, lower on two, and 76 habitats remained the same. In this (2024) submission there are two additional habitats which were not included in 2014 (Annual vegetation of drift lines and Permanent glaciers). Consequently, the hereby submitted $CL_{emp}N$ for habitat types represented at Swedish N2000 sites based on revision of Bobbink et al. (Bobbink et al., 2022) and re-assessment by Swedish national experts is to a large extent a confirmation of the previous (2014) submission (Figure 33).

Apart from $CL_{emp}N$ for the habitat types represented at the Swedish N2000 sites, the $CL_{emp}N$ was also set for individual plant species identified at the Swedish N2000 sites (Table 33). This has been done by expert judgement by the experts from the Swedish Species Information Centre (ArtDatabanken). The $CL_{emp}N$ for the individual N2000 sites was then set as a minimum of habitat $CL_{emp}N$ (Table 32) and $CL_{emp}N$ of the plant species listed at the site (Table 33).

Figure 33 **$CL_{emp}N$ kgN/ha/yr 2014 submission (left) $CL_{emp}N$ kgN/ha/yr 2024 submission (right). For most of the 4029 N2000 sites the $CL_{emp}N$ set in 2014 was confirmed by the 2024 assessment.**



C.13.5 Gridding of N2000 sites and $CL_{emp}N$ exceedance calculation

The geographical data for the N2000 areas was collected from The Swedish Environmental Protection Agency. The data was then processed with ArcGis and gridded with the tool Grid Index Features (Input features: N2000, Polygon With: 0.10, Polygon Height: 0.05, decimal degrees) and data was added trough Join field.

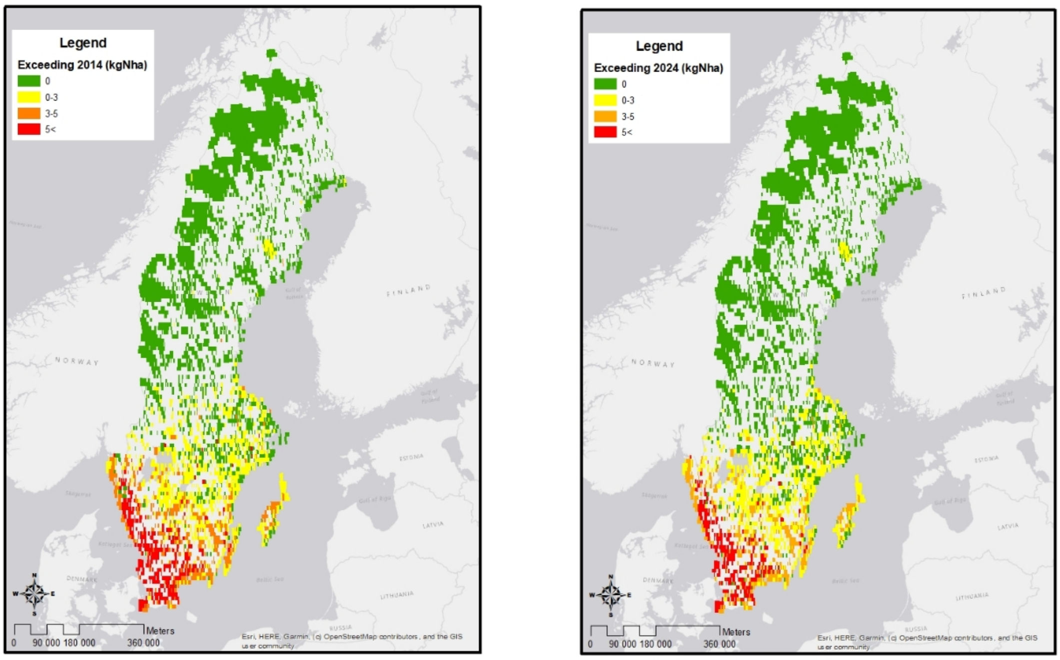
The $CL_{emp}N$ exceedance was calculated from nitrogen deposition (2018) by Spatial join (operation: JOIN_ONE_TO_ONE, Match Option: INTERSECT). The exceeding deposition was calculated by the following expression:

[LOWEST_CL_20XX] - [Ndep_kgNha]

C.13.6 Comparisons-previous reporting

To illustrate the impact of the new derived empirical critical loads for the N2000-sites, the CL exceedance was calculated and compared with the exceedance calculated from $Cl_{emp}N$ Swedish reporting 2014 (Figure 34), using N deposition for year 2018 from EMEPs open data at: https://www.emep.int/mscw/mscw_ydata.html, EMEP01_rv4_35_year.2018met_2018emis.nc.

Figure 34 **Exceedance $CL_{emp}N$ 2014 submission (left) and $CL_{emp}N$ 2024 submission (right) using N-deposition from EMEP for year 2018. Using the $CL_{emp}N$ submitted by Sweden in 2014 the CL was (deposition year 2018) exceeded at 14.9% N2000 area, which is essentially the same outcome as the current submission (14.4% area exceedance).**



The relatively low percentage area with $CL_{emp}N$ exceedance calculated for whole Sweden is, however, not the only take-home message. It needs to be noted, that the majority of the Swedish N2000 area is concentrated in the northern part of the country where several large national parks are located, and where the N deposition is - and always has been –low. In the southern and southwestern part of the country, the N2000 sites with exceedance of $CL_{emp}N$ dominate (Figure 34). The Swedish N2000 sites stretches from latitude 54.8oN to 69oN. As an example, at the southernmost roughly third of the country (south of 59.5oN) nearly the whole N2000 area (97%) has an exceedance of $CL_{emp}N$, based on deposition year 2018 (Figure 34).

Table 32 Habitats

HABITATCODE	Cl (kgN/ha/yr)	Swedish description	English description	Source	Eunis
1130	20-30	Estuarier	Estuaries	Bobbink & Hettelingh, 2011	X01
1140	20-30	Blottade ler- och sandbottnar	Mudflats and sandflats not covered by seawater at low tide	Swedish expert decision	MA52
1150	20-30	Laguner	Coastal lagoons	Bobbink & Hettelingh, 2011	X02/X03
1160	20-30	Stora vikar och sund	Large shallow inlets and bays	Swedish expert decision	
1220	8-15	Sten- och grusvallar	Perennial vegetation of stony banks	Bobbink & Hettelingh, 2011	N21
1230	3-5	Vegetationsklädda havsklippor	Vegetated sea cliffs of the Atlantic and Baltic Coasts	Swedish expert decision	N34
1310	20-30	Glasörtstränder	Salicornia and other annuals colonizing mud and sand	Bobbink et al., 2022	MA225
1330	10-20	Salta strandängar	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)	Bobbink et al., 2022	MA223/MA224
1610	5-10	Rullstensåsöar i Östersjön	Baltic esker islands with sandy, rocky and shingle beach vegetation and sublittoral vegetation	Swedish expert decision	
1620	5-10	Skär och små öar i Östersjön	Boreal Baltic islets and small islands	Swedish expert decision	N31
1630	10-20	Strandängar vid Östersjön	Boreal Baltic coastal meadows	Swedish expert decision	MA232
1640	8-15	Sandstränder vid Östersjön	Boreal Baltic sandy beaches with perennial vegetation	Swedish expert decision	N11
1650	10-15	Smala Östersjövikar	Boreal Baltic narrow inlets	Swedish expert decision	MB63
2110	8-15	Fördyner	Embryonic shifting dunes	Swedish expert decision	N13,N14
2120	5-10	Vita dyner	Shifting dunes along the shoreline with Ammophila arenaria ("white dunes")	Swedish expert decision	N13,N14

HABITATCODE	Cl (kgN/ha/yr)	Swedish description	English description	Source	Eunis
2130	5-10	Grå dyner	Fixed coastal dunes with herbaceous vegetation ("grey dunes")	Swedish expert decision	N15
2140	5-10	Risdyner	Decalcified fixed dunes with Empetrum nigrum	Swedish expert decision	N18,N19
2170	5-10	Sandvidedyner	Dunes with Salix repens ssp. argentea (Salicion arenariae)	Swedish expert decision	N1A
2180	5-10	Trädklädda dyner	Wooded dunes of the Atlantic, Continental and Boreal region	Swedish expert decision	N1D/N1F
2190	5-10	Dynvåtmarker	Humid dune slacks	Swedish expert decision	N1H
2320	5-10	Rissandhedar	Dry sand heaths with Calluna and Empetrum nigrum	Swedish expert decision	S42
2330	5-10	Grässandhedar	Inland dunes with open Corynephorus and Agrostis grasslands	Swedish expert decision	R1P/R1Q
3110	3-5	Näringsfattiga slättsjöar	Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae)	Swedish expert decision	C1.1/C1.2
3130	3-5	Ävjestrandsjöar	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea	Swedish expert decision	C1.1/C1.2
3140	3-10	Kransalgsjöar	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.	Swedish expert decision	C1.2
3150	5-10	Naturligt näringsrika sjöar	Natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation	Swedish expert decision	C1.3
3160	5-10	Myrsjöar	Natural dystrophic lakes and ponds	Bobbink et al., 2022	C1.4

HABITATCODE	Cl (kgN/ha/yr)	Swedish description	English description	Source	Eunis
3210	5-10	Större vattendrag	Fennoscandian natural rivers	Swedish expert decision	C2.2/C2.3
3220	3-5	Alpina vattendrag	Alpine rivers and the herbaceous vegetation along their banks	Swedish expert decision	C2.2/C2.3
3260	5-10	Mindre vattendrag	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation	Swedish expert decision	C2.2/C2.3
4010	5-10	Fukthedar	Northern Atlantic wet heaths with Erica tetralix	Swedish expert decision	S411
4030	5-10	Torra hedar	European dry heaths	Swedish expert decision	S42
4060	5-10	Alpina rishedar	Alpine and Boreal heaths	Bobbink et al., 2022	S2
4080	5-10	Alpina videbuskmarker	Sub-Arctic Salix spp. scrub	Bobbink et al., 2022	S2
5130	5-10	Enbuskmarker	Juniperus communis formations on heaths or calcareous grasslands	Swedish expert decision	S31
6110	3-5	Basiska berghällar	Rupicolous calcareous or basophilic grasslands of the Alysso-Sedion albi	Swedish expert decision	R13
6120	3-5	Sandstäpp	Xeric sand calcareous grasslands	Swedish expert decision	R1P/R1Q
6150	5-10	Alpina silikatgräsmarker	Siliceous alpine and boreal grasslands	Bobbink et al., 2022	R42,R43
6170	5-10	Alpina kalkgräsmarker	Alpine and subalpine calcareous grasslands	Bobbink et al., 2022	R44
6210	5-10	Kalkgräsmarker	Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (* important orchid sites)	Swedish expert decision	R1A
6230	5-10	Stagg-gräsmarker	Species-rich Nardus grasslands, on silicious substrates in mountain	Swedish expert decision	R1M

HABITATCODE	Cl (kgN/ha/yr)	Swedish description	English description	Source	Eunis
			areas (and submountain areas in Continental Europe)		
6270	5-10	Silikatgräsmarker	Fennoscandian lowland species-rich dry to mesic grasslands	Swedish expert decision	R1P
6280	3-5	Alvar	Nordic alvar and precambrian calcareous flatrocks	Swedish expert decision	R1A
6410	8-15	Fuktängar	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae)	Swedish expert decision	R37
6430	8-15	Högörtängar	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	Swedish expert decision	R55/R56
6450	10-20	Svämängar	Northern boreal alluvial meadows	Swedish expert decision	R356
6510	8-15	Slåtterängar i låglandet	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)	Swedish expert decision	R22
6520	8-15	Högländta slåtterängar	Mountain hay meadows	Swedish expert decision	R23
6530	8-15	Lövängar	Fennoscandian wooded meadows	Swedish expert decision	X09
7110	5-10	Högmossar	Active raised bogs	Bobbink et al., 2022	Q1
7120	5-10	Skadade högmossar	Degraded raised bogs still capable of natural regeneration	Swedish expert decision	Q112
7130	5-10	Terrängtäckande mossar	Blanket bogs (* if active bog)	Bobbink et al., 2022	Q1
7140	5-10	Öppna mossar och kärr	Transition mires and quaking bogs	Swedish expert decision	Q2
7160	5-10	Källor och källkärr	Fennoscandian mineral-rich springs and springfens	Swedish expert decision	C2.11/ C2.18/ C2.1A
7210	5-10	Agkärr	Calcareous fens with Cladium mariscus and species of the Caricion davallianae	Swedish expert decision	Q534

HABITATCODE	Cl (kgN/ha/yr)	Swedish description	English description	Source	Eunis
7220	5-10	Kalktuffkällor	Petrifying springs with tufa formation (Cratoneurion)	Swedish expert decision	C2.12
7230	5-10	Rikkärr	Alkaline fens	Swedish expert decision	Q41-Q44
7240	5-10	Alpina översilningskärr	Alpine pioneer formations of the Caricion bicoloris-atrofuscae	Swedish expert decision	Q45
7310	5-10	Aapamyrar	Aapa mires	Swedish expert decision	Q3
7320	5-10	Palsmyrar	Palsa mires	Swedish expert decision	Q3
8110	5-10	Silikatrasmarker	Siliceous scree of the montane to snow levels (Androsacetalia alpinae and Galeopsietalia ladani)	Swedish expert decision	U21/U22
8120	5-10	Kalkrasmarker	Calcareous and calcshist screes of the montane to alpine levels (Thlaspietea rotundifolii)	Swedish expert decision	U25/U26
8210	3-5	Kalkbranter	Calcareous rocky slopes with chasmophytic vegetation	Swedish expert decision	U36/U37
8220	3-5	Silikatbranter	Siliceous rocky slopes with chasmophytic vegetation	Swedish expert decision	U31/U32
8230	3-5	Hällmarkstorräng	Siliceous rock with pioneer vegetation of the Sedo-Scleranthion or of the Sedo albi-Veronicion dillenii	Swedish expert decision	R12
8240	3-5	Karsthällmarker	Limestone pavements	Swedish expert decision	U3E
9010	5-10	Taiga	Western Taïga	Bobbink & Hettelingh, 2011	T3G
9020	3-5	Nordlig ädellövskog	Fennoscandian hemiboreal natural old broad-leaved deciduous forests (Quercus, Tilia, Acer,	Swedish expert decision	T1E

HABITATCODE	Cl (kgN/ha/yr)	Swedish description	English description	Source	Eunis
			Fraxinus or Ulmus) rich in epiphytes		
9030	5-10	Landhöjningsskog	Natural forests of primary succession stages of land upheaval coast	Swedish expert decision	T12
9040	5-10	Fjällbjörkskog	Nordic subalpine/subarctic forests with Betula pubescens ssp. czerepanovii	Swedish expert decision	T1C
9050	5-10	Näringsrik granskog	Fennoscandian herb-rich forests with Picea abies	Bobbink & Hettelingh, 2011	T3F
9060	5-10	Åsbarrskog	Coniferous forests on, or connected to, glaciofluvial eskers	Swedish expert decision	T31,T32
9070	5-10	Trädbeklädd betesmark	Fennoscandian wooded pastures	Swedish expert decision	X09
9080	5-10	Lövsumpskog	Fennoscandian deciduous swamp woods	Swedish expert decision	T15
9110	3-5	Näringsfattig bokskog	Luzulo-Fagetum beech forests	Swedish expert decision	T17,T18
9130	10-15	Näringsrik bokskog	Asperulo-Fagetum beech forests	Bobbink et al., 2022	T17,T18
9160	10-15	Näringsrik ekskog	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the Carpinion betuli	Swedish expert decision	T1E
9180	10-15	Ädellövskog i branter	Tilio-Acerion forests of slopes, screes and ravines	Swedish expert decision	T1F
9190	3-5	Näringsfattig ekskog	Old acidophilous oak woods with Quercus robur on sandy plains	Swedish expert decision	T1B
91D0	5-10	Skogsbevuxen myr	Bog woodland	Swedish expert decision	T16/T3J/T3K
91E0	10-20	Svämlövskog	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)	Swedish expert decision	T11/T12

HABITATCODE	Cl (kgN/ha/yr)	Swedish description	English description	Source	Eunis
91F0	10-20	Svämädellövskog	Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris)	Swedish expert decision	T13
1210	20-30	Driftvallar	Annual vegetation of drift lines	Swedish expert decision	N11
8340	3-5	Permanenta glaciärer	Permanent glaciers	Swedish expert decision	U42
Excluded:					
1110		Sandbankar	Sandbanks which are slightly covered by sea water all the time	Swedish expert decision	M23
1170		Rev	Reefs	Swedish expert decision	MA13
1180		Undervattensstrukturer bildade av utläckande gas	Submarine structures made by leaking gases	Swedish expert decision	MB128
8310		Grottor	Caves not open to the public		U11
8330		Marina grottor, helt eller delvis under vattenytan	Submerged or partially submerged sea caves		MA12

Table 33 **Species**

Swedish name	**Latin name**	**CL (kg N/ha/yr)**
Alvarmalört	*Artemisia oelandica*	3-5
Avarönn	*Sorbus teodori*	5-10
Barkkvastmossa	*Dicranum viride*	5-10
Blockdraba	*Draba cacuminum*	3-5
Bottnisk malört	*Artemisia campestris subsp. bottnica*	8-15
Brudkulla	*Gymnadenia runei*	5-10
Brunbräken	*Asplenium adulterinum*	3-5
Brynia	*Brachythecium novae-angliae*	5-10
Dvärglåsbräken	*Botrychium simple*	3-5
Fjällkrassing	*Braya linearis*	3-5
Fjällviva	*Primula scandinavica*	5-10
Flytsvalting	*Luronium natans*	5-10
Gotlandssippa	*Pulsatilla vulgaris subsp. gotlandica*	3-5
Gotländsk hättemossa	*Orthotrichum rogeri*	3-5
Gotländsk nunneört	*Corydalis gotlandica*	5-10
Grusnarv	*Arenaria humifusa*	3-5
Grön sköldmossa	*Buxbaumia viridis*	5-10
Guckusko	*Cypripedium calceolus*	5-10
Gulyxne	*Liparis loeselii*	5-10
Hårklomossa	*Dichelyma capillaceu*	10-20
Hällebräcka	*Saxifraga osloënsis*	3-5
Hänggräs	*Arctophila fulva*	10-20
Ishavshästsvans	*Hippuris tetraphylla*	10-20
Kalkkrassing	*Erucastrum supinum*	3-5
Kolstarr	*Carex holostoma*	3-5
Käppkrokmossa	*Hamatocaulis vernicosus*	5-10
Laestadiusvallmo	*Papaver radicatum subsp. laestadianum*	3-5
Lappglansmossa	*Orthothecium lapponicum*	5-10
Lappranunkel	*Coptidium lapponicum*	5-10
Lappvallmo	*Papaver radicatum subsp. radicatum*	3-5
Lappviol	*Viola rupestris subsp. relicta*	3-5

Swedish name	Latin name	CL (kg N/ha/yr)
Långskaftad svanmossa	*Meesia longiseta*	5-10
Mikroskapania	*Scapania carinthiaca*	5-10
Myrbräcka	*Saxifraga hirculus*	5-10
Nipsippa	*Pulsatilla patens*	3-5
Nordisk klipptuss	*Cynodontium suecicum*	5-10
Norna	*Calypso bulbosa*	5-10
Platt spretmossa	*Herzogiella turfacea*	5-10
Polarblära	*Silene involucrata*	3-5
Ryssbräken	*Diplazium sibiricum*	5-10
Ryssnarv	*Moehringia lateriflora*	5-10
Sjönajas	*Najas flexilis*	5-10
Skogsrör	*Calamagrostis chalybaea*	5-10
Skånsk sandnejlika	*Dianthus arenarius subsp. arenarius*	3-5
Småsvalting	*Alisma wahlenbergii*	5-10
Snöfryle	*Luzula nivalis*	5-10
Späd bäckmossa	*Campylophyllum montanum*	5-10
Strandviva	*Primula nutans*	8-15
Styv kalkmossa	*Tortella rigens*	5-10
Sötgräs	*Cinna latifolia*	10-20
Taigakrokmossa	*Hamatocaulis lapponicus*	5-10
Trubbklockmossa	*Encalypta mutica*	5-10
Vedtrådmossa	*Cephalozia macounii*	5-10
Venhavre	*Trisetum subalpestre*	3-5
Ävjepilört	*Persicaria foliosa*	3-5
Öselskallra	*Rhinanthus osiliensis*	5-10

C.14 Switzerland

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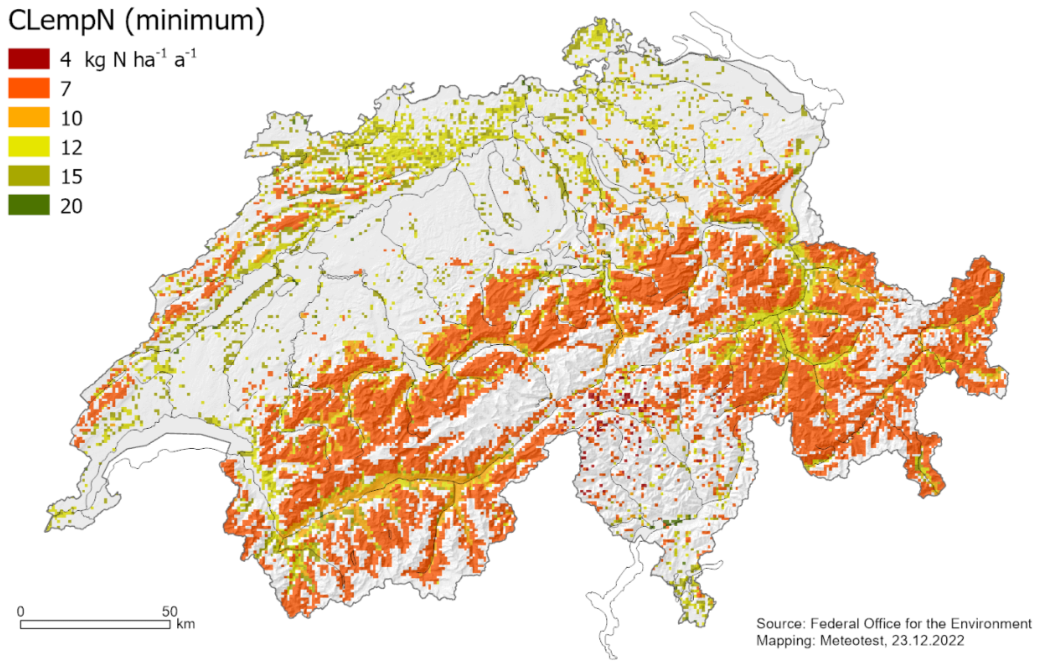
C.14.1 Overview

The Coordination Centre for Effects (CCE) launched a data call in February 2023 with the main objective to implement the recently reviewed and updated empirical Critical Load ($CL_{emp}N$). Switzerland has recently updated the national maps of $CL_{emp}N$ (Rihm & Künzle, 2023). The new maps were used in the present answer to the data call.

The empirical method for mapping critical loads of nutrient nitrogen includes different natural and semi-natural ecosystems, such as raised bogs, fens, species-rich grassland, alpine scrub habitats, oligotrophic alpine lakes and poorly managed forest types with rich ground flora. The mapping was done on a 1x1 km^2 grid combining several input maps of nature conservation areas and vegetation types. The total sensitive area amounts to 13 934 km^2 as shown in Figure 35.

Figure 35 **Empirical critical loads of nutrient nitrogen for (semi-)natural ecosystems, $CL_{emp}N$, minimum per km^2.**



Source: Federal Office for the Environment
Mapping: Meteotest, 23.12.2022

C.14.2 Mapping Methods

The selection of sensitive ecosystems to be protected by applying the empirical method is based on ecosystem and vegetation data compiled from various sources described below. All of the selected ecosystems are of high conservation importance with respect to biodiversity, landscape quality and ecosystem services. They include natural as well as semi-natural ecosystem types. Overall, 45 sensitive ecosystem types according to EUNIS classes were identified and included in the critical load data set:

- 21 various so-called “types of vegetation worthy of protection” from the vegetation atlas by Hegg et al. (Hegg O. et al., 1993) including rare and species-rich forest types, alpine heaths, grasslands and surface waters. The atlas contains distribution maps for 97 vegetation types with a resolution of 1x1 km^2. 21 vegetation types sensitive to eutrophication were selected (see Table 34).

- 1 type of mountain hay meadow (see Table 34) in montane to sub-alpine altitudinal zones with more than 35 species per 10 m^2 (Roth et al. 2013). This applies to 122 sites of the Swiss Biodiversity Monitoring[16] (BDM, indicator Z9).

- 1 type of raised bog from the Federal Inventory of Raised and Transitional Bogs of National Importance (Appendix to Swiss Confederation 1991) (see Table 34). This data set[17] is available in vector format at a scale of 1:25'000. The version used for mapping is from 2017. The inventory contains only bogs with relevant occurrences of *sphagnion fusci*.

- 2 types of poor fens and 2 types of rich fens from the Federal Inventory of Fenlands of National Importance (Appendix to Swiss Confederation 1994) (see Table 34). This data set is available in vector format at a scale of 1:25'000.

- 1 type of oligotrophic alpine lakes (see Table 34). The catchments of 100 lakes in Southern Switzerland at altitudes between 1'650 m and 2'700 m (average 2'200 m) were mapped byPosch et al. (2007). To a large extent the selected catchments consist of crystalline bedrock and are therefore sensitive to acidification and eutrophication.

- 18 types of dry grassland (TWW) from the National Inventory of Dry Grasslands of National Importance (Eggenberg S. et al., 2001) (see Table 35). This data set is available in vector format at a scale of 1:25'000. Many of those grasslands are extensively managed as hay meadows. They also include alpine and subalpine grassland.

For most of the selected ecosystems a value in the middle of the proposed range was chosen as the critical load. Only in the case of fens and several grassland types the critical load value was set near the lower end of the range because the respective ecosystems are considered to be more sensitive than the average, since they are nutrient poor or located in relatively high altitudes with short vegetation periods.

Raised bogs, oligotrophic ponds, alpine grassland, alpine heaths and most of the selected forest types are (semi-)natural ecosystems, i.e. they are not managed or only poorly managed.

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[16] http://www.biodiversitymonitoring.ch

[17] https://www.bafu.admin.ch/bafu/de/home/themen/biodiversitaet/fachinformationen/oekologische-infrastruktur/biotope-von-nationaler-bedeutung/moore.html

Fens and species-rich grassland below the alpine level are semi-natural systems, in general. They developed under permanent traditional management over centuries. When these extensive forms of management change, the ecosystems generally decrease in biodiversity.

The TWW data set complements well the grassland types mapped by Hegg et al. (Hegg O. et al., 1993). It contains 18 vegetation groups, which partially also occur in the inventory of Hegg. The two inventories are used here in a complementary way, because they answer different purposes: The atlas by Hegg gives an overview of the occurrence of selected vegetation types, while TWW focuses on the precise description of sites with national importance.

For the data and maps used in the data call, the outlines of all ecosystem-specific polygons (in vector format) were converted to a 1x1 km^2 grid (present/absent criterion). If more than one ecosystem type occurs within a 1x1 km^2 grid-cell, the lowest value of $CL_{emp}N$ was selected for this cell.

In Switzerland, empirical critical loads for nitrogen are not applied for productive forests. Instead, critical loads are calculated with the SMB method on the sites of the national forest inventory (NFI). If a NFI-site is situated on a 1x1 km^2 grid cell, where also $CL_{emp}N$ occur, EcoArea was set to 0.8 km^2 for the forest site and to 0.2 km^2 for the empirical site. Thus, double area counts were excluded. SMB critical loads itself are not considered in the empirical data set. Nevertheless, they need to be respected for integrated assessment of critical loads exceedances in Switzerland.

The protection status 9 (national nature protection program) applies to the raised bogs, fens and dry grassland (TWW). For the other data sources, no specific nature protection programs apply but those areas are globally protected by (among others) the Federal Acts on the Forest and on the Protection of the Environment.

Table 34 **Selected ecosystems for the application of empirical critical loads, $CL_{emp}N$, applied in Switzerland. Units are kg N ha^{-1} a^{-1}.**

Ecosystem type	$CL_{emp}N$ range	Relevant vegetation types in Switzerland	EUNIS code	$CL_{emp}N$
Broadleaved deciduous forest (EUNIS T1)	10-15	Quercion robori-petraeae *(Traubeneichen-wald)* Quercion pubescentis *(Flaumeichenwald)* Fraxino orno-Ostryon *(Mannaeschen-Hopfen-buchwald)*	T1912 T1911 T193	12 12 12
Coniferous forests (EUNIS T3)	3-15	Molinio-Pinetum *(Pfeifengras-Föhrenwald)* Ononido-Pinion *(Hauhechel-Föhrenwald)* Cytiso-Pinion *(Geissklee-Föhrenwald)* Calluno-Pinetum *(Heidekraut-Föhrenwald)* Erico-Pinion mugi (Ca) *(Erika-Bergföhrenwald auf Kalk)* Erico-Pinion sylvestris *(Erika-Föhrenwald)*	T35 T353 T35 T35 T348 T354	12 12 12 10 12 12

Ecosystem type	$CL_{emp}N$ range	Relevant vegetation types in Switzerland	EUNIS code	$CL_{emp}N$
Arctic and (sub)-alpine scrub habitats (EUNIS S2)	5-10	Juniperion nanae *(Zwergwacholderheiden)* Loiseleurio-Vaccinion *(Alpenazaleenheiden)*	S2311 S2211	7 7
semi-dry perennial calcareous grassland (meadow steppe)	10-20	Mesobromion (erecti) *(Trespen-Halbtrockenrasen)*	R1A	15
Molinia caerulea meadows	15-25	Molinion (caeruleae) *(Pfeifengrasrieder)*	R371	15
Mountain hay meadows	10-15	Grassland types 4.5.1-4.5.4 (Delarze et al. 2008)	R23	12
(sub)-alpine grassland	5-10	Chrysopogonetum grylli *(Goldbart-Halbtrockenrasen)* Seslerio-Bromion (Koelerio-Seslerion) *(Blaugras-Trespen-Halbtrockenrasen)* Stipo-Poion molinerii *(Engadiner Steppenrasen)*, sub-alpine Elynion *(Nacktriedrasen)*, alpine	R43 R4431 R44 R4421	10 10 10 7
Permanent oligotrophic lakes, ponds and pools	2-10	Littorellion *(Strandling-Gesellschaften)*	C1.1	7
Alpine and sub-Arctic clear water lakes	2-4	Sensitive alpine lakes in Southern Switzerland	C1.1	4
Raised and blanket bogs	5-10	Sphagnion fusci *(Hochmoor)*	Q11	7
Valley mires, poor fens and transition mires	5-15	Scheuchzerietalia *(Scheuchzergras)*, occurence of raised bog vegetation Caricion fuscae *(Braunseggenried)*	Q22 Q22	10 12
Rich fens	15-25	Caricion davallianae *(Davallsseggenried)*, Molinion Other fens: Phragmition,Magnocaricon, Calthion/ Filipendulion	Q41 Q43	15 20

Table 35 Empirical critical loads for nitrogen, $CL_{emp}N$, assigned to the vegetation types of the National Inventory of Dry Grasslands (TWW), in kg N ha^{-1} a^{-1}.

TWW-code		Vegetation type	EUNIS	Remarks	$CL_{emp}N$
1	CA	Caricion austro-alpinae *(Südalpine Blaugrashalde)*	R44	(sub-)alpine grassland	7
2	CB	Cirsio-Brachypodion *(Subkontinentaler Trockenrasen)*	R1A	similar to TWW 18 (Mesobromion), also used as hay meadow	12
3	FP	Festucion paniculatae *(Goldschwingelhalde)*	R4321	similar to TWW 13 (Festucion variae); also mapped by Hegg et al. (Hegg O. et al., 1993)	7
4	LL	low diversity, low altitude grassland *(artenarme Trockenrasen der tieferen Lagen)*	R1A	contains different types, promising diversity when mown	15
5	AI	Agropyrion intermedia *(Halbruderaler Trockenrasen)*	R1	transitional type	15
6	SP	Stipo-Poion *(Steppenartiger Trockenrasen)*	R1B3	pastures/fallows in large inner-alpine valleys; $CL_{emp}N$ based on national expert-judgment (Hegg O. et al., 1993)	10
7	MB_{SP}	Mesobromion / Stipo-Poion *(Steppenartiger Halbtrockenrasen)*	R1A32	pastures, slightly more nutrient-rich than Mesobromion (TWW18)	15
8	XB	Xerobromion *(Subatlantischer Trockenrasen)*	R1A42	meadows/pastures/fallows in large inner-alpine valleys; $CL_{emp}N$ based on national expert-judgment (Hegg O. et al., 1993)	12
9	MB_{XB}	Mesobromion / Xerobromion *(Trockener Halbtrockenrasen)*	R1A32	similar to TWW 18 (Mesobromion)	12
10	LH	low diversity, high altitude grassland *(artenarme Trockenrasen der höheren Lagen)*	R1A	contains different types of dry grassland at high altitude	12
11	CF	Caricion ferrugineae *(Rostseggenhalde)*	R4412	(sub-)alpine grassland; also mapped by Hegg et al. (Hegg O. et al., 1993)	7
12	AE	Arrhenatherion elatioris *(Trockene artenreiche Fettwiese)*	R23	often used as meadows, lower range chosen as it occurs at all altitude levels	12
13	FV	Festucion variae *(Buntschwingelhalde)*	R432	(sub-)alpine grassland, middle of the range chosen	7

TWW-code		**Vegetation type**	**EUNIS**	**Remarks**	**$CL_{emp}N$**
14	SV	Seslerion variae *(Blaugrashalde)*	R4431	alpine grassland, middle of the range chosen; also mapped by Hegg et al.	7
15	NS	Nardion strictae *(Borstgrasrasen)*	R431	meadows, subalpine	12
16	OR	Origanietalia *(Trockene Saumgesellschaft)*	R23	meadows/fallows	15
17	MB AE	Mesobromion / Arrhenatherion *(Nährstoffreicher Halbtrockenrasen)*	R1A3	slightly more nutrient-rich than Mesobromion (TWW18)	15
18	MB	Mesobromion *(Echter Halbrockenrasen)*	R1A32	genuine semi-dry grassland	12

C.15 United Kingdom

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C.15.1 Introduction

Atmospheric pollution by reactive nitrogen (N) is damaging for many habitats (Phoenix et al., 2012). The UK National Focal Centre (NFC) provides datasets and maps of the concentrations and depositions of acidifying and eutrophying pollutants, and assesses impacts on habitats through calculating exceedances of critical loads and critical levels (Rowe et al., 2022). The critical load for N is the N deposition rate below which *significant harmful effects on specified sensitive elements of the environment do not occur, according to present knowledge* (Nilsson & Grennfelt, 1988).

Exceedance statistics for N are calculated in relation to the “empirical critical load for nutrient nitrogen” ($CL_{emp}N$), for all UK habitats apart from managed woodlands. The $CL_{emp}N$ is defined on the basis of evidence from N addition experiments and from ecological surveys in relation to the gradient in N pollution. In 2021-22, a review of evidence was carried out, including studies carried out since the previous review in 2011(Bobbink & Hettelingh, 2011). The new review was published in August 2023 (Bobbink et al., 2022). Co-funding from Defra and from the UN-ECE Coordination Centre for Effects enabled UK scientists to contribute substantially to this review, including lead authorships on the chapters for Grassland and for Mires. The new review included evidence from surveys as well as N addition experiments, for the first time.

The $CL_{emp}N$ values are presented as a range for each habitat, to represent the variation in sensitivity within the habitat, and also uncertainty in both ecosystem response and N addition rate in the studies that were considered. To simplify reporting by the NFC, exceedances are calculated in relation to a single value within the recommended range, termed the mapping value.

For many habitats, the new review recommended changes to the $CL_{emp}N$ ranges for many habitats. It was therefore necessary to reconsider the mapping values, and an expert group was formed for this purpose. In this report we summarise the review process, present alternative mapping values and their implications for critical load exceedance statistics, and describe how mapping values were assigned.

C.15.2 The review process

Empirical critical loads of nitrogen ($CL_{emp}N$) have been established for Europe under the auspices of the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention) (Achermann & Bobbink, 2003; Bobbink & Hettelingh, 2011; Grennfelt & Thörnelöf, 1992). The Coordination Centre for Effects (CCE) initiated a project in 2020 to review previous and new information on the impacts of nitrogen on natural and semi-natural ecosystems, and bring the

$CL_{emp}N$ values up to date. Following an online meeting in June 2020, an international team of 43 scientists prepared a background document which was presented at a workshop held in October 2021, in Berne and online. UK scientists participated in chapters focused on individual habitats as defined using the European Nature Information System (EUNIS) classes:

- N Coastal Habitats (Laurence Jones, UKCEH)
- C Inland Surface Water Habitats (Linda May, UKCEH)
- Q Mire, bog and fen habitats (Chris Field, Manchester Metropolitan University, lead author)
- R Grasslands and Tall Forb Habitats (Carly Stevens, Lancaster University, lead author)
- S Heathland, Scrub and Tundra Habitats (Andrea Britton, James Hutton Institute)
- T Forest Habitats (Mike Perring, UKCEH).

As with the previous review in 2011, $CL_{emp}N$ values were assessed using outcomes of field addition experiments that had independent N treatments and realistic N loads and durations. The new review also assessed gradient studies on atmospheric N deposition. For many habitats, changes to the $CL_{emp}N$ ranges were proposed. A reliability score is given to indicate the strength of the evidence underlying the proposed range, on a three-point scale (Reliable, Quite Reliable, or based on Expert Judgement). These reliability scores were also updated for many habitats. The review report includes a new chapter, “Use of $CL_{emp}N$ in risk assessment and nature protection”, which presents guidance on how $CL_{emp}N$ values can be applied, and gives examples of the use of $CL_{emp}N$ on different scales and in different European countries.

C.15.3 Summary of the review

Following the review of evidence, $CL_{emp}N$ ranges were agreed on for all the EUNIS classes (at Level 2 or Level 3) that were assessed (Table 36).

Table 36 **Comparison of critical loads for nutrient nitrogen as established in reviews in 2011 (Bobbink & Hettelingh, 2011) and in 2022 (Bobbink et al., 2022), for habitats that are currently mapped nationally by the UK National Focal Centre. Reliability is indicated as follows: ## Reliable, # Quite reliable, (#) Expert judgement.**

Habitat	EUNIS code 2012	EUNIS code 2021	Critical Load range Bobbink et al 2011 kg N ha^{-1} yr^{-1}	Critical Load range Bobbink et al 2022 kg N ha^{-1} yr^{-1}	Reliability (2022)
Saltmarsh	A2.53; A2.54; A2.55	MA223 MA224 MA225	20-30	10-20 (upper-mid) 10-20 (mid-low) 20-30 (pioneer)	(#) (#) (#)
Acid grassland	E1.7 E3.52	R372 R1M	10-15 (dry) 10-20 (wet)	6-10 (dry) 10-20 (wet)	## (#)
Calcareous grassland	E1.26	R1A	15-25	10-20	##
Dune grassland	B1.4	N15	8-15	5-15	##

Habitat	EUNIS code 2012	EUNIS code 2021	Critical Load range Bobbink et al 2011 kg N ha^{-1} yr^{-1}	Critical Load range Bobbink et al 2022 kg N ha^{-1} yr^{-1}	Reliability (2022)
Dwarf shrub heath	F4.11; F4.2	S411; S42	10-20	5-15	## ##
Montane	E4.2	E4.2	5-10	5-10	#
Bog	D1	Q1	5-10	5-10	##
Scots Pine woodland	G3.4	T35	5-15	5-15	#
Managed coniferous woodland[1]	G3	T31	(5-15)	(10-15)	(#)
Beech woodland	G1.6	T17	10-20	10-15	(#)
Acidophilous oak woodland	G1.8	T1B	10-15	10-15	(#)
Managed broadleaved woodland	G1	T1	10-20	10-15	##
Mixed woodland	G4	-	10-20	Not given	-

[1] Critical loads applied to managed coniferous woodland by the UK National Focal Centre are based on a simple mass balance approach rather than the empirical critical load, hence these ranges are shown in brackets.

Overall, the review concluded that the lower value of the $CL_{emp}N$ range needed to decrease for more than 40% of the EUNIS habitats considered. In only one case was the upper value increased. The review recommended more research to establish $CL_{emp}N$ values for understudied ecosystems, including many mires, freshwaters and coastal habitats, and all those habitats where the Reliability score was given as “expert judgement”.

C.15.4 Mapping values

For Trends Reports, exceedances are calculated in relation to a single value within each range, the *mapping value*. For Trends Reports up until 2022, the middle of the range as defined in Bobbink and Hettelingh (2011) was used as the mapping value for most habitats. The mapping value for Bog habitats was modified according to annual precipitation, and the mapping value for Dune Grasslands was modified according to soil acidity based on the occurrence of the grass *Corynephorus canescens* (see Table 38). Following the review of $CL_{emp}N$ values, an expert group was convened in autumn 2022 to consider what mapping values should be used. The group included representatives from the pollution impacts research community, including several of the chapter authors for the 2022 review, from the Statutory Nature Conservation Agencies (SNCAs), and from Defra (Table 37).

Table 37 Participants in the expert group formed to discuss $CL_{emp}N$ mapping values.

Name	Institution	Name	Institution
Khalid Aazem	JNCC	Linda May	UKCEH
Simon Bareham	NRW	Áine O'Reilly	DAERA
Katharine Blythe	Natural England	Ed Rowe	UKCEH
Andrea Britton	James Hutton Institute	Simon Smart	UKCEH
Nancy Dise	UKCEH	Carly Stevens	Lancaster U
Chris Field	MMU	Charlotte Tomkinson	Natural England
Lydia Hunt	Natural England	Kerry Vitalis	Defra
Laurence Jones	UKCEH	David Vowles	Defra
Sue Marrs	NatureScot	Susan Zappala	JNCC

To illustrate the implications of using different mapping values, some of the results that are presented in Trends Reports were calculated using different alternatives. Table 38 shows the mapping values used previously for each habitat, which as noted above were mainly the midpoints of the published ranges, plus two alternatives: the midpoint of the new range, and the lower end of the new range.

Table 38 Comparison of alternative mapping values for the critical load for nutrient nitrogen for UK habitats: a) values used for previous reporting, which are mainly the midpoint of the range proposed in Bobbink and Hettelingh (2011); b) midpoints of the new ranges proposed in Bobbink et al. (2022) and c) lower ends of the new ranges.

Habitat	EUNIS code 2021	Previous UK mapping value(s) kg N ha^{-1} yr^{-1}	Midpoint of new range kg N ha^{-1} yr^{-1}	Lower end of new range kg N ha^{-1} yr^{-1}
Saltmarsh	MA223 MA224 MA225	25	15	10
Acid grassland	R372 R1M	10 (dry) 15 (wet)	8 (dry) 15 (wet)	6 (dry) 10 (wet)
Calcareous grassland	R1A	15	15	10
Dune grassland	N15	9; 12 [1]	10	5
Dwarf shrub heath	S411; S42	10	10	5
Montane	E4.2	7	7.5	5
Bog	Q1	8; 9; 10 [2]	7.5	5
Scots Pine woodland [3]	T35	12	10	5

Habitat	EUNIS code 2021	Previous UK mapping value(s) kg N ha^{-1} yr^{-1}	Midpoint of new range kg N ha^{-1} yr^{-1}	Lower end of new range kg N ha^{-1} yr^{-1}
Managed coniferous woodland [4]	T31	12	(12.5)	(10)
Beech woodland	T17	15	12.5	10
Acidophilous oak woodland	T1B	10	12.5	10
Managed broadleaved woodland	T1	12	12.5	10
Mixed woodland [5]	-	12	12.5	10

[1] Depending on pH; acid dune grassland was thought to be more sensitive than calcareous dune grassland.

[2] Depending on annual precipitation; bogs in drier regions were thought to be more sensitive than bogs in wetter regions.

[3] Native scots pine woodland assumed to be closest to **T35 Temperate continental Pinus sylvestris forest**, rather than **T3G Pinus sylvestris light taiga**.

[4] In the review, a lower Critical Load range was set for the broad class **T3 Coniferous forest** (3-15 kg N ha^{-1} yr^{-1}) than for **T35 Temperate continental Pinus sylvestris forest**. Since UK coniferous woodland outside the native range of Pinus sylvestris is considered to be managed, this habitat was assumed to be closest to **T31 Temperate mountain Picea forest**. However, currently the critical load for managed coniferous woodland is calculated using a mass-balance approach and the empirical critical load is not applied, hence these figures are shown in brackets.

[5] A critical load range was not given for **Mixed woodland** in the 2022 review. This habitat was assumed to be closest to **T1 Managed broadleaved woodland.**

C.15.5 Comparison of exceedance results using different mapping values

For several habitats the midpoint of the new range was lower than the previous mapping value (Table 38), but using the new midpoints as mapping values made relatively difference to the percentage area where $CL_{emp}N$ was exceeded (Table 39) nor to Excess Nitrogen (Table 40). Using the lower end of the range rather than the midpoint made a larger difference, for example increasing the percentage area of sensitive habitat in the UK where the $CL_{emp}N$ was exceeded from 68.3% to 90.1% (Table 39). This is shown clearly in UK maps of Excess Nitrogen, in which using the lower end of the range means that the only substantial area of non-exceedance is in central north Scotland (Figure 36).

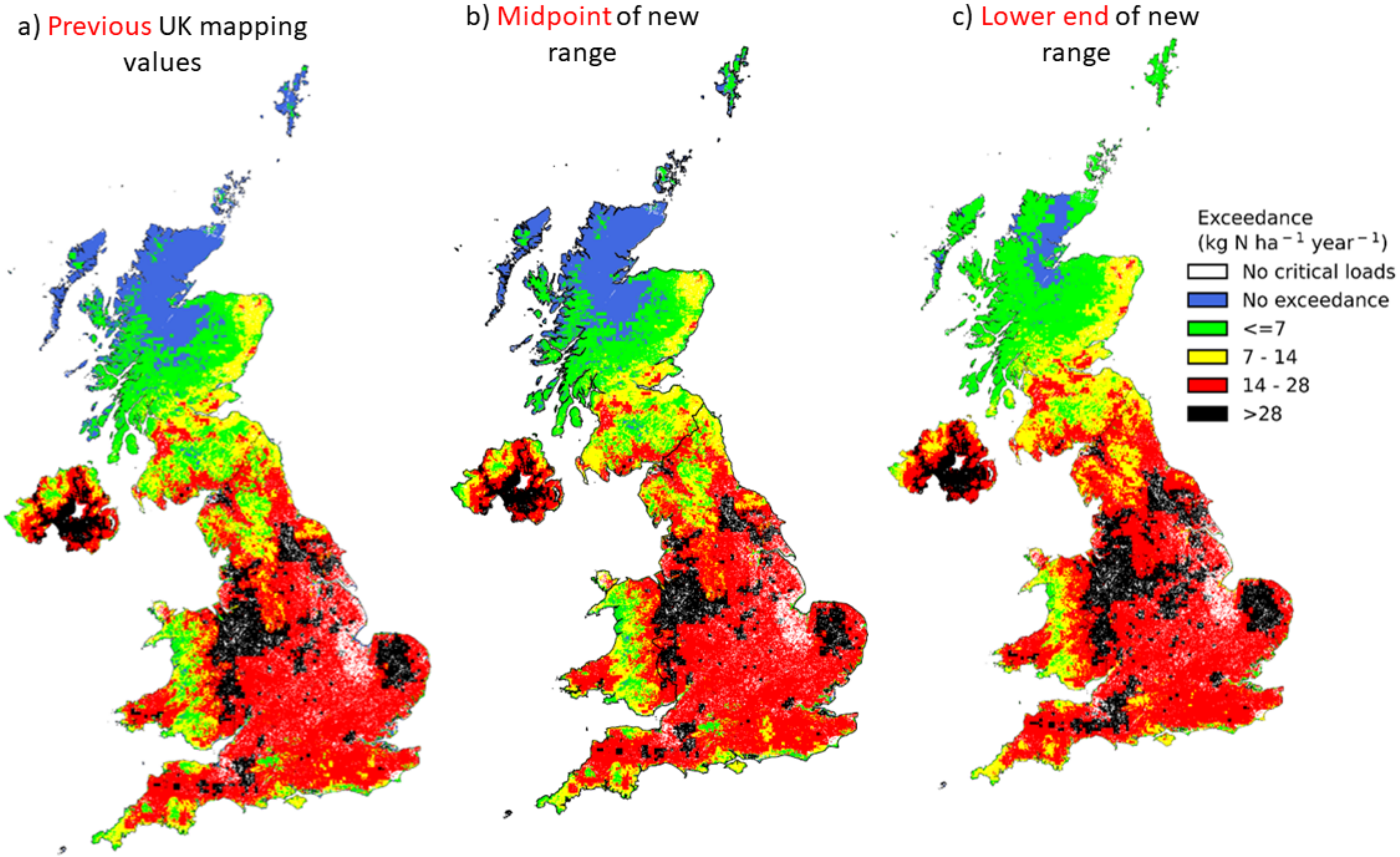
Table 39 **Percentage area of Nitrogen-sensitive habitats where nutrient nitrogen critical loads are exceeded, using different definitions of critical load: the previous mapping value, mainly the midpoint of the ranges established in 2011 (Bobbink & Hettelingh, 2011); the midpoint of the ranges established in the new review (Bobbink et al., 2022) and the lower end of the ranges established in the new review.**

	Previous mapping values	Midpoint of new range	Lower end of new range
	% Area exceeding the critical load		
England	97.5	99.1	100.0
Wales	92.0	92.9	99.9
Scotland	45.4	47.1	83.0
NI	98.3	98.6	99.4
UK	66.8	68.3	90.1

Table 40 **Excess Nitrogen (i.e. Average Accumulated Exceedance) for Nitrogen-sensitive habitats, using different definitions of critical load: the previous mapping value, mainly the midpoint of the ranges established in 2011 (Bobbink & Hettelingh, 2011); the midpoint of the ranges established in the new review ; and the lower end of the ranges established in the new review.**

	Previous mapping values	Midpoint of new range	Lower end of new range
	Excess Nitrogen (kg ha^{-1} yr^{-1})		
England	16.4	16.4	19.3
Wales	10.7	10.9	13.7
Scotland	2.7	2.7	4.7
NI	15.1	15.4	18.4
UK	7.8	7.9	10.2

Figure 36 Excess Nitrogen (Average Accumulated Exceedance of nutrient-nitrogen critical load) in 2018-20, as calculated with alternative mapping values: (a) previous UK CL_{empN} mapping values, (b) midpoint of new range, and (c) lower end of new range.



C.15.6 Mapping values – discussion

The Expert Group held three virtual meetings (22nd Sept 2022, 11th Jan 2023 and 9th Feb 2023) to discuss what mapping values should be applied. A similar discussion was convened following the previous review of $CL_{emp}N$ (Hall, 2010) in which it was noted that Signatory Parties to the CLRTAP are free to decide where to set the CL within each range, and whether or not to apply modifying factors to reflect differential sensitivity of the habitat, for example with greater rainfall or lower soil pH. The 2010 discussion concluded that the mapping value should be the mid-point of each range, unless specific evidence from the UK suggested using a different value.

Key points made in the in 2022 - 2023 discussion were:

- There is now more evidence for decreases in occurrence in individual species at low rates of N deposition.
- The new $CL_{emp}N$ ranges are based on a thorough review of evidence in relation to the habitat, not only for single species.
- There is also evidence of biogeochemical changes at the low end of the range.
- The meaning of the lower end of the range is intended to be similar for all habitats, i.e. that there is some evidence for harmful effects at this lower end.
- There is a continuum from pristine to degraded examples of each habitat, but most habitats in England in particular have been in exceedance of $CL_{emp}N$ for a long period, so restoration and recovery are more relevant concepts than is the protection of pristine habitats.
- However, the UK does include fairly pristine habitats, and there is emerging evidence of harm to these habitats even at low N deposition rates. For this reason, it was decided in the review not to recommend the use of a rainfall modifier for bogs.
- For example, many areas of Scotland still receive low rates of N deposition, and the lower end of the range is more relevant for Scotland.
- The ranges reflect uncertainty about the point where harmful effects occur. For example, productivity in calcareous grasslands is often limited by P availability, so they are able to receive comparatively large loads of N before becoming eutrophic.
- In practice, the lower end of the range has usually been applied by the SNCAs when assessing developments. There is a case for using the same basis for national-scale statistics and maps.
- There are comparatively few sites receiving low rates of N deposition, so evidence is limited at the low end.
- Nevertheless, the lower end of the range represents the point where there is evidence that harm starts.

It was noted that changing the mapping value to the lower end of the range would greatly increase exceedance statistics, e.g. the area of N-sensitive habitat in England where $CL_{emp}N$ is exceeded would increase to 100 % (Table 39). This might make targets for non-exceedance seem unattainable, and there is an argument that more achievable targets are more likely to be addressed. However, the group reached a consensus that the mapping value must be defined solely using scientific evidence.

C.15.7 Mapping values – conclusions

After extensive discussion, the following recommendations were agreed by the expert group:

1. The mapping value for $CL_{emp}N$ should be set to the lower end of the published range for each habitat.
2. Environmental factors such as rainfall or soil pH should not be used as modifiers for the mapping values.
3. The same value of $CL_{emp}N$ should be applied to habitats in all UK countries.

D Annex 4: Results of ex-post-analysis with Empirical Critical Load ($CL_{emp}N$) data

D.1 Tables evaluating exceedance of NFC reported $CL_{emp}N$

Table 41 AAE [kg ha^{-1} a^{-1}] and AAR [%] evaluating exceedance of NFC reported $CL_{emp}N$ for different scenarios for 2040

	receptor area		Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	% of total country area	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
Austria	54.375	64,8	4,6	71,9	1,3	32,2	1,0	25,7	0,9	23,4	0,5	16,3
Belgium	6.480	21,2	5,6	93,6	0,6	26,6	0,3	16,5	0,3	14,9	0,2	8,8
Bulgaria	47.399	42,7	0,5	23,1	0,2	10,1	0,2	7,6	0,1	5,4	0,1	4,8
Croatia	34.210	60,4	1,8	56,6	0,4	17,7	0,3	13,2	0,2	9,0	0,1	7,4
Cyprus	3.358	36,3	3,2	93,7	3,7	94,1	3,3	93,7	2,4	92,3	2,2	92,2
Czech Republic	23.831	30,2	7,3	97,8	1,4	59,9	0,8	45,5	0,6	39,4	0,3	30,7
Denmark	7.600	17,6	7,7	84,9	2,9	68,0	2,1	64,0	1,6	59,2	1,1	49,8
Estonia	32.188	71,2	0,1	8,8	0,0	2,9	0,0	2,7	0,0	2,3	0,0	0,8
Finland	23.688	7,0	0,1	6,5	0,0	3,1	0,0	2,6	0,0	2,4	0,0	1,8
France	234.568	42,5	3,1	55,3	1,0	32,0	0,8	28,6	0,6	25,7	0,4	20,6
Germany	93.924	26,3	3,4	92,4	0,5	43,2	0,4	34,2	0,4	31,9	0,2	19,6
Greece	66.817	50,6	1,1	41,2	0,7	34,2	0,6	30,9	0,4	26,0	0,3	23,9
Hungary	26.238	28,2	3,4	77,2	0,7	26,5	0,5	16,0	0,4	11,7	0,3	10,2
Ireland	17.283	24,6	2,2	56,0	1,9	48,5	1,8	46,5	1,7	46,2	1,1	34,1
Italy	272.936	90,6	3,2	69,5	1,2	37,3	0,9	31,9	0,7	27,1	0,6	23,5
Latvia	44.707	69,2	0,3	29,8	0,0	1,3	0,0	1,1	0,0	1,0	0,0	0,8

	receptor area		Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km^2	% of total country area	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
Lithuania	28.720	44,0	1,8	72,5	0,2	19,6	0,1	11,3	0,1	6,3	0,0	1,5
Luxembourg	1.541	59,6	10,0	97,8	3,5	61,8	2,9	61,0	2,6	60,5	1,7	57,0
Malta	9	2,8	3,1	58,2	2,2	58,1	1,9	58,1	1,7	58,1	1,6	58,1
Netherlands	2.061	5,0	13,7	87,8	7,3	76,0	6,7	75,1	6,5	74,4	5,7	73,4
Poland	97.128	31,1	5,0	97,2	0,7	80,3	0,2	60,6	0,0	39,0	0,0	16,5
Portugal	44.976	48,8	1,0	30,3	0,5	22,8	0,4	20,9	0,3	17,1	0,2	12,2
Romania	96.882	40,6	0,6	20,9	0,3	7,2	0,2	6,3	0,2	5,6	0,1	5,2
Slovakia	24.117	50,2	2,0	74,9	0,2	7,7	0,2	5,4	0,1	4,3	0,1	4,0
Slovenia	13.383	66,0	5,7	92,2	1,7	52,6	1,1	37,8	0,9	32,4	0,5	20,7
Spain	246.288	48,7	2,7	68,0	1,5	52,4	1,4	50,0	0,9	40,7	0,6	33,4
Sweden	50.247	11,2	0,4	12,2	0,1	8,9	0,1	7,6	0,1	6,6	0,1	4,9
EU-27	**1.594.954**	**38,5**	**1,3**	**50,0**	**0,4**	**29,4**	**0,3**	**25,3**	**0,2**	**20,9**	**0,1**	**16,3**
Andorra	422	90,1	0,1	14,4	0,0	3,7	0,0	3,7	0,0	0,1	0,0	0,1
Iceland	58.715	57,0	0,0	2,0	0,0	0,1	0,0	0,1	0,0	0,1	0,0	0,0
Liechtenstein	100,00	62,6	4,9	94,1	1,0	63,1	0,7	34,6	0,6	32,5	0,4	25,3
Norway	303.757	78,9	0,5	22,4	0,1	12,4	0,1	11,0	0,1	10,2	0,0	8,1
San Marino	13	21,4	1,5	99,0	0,1	1,2	0,0	1,2	0,0	1,2	0,0	1,2
Switzerland	13.934	33,8	2,8	46,2	1,4	30,1	1,0	25,9	1,0	25,1	0,8	22,0
United Kingdom	93.777	38,7	1,9	52,2	0,6	28,1	0,3	21,1	0,3	20,4	0,1	13,1
Non-EU	**470.717**	**60,9**	**0,6**	**26,2**	**0,1**	**14,3**	**0,1**	**11,9**	**0,1**	**11,3**	**0,0**	**8,4**
Albania	17.353	60,4	1,5	39,9	1,1	32,8	1,0	28,7	0,7	22,2	0,7	21,1

	receptor area		Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	% of total country area	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
Bosnia and Herzegovina	33.596	65,6	1,3	42,3	0,5	22,5	0,3	15,9	0,2	10,6	0,1	7,4
Kosovo	5.937	54,5	0,3	18,2	0,1	4,0	0,1	3,3	0,0	2,3	0,0	1,9
Montenegro	10.650	77,1	0,3	11,2	0,1	5,3	0,1	4,2	0,1	3,7	0,1	2,7
North Macedonia	15.525	60,4	0,3	11,5	0,2	7,5	0,1	6,9	0,1	5,9	0,1	5,1
Serbia	33.237	42,9	1,6	49,5	0,5	17,9	0,3	13,1	0,2	8,8	0,1	5,3
WB countries	**116.298**	**56,0**	**1,1**	**35,8**	**0,4**	**18,2**	**0,3**	**14,1**	**0,2**	**10,1**	**0,2**	**7,8**
Armenia	110.65	37,2	2,2	57,6	4,1	73,9	3,4	65,8	2,7	62,4	2,6	62,0
Azerbaijan	28.073	32,4	1,6	52,9	2,7	71,9	1,9	59,4	1,5	53,6	1,3	49,8
Belarus	117.179	56,4	2,6	82,6	1,5	65,0	1,0	51,0	0,4	31,2	0,1	10,0
Georgia	49.175	71,3	0,9	37,0	1,2	49,4	0,8	38,0	0,4	21,5	0,3	17,6
Kazakhstan	900.333	33,0	0,0	2,7	0,1	4,3	0,0	3,4	0,0	2,6	0,0	2,2
Kyrgyzstan	53.814	26,9	0,8	17,5	1,4	25,9	1,0	21,3	0,8	17,7	0,7	16,7
Moldova	4.266	12,6	0,2	22,6	0,2	18,5	0,1	3,8	0,0	0,5	0,0	0,3
Russia	3.323.814	19,4	0,0	8,3	0,0	7,3	0,0	4,7	0,0	4,1	0,0	2,2
Tajikistan	32.965	23,0	1,3	42,7	2,5	53,8	1,8	48,5	1,4	45,7	1,4	45,0
Turkey	309.969	39,6	2,3	48,5	4,2	68,7	3,3	61,5	1,9	45,8	1,8	44,5
Turkmenistan	121.356	24,9	0,3	25,9	0,8	45,0	0,5	34,3	0,4	24,7	0,3	22,3
Ukraine	147.653	24,5	1,4	52,2	0,7	37,7	0,4	23,3	0,2	15,8	0,1	7,7
Uzbekistan	116.913	26,0	1,2	40,2	2,0	47,6	1,4	41,4	1,1	38,0	1,0	37,0
EECCA countries & Turkey	**5.216.576**	**22,8**	**0,1**	**14,1**	**0,2**	**15,2**	**0,1**	**11,6**	**0,1**	**9,1**	**0,1**	**6,9**

Table 42 Relative change in AAE and AAR for $CL_{emp}N$ (NFC) under the different scenarios for 2040 in comparison to the baseline scenario 2015

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]
Austria	-72,6	-55,3	-79,1	-64,2	-81,2	-67,4	-88,3	-77,4
Belgium	-89,8	-71,6	-94,1	-82,3	-94,8	-84,1	-97,2	-90,6
Bulgaria	-55,6	-56,3	-66,1	-67,3	-81,3	-76,7	-84,9	-79,4
Croatia	-76,9	-68,7	-83,7	-76,6	-89,6	-84,2	-92,4	-87,0
Cyprus	17,9	0,4	5,3	0,0	-23,6	-1,5	-30,6	-1,5
Czech Republic	-81,5	-38,8	-89,4	-53,5	-91,4	-59,7	-95,2	-68,6
Denmark	-62,5	-19,9	-72,7	-24,6	-79,8	-30,3	-85,9	-41,4
Estonia	-83,1	-67,0	-89,3	-69,7	-93,2	-73,4	-99,6	-91,1
Finland	-83,8	-53,0	-81,4	-60,0	-82,7	-62,5	-90,5	-72,5
France	-69,1	-42,2	-75,1	-48,3	-80,2	-53,6	-87,1	-62,7
Germany	-85,7	-53,3	-88,7	-63,0	-89,0	-65,5	-94,0	-78,7
Greece	-34,7	-17,0	-47,7	-25,0	-63,7	-37,0	-69,6	-42,0
Hungary	-80,1	-65,6	-86,1	-79,3	-89,4	-84,8	-91,9	-86,8
Ireland	-16,4	-13,5	-20,9	-17,0	-22,6	-17,5	-52,6	-39,0
Italy	-62,6	-46,4	-71,7	-54,1	-76,9	-61,1	-82,3	-66,1
Latvia	-93,8	-95,7	-96,2	-96,4	-96,9	-96,7	-98,8	-97,3
Lithuania	-88,6	-73,0	-94,4	-84,4	-96,9	-91,3	-99,2	-97,9
Luxembourg	-64,5	-36,7	-70,7	-37,6	-73,9	-38,1	-82,6	-41,7
Malta	-29,0	-0,3	-40,2	-0,3	-45,2	-0,3	-48,7	-0,3
Netherlands	-46,9	-13,4	-51,4	-14,5	-52,2	-15,3	-58,4	-16,4
Poland	-86,7	-17,4	-96,1	-37,6	-99,1	-59,9	-100,0	-83,1

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
Portugal	-56,6	-24,7	-62,0	-31,1	-70,7	-43,6	-84,4	-59,6
Romania	-52,9	-65,6	-60,1	-69,8	-68,7	-73,0	-73,0	-75,0
Slovakia	-89,5	-89,8	-92,3	-92,8	-94,1	-94,3	-95,6	-94,7
Slovenia	-70,8	-43,0	-80,0	-59,0	-83,6	-64,8	-90,8	-77,6
Spain	-45,0	-23,0	-49,3	-26,5	-66,9	-40,2	-76,7	-50,9
Sweden	-68,4	-26,9	-75,1	-37,6	-77,9	-45,8	-85,4	-60,1
EU-27	-72,8	-41,2	-79,2	-49,4	-85,1	-58,2	-90,8	-67,3
Andorra	-90,9	-74,2	-97,5	-74,2	-99,5	-99,5	-99,7	-99,5
Iceland	-100,0	-93,6	-85,1	-93,7	-85,1	-95,0	-91,5	-98,2
Liechtenstein	-78,7	-33,0	-85,7	-63,2	-86,7	-65,4	-91,1	-73,0
Norway	-74,0	-44,9	-78,8	-51,0	-81,8	-54,3	-91,0	-63,9
San Marino	-96,8	-98,8	-98,1	-98,8	-99,0	-98,8	-99,6	-98,8
Switzerland	-51,6	-34,8	-62,7	-44,0	-64,4	-45,8	-71,2	-52,4
United Kingdom	-70,4	-46,1	-83,0	-59,6	-83,7	-60,9	-92,7	-74,9
Non-EU	-80,6	-45,4	-87,2	-54,5	-88,7	-57,0	-95,3	-68,1
Albania	-22,4	-17,7	-32,7	-27,9	-51,5	-44,3	-54,9	-47,0
Bosnia and Herzegovina	-63,9	-46,9	-77,7	-62,5	-85,9	-75,0	-90,9	-82,5
Kosovo	-72,9	-78,0	-77,9	-82,0	-84,9	-87,6	-87,5	-89,4
Montenegro	-49,8	-52,7	-59,6	-62,5	-69,3	-67,0	-73,9	-75,8
North Macedonia	-51,2	-35,2	-63,4	-40,0	-75,9	-48,9	-80,9	-55,4
Serbia	-72,3	-63,8	-82,6	-73,6	-89,4	-82,1	-94,4	-89,3
WB countries	**-59,5**	**-49,2**	**-71,0**	**-60,7**	**-81,0**	**-71,7**	**-85,8**	**-78,1**

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
Armenia	81,2	28,3	50,1	14,4	20,4	8,4	14,2	7,8
Azerbaijan	71,5	35,8	24,2	12,1	-4,4	1,2	-17,7	-6,0
Belarus	-44,1	-21,2	-63,8	-38,3	-83,8	-62,3	-95,4	-87,8
Georgia	43,5	33,4	-4,3	2,7	-51,4	-41,8	-60,1	-52,5
Kazakhstan	141,0	62,4	48,6	26,6	3,2	-2,1	-23,7	-15,4
Kyrgyzstan	69,9	48,1	23,7	21,9	-9,0	1,6	-16,7	-4,4
Moldova	23,5	-18,1	-61,1	-83,0	-93,5	-97,9	-95,3	-98,6
Russia	35,1	-12,6	-43,2	-44,1	-54,1	-50,9	-77,0	-74,1
Tajikistan	88,7	25,9	39,6	13,6	10,9	7,1	6,6	5,5
Turkey	80,5	41,5	39,2	26,8	-18,1	-5,6	-22,0	-8,2
Turkmenistan	142,2	73,9	65,2	32,5	11,2	-4,4	-0,9	-13,7
Ukraine	-45,9	-27,8	-73,0	-55,3	-82,2	-69,8	-91,4	-85,3
Uzbekistan	63,6	18,3	17,6	2,9	-9,6	-5,4	-15,5	-8,0
EECCA countries & Turkey	**95,6**	**7,1**	**31,7**	**-17,9**	**-30,6**	**-35,8**	**-36,5**	**-50,9**

Table 43 **AAE [kg ha^{-1} a^{-1}] and AAR [%] for EUNIS Level-3 grassland ecosystems (R) evaluating exceedance of NFC reported Empirical Critical Loads for different scenarios for 2040 (only those R grasslands being part of and displayed in Annex A)**

	receptor area	Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
Semi-dry perennial calcareous grassland (meadow steppe) (R1A)	45.162	0,1	4,2	0,1	3,3	0,0	2,3	0,0	1,2	0,0	0,9
Mediterranean closely grazed dry grassland (R1D)	6.044	1,8	78,9	1,6	61,2	1,3	53,7	0,7	36,1	0,6	29,2
Mediterranean tall perennial dry grassland (R1E)	508.051	0,6	25,3	1,0	33,3	0,8	28,3	0,6	24,2	0,5	22,9
Mediterranean annual-rich dry grassland (R1F)	1.996	2,9	83,8	3,3	68,6	2,8	66,4	2,1	60,6	1,9	56,6
Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta (R1M)	21.276	1,2	55,3	0,4	27,1	0,2	18,8	0,2	17,8	0,1	9,0
Oceanic to subcontinental inland sand grassland on dry acid and neutral soils (R1P)	5.739	0,7	19,1	0,3	9,4	0,3	8,8	0,2	8,0	0,2	6,0
Inland sanddrift and dune with siliceous grassland (R1Q)	60	11,2	100,0	4,5	91,9	3,8	91,0	3,7	89,8	2,2	69,1
Low and medium altitude hay meadow (R22)	201.405	0,3	12,9	0,2	8,0	0,1	5,7	0,0	2,8	0,0	2,0
Mountain hay meadow (R23)	3.799	0,3	10,8	0,5	15,5	0,4	14,3	0,2	9,4	0,2	8,7
Moist or wet mesotrophic to eutrophic hay meadow (R35)	246.605	0,0	0,1	0,0	0,3	0,0	0,2	0,0	0,0	0,0	0,0
Temperate and boreal moist or wet oligotrophic grassland (R37)	872	2,8	35,0	1,1	22,9	0,9	19,6	0,8	18,6	0,5	15,0
Boreal and arctic acidophilous alpine grassland (R42)	149.141	0,0	0,3	0,0	0,4	0,0	0,3	0,0	0,2	0,0	0,2
Temperate acidophilous alpine grassland (R43)	117.074	0,9	39,6	1,7	49,0	1,3	42,4	0,9	34,5	0,9	31,0
Arctic-alpine calcareous grassland (R44)	43.595	1,0	41,8	1,2	41,4	0,9	32,9	0,6	25,3	0,6	21,8

Table 44 **Relative change in AAE and AAR for $CL_{emp}N$ (NFC) under the different scenarios for 2040 in comparison to the baseline scenario 2015 (only those R grassland ecosystem types being part of and displayed in Annex A)**

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]
Semi-dry perennial calcareous grassland (meadow steppe) (R1A)	-17,6	-20,7	-54,2	-46,1	-78,7	-72,7	-85,1	-77,9
Mediterranean closely grazed dry grassland (R1D)	-11,9	-22,4	-29,8	-31,9	-60,4	-54,3	-67,1	-62,9
Mediterranean tall perennial dry grassland (R1E)	71,3	31,7	27,8	11,7	-3,7	-4,5	-11,6	-9,6
Mediterranean annual-rich dry grassland (R1F)	14,6	-18,1	-4,5	-20,8	-28,7	-27,6	-35,1	-32,5
Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta (R1M)	-70,5	-51,0	-83,5	-65,9	-84,8	-67,7	-94,1	-83,8
Oceanic to subcontinental inland sand grassland on dry acid and neutral soils (R1P)	-56,9	-51,0	-63,2	-53,9	-66,7	-57,9	-79,8	-68,6
Inland sanddrift and dune with siliceous grassland (R1Q)	-59,3	-8,1	-66,1	-9,0	-67,3	-10,2	-80,3	-30,9
Low and medium altitude hay meadow (R22)	-47,8	-38,3	-70,8	-56,2	-89,3	-78,5	-93,1	-84,7
Mountain hay meadow (R23)	79,3	44,5	42,4	32,5	-32,6	-12,2	-39,3	-19,3
Moist or wet mesotrophic to eutrophic hay meadow (R35)	205,6	122,3	77,8	76,3	-88,9	-63,1	-88,9	-68,5
Temperate and boreal moist or wet oligotrophic grassland (R37)	-58,6	-34,7	-68,3	-44,0	-72,7	-47,1	-81,9	-57,2
Boreal and arctic acidophilous alpine grassland (R42)	-12,5	3,7	-29,5	-18,6	-41,1	-30,9	-65,2	-42,6
Temperate acidophilous alpine grassland (R43)	84,8	23,6	47,4	6,9	4,0	-12,9	-3,6	-21,8
Arctic-alpine calcareous grassland (R44)	24,5	-1,2	-3,4	-21,4	-35,8	-39,6	-41,8	-48,0

D.2 Tables evaluating exceedance of harmonised minimum Empirical Critical Loads

Table 45 AAE [kg ha^{-1} a^{-1}] and AAR [%] evaluating exceedance of harmonised minimum Empirical Critical Loads for different scenarios for 2040

	receptor area		Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	% of total country area	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
Austria	54.375	64,8	5,5	81,9	1,7	46,0	1,3	38,5	1,2	35,6	0,8	26,7
Belgium	14.455	47,3	12,5	99,8	6,2	96,9	5,0	90,8	4,7	87,7	3,6	77,8
Bulgaria	47.399	42,7	1,1	48,5	0,4	25,7	0,3	18,4	0,1	7,5	0,1	6,3
Croatia	34.210	60,4	2,9	78,4	0,8	37,6	0,5	26,3	0,3	15,8	0,2	9,8
Cyprus	3.358	36,3	3,2	94,2	3,8	94,2	3,4	94,1	2,4	92,8	2,2	92,8
Czech Republic	34.871	44,2	7,7	96,8	2,3	56,1	1,8	48,3	1,6	45,3	1,3	38,2
Denmark	7.600	17,6	8,7	97,7	3,3	77,3	2,4	71,6	1,8	66,7	1,3	56,4
Estonia	32.188	71,2	1,9	51,3	0,9	47,6	0,7	47,5	0,6	47,5	0,3	45,6
Finland	268.395	79,3	0,7	47,7	0,1	19,1	0,1	16,4	0,1	15,2	0,0	8,8
France	234.568	42,5	4,2	75,0	1,4	44,3	1,2	40,4	0,9	36,3	0,6	28,7
Germany	158.800	44,5	11,3	98,4	4,1	75,0	3,5	68,1	3,4	66,0	2,4	54,4
Greece	66.817	50,6	1,2	47,5	0,7	36,2	0,6	32,0	0,4	26,6	0,3	24,4
Hungary	26.238	28,2	5,0	91,9	1,4	59,2	0,9	44,7	0,5	27,7	0,3	15,7
Ireland	17.283	24,6	2,9	73,8	2,4	63,9	2,3	61,5	2,2	60,4	1,4	48,2
Italy	139.016	46,1	4,4	68,6	2,1	44,2	1,7	39,5	1,5	35,7	1,2	32,4
Latvia	44.707	69,2	2,2	50,2	1,2	41,3	1,0	40,9	0,9	40,8	0,6	40,7
Lithuania	28.720	44,0	2,9	77,1	1,2	27,6	1,0	24,3	0,9	23,3	0,7	21,1
Luxembourg	1.541	59,6	11,5	100,0	4,2	90,4	3,5	84,2	3,0	76,3	2,1	60,9
Malta	9	2,8	3,6	58,2	2,7	58,2	2,3	58,2	2,2	58,2	2,1	58,2

	receptor area		**Base 2015**		**CLE 2040**		**Opt 2040**		**Opt_hv 2040**		**MTFR 2040**	
	km²	**% of total country area**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**	**AAE [kg ha^{-1} a^{-1}]**	**AAR [%]**
Netherlands	11.366	27,4	21,1	100,0	14,5	99,0	13,7	98,7	13,5	98,6	12,4	98,3
Poland	117.322	37,5	7,3	94,6	3,0	74,3	2,1	62,8	1,5	49,0	1,0	34,3
Portugal	44.976	48,8	1,1	33,6	0,5	23,8	0,4	21,8	0,3	17,9	0,2	12,4
Romania	96.882	40,6	1,0	39,7	0,3	15,6	0,3	11,1	0,2	8,2	0,2	7,2
Slovakia	24.117	50,2	2,8	83,4	0,4	18,6	0,3	12,1	0,2	8,9	0,1	6,6
Slovenia	13.383	66,0	6,9	98,7	2,4	69,6	1,7	59,4	1,4	49,2	0,8	32,9
Spain	235.123	46,5	3,2	61,9	1,9	49,8	1,8	47,9	1,2	40,1	0,9	33,7
Sweden	357.426	79,4	0,7	31,2	0,2	14,6	0,1	13,2	0,1	12,6	0,1	10,3
EU-27	**2.115.145**	**51,0**	**2,3**	**60,3**	**0,7**	**38,2**	**0,6**	**34,0**	**0,5**	**30,1**	**0,3**	**24,3**
Andorra	422	90,1	0,5	44,7	0,2	20,3	0,2	20,3	0,1	16,6	0,1	11,3
Iceland	58.715	57,0	0,0	2,1	0,0	0,2	0,0	0,2	0,0	0,2	0,0	0,0
Liechtenstein	100	62,6	6,2	99,7	2,2	78,5	1,7	47,9	1,7	42,2	1,4	42,2
Norway	209.373	54,4	0,4	16,6	0,1	7,4	0,1	6,2	0,1	5,5	0,0	4,0
San Marino	13	21,4	4,2	99,0	0,9	99,0	0,1	8,5	0,0	1,2	0,0	1,2
Switzerland	22.305	54,0	6,9	69,8	4,1	55,9	3,4	53,0	3,3	51,4	2,8	48,2
United Kingdom	63.632	26,2	2,0	43,5	0,8	27,2	0,5	22,5	0,5	22,0	0,3	16,9
Non-EU	**354.560**	**45,9**	**0,9**	**22,4**	**0,4**	**12,8**	**0,3**	**11,1**	**0,3**	**10,5**	**0,2**	**8,4**
Albania	17.353	60,4	2,1	57,0	1,6	46,1	1,4	42,5	0,9	34,6	0,9	33,0
Bosnia and Herzegovina	33.596	65,6	1,9	55,6	0,8	35,8	0,5	27,1	0,3	20,2	0,2	11,1
Kosovo	5.937	54,5	1,0	50,0	0,2	10,5	0,2	8,7	0,1	6,2	0,1	5,7
Montenegro	10.650	77,1	0,7	24,6	0,4	18,8	0,3	15,9	0,3	14,1	0,2	13,1

	receptor area		Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	% of total country area	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
North Macedonia	15.525	60,4	0,5	24,2	0,2	11,0	0,1	8,4	0,1	7,1	0,1	6,3
Serbia	33.237	42,9	2,8	69,2	1,0	39,7	0,6	29,1	0,4	19,5	0,2	12,3
WB countries	**116.298**	**56,0**	**1,8**	**52,4**	**0,8**	**32,3**	**0,5**	**25,5**	**0,3**	**19,1**	**0,2**	**14,0**
Armenia	11.065	37,2	3,6	77,7	5,9	94,4	4,9	83,9	4,1	75,1	4,0	73,6
Azerbaijan	28.073	32,4	2,2	75,6	3,7	87,6	2,7	78,9	2,1	73,0	1,8	67,1
Belarus	117.179	56,4	4,3	88,6	3,0	77,6	2,4	65,0	1,7	47,9	1,2	35,9
Georgia	49.175	71,3	1,9	63,3	2,4	73,0	1,8	64,6	1,1	47,2	0,9	41,2
Kazakhstan	900.333	33,0	0,0	3,8	0,1	5,5	0,1	4,5	0,0	3,7	0,0	3,4
Kyrgyzstan	53.814	26,9	1,3	31,5	2,2	42,1	1,6	37,1	1,3	31,7	1,2	30,2
Moldova	4.266	12,6	1,1	55,9	0,9	57,4	0,4	26,5	0,1	9,6	0,0	2,8
Russia	3.323.814	19,4	0,1	22,3	0,0	20,7	0,0	17,9	0,0	17,1	0,0	12,3
Tajikistan	32.965	23,0	1,6	54,8	3,0	64,5	2,3	60,6	1,8	57,7	1,7	56,8
Turkey	309.969	39,6	2,9	62,7	5,2	81,7	4,1	76,6	2,4	58,9	2,3	57,4
Turkmenistan	121.356	24,9	0,3	25,9	0,8	45,1	0,5	34,4	0,4	24,8	0,3	22,3
Ukraine	147.653	24,5	2,5	62,2	1,7	51,9	1,1	41,4	0,9	30,6	0,6	22,0
Uzbekistan	116.913	26,0	1,3	42,3	2,1	49,3	1,5	43,3	1,2	40,2	1,1	39,0
EECCA countries & Turkey	**5.216.576**	**22,8**	**0,1**	**25,0**	**0,3**	**25,7**	**0,2**	**22,3**	**0,1**	**19,5**	**0,1**	**15,7**

Table 46 Relative change in AAE and AAR for $CL_{emp}N$ (min) under the different scenarios for 2040 in comparison to the baseline scenario 2015

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]	Δ AAE [%]	Δ AAR [%]
Austria	-68,3	-43,9	-75,3	-53,0	-77,7	-56,5	-86,2	-67,4
Belgium	-50,8	-3,0	-59,8	-9,1	-62,1	-12,2	-71,4	-22,1
Bulgaria	-59,5	-47,0	-74,1	-62,1	-89,4	-84,6	-91,6	-87,1
Croatia	-73,9	-52,0	-82,6	-66,4	-90,1	-79,9	-94,1	-87,5
Cyprus	17,9	0,0	5,2	-0,1	-23,6	-1,5	-30,5	-1,5
Czech Republic	-69,5	-42,0	-76,6	-50,0	-78,8	-53,2	-82,9	-60,5
Denmark	-62,3	-20,9	-72,1	-26,6	-78,9	-31,7	-84,8	-42,2
Estonia	-55,2	-7,3	-62,9	-7,4	-66,7	-7,4	-83,3	-11,1
Finland	-82,3	-59,9	-86,7	-65,6	-88,7	-68,2	-95,8	-81,5
France	-65,8	-41,0	-72,3	-46,1	-77,7	-51,6	-85,2	-61,7
Germany	-63,6	-23,8	-69,0	-30,8	-70,2	-32,9	-79,0	-44,7
Greece	-38,1	-23,8	-50,5	-32,6	-65,8	-44,0	-71,4	-48,6
Hungary	-71,8	-35,6	-82,2	-51,3	-89,2	-69,9	-93,0	-82,9
Ireland	-16,3	-13,4	-20,8	-16,7	-22,5	-18,2	-51,0	-34,7
Italy	-52,1	-35,5	-61,4	-42,4	-67,1	-47,9	-73,2	-52,7
Latvia	-47,3	-17,7	-54,9	-18,4	-59,3	-18,6	-72,6	-18,8
Lithuania	-59,8	-64,2	-65,4	-68,5	-69,2	-69,8	-77,1	-72,6
Luxembourg	-63,2	-9,6	-70,1	-15,8	-73,6	-23,7	-81,7	-39,1
Malta	-25,1	0,0	-34,8	0,0	-39,2	0,0	-42,2	0,0
Netherlands	-31,5	-1,0	-35,0	-1,3	-36,0	-1,4	-41,1	-1,7
Poland	-58,7	-21,4	-70,7	-33,6	-79,6	-48,2	-86,4	-63,8

	CLE 2040		**Opt 2040**		**Opt_hv 2040**		**MTFR 2040**	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
Portugal	-57,9	-29,1	-63,2	-35,2	-71,9	-46,7	-85,3	-63,1
Romania	-65,3	-60,6	-72,8	-72,1	-80,0	-79,4	-83,2	-82,0
Slovakia	-86,2	-77,7	-90,5	-85,5	-93,4	-89,3	-95,1	-92,1
Slovenia	-65,1	-29,5	-75,2	-39,8	-79,5	-50,2	-88,2	-66,7
Spain	-40,5	-19,6	-45,0	-22,6	-63,0	-35,2	-73,1	-45,6
Sweden	-76,0	-53,1	-81,1	-57,7	-83,9	-59,4	-92,3	-67,1
EU-27	**-69,2**	**-36,7**	**-75,6**	**-43,6**	**-80,4**	**-50,1**	**-87,7**	**-59,7**
Andorra	-60,1	-54,7	-65,2	-54,7	-80,6	-62,8	-88,4	-74,7
Iceland	-81,6	-89,7	-84,5	-90,1	-84,5	-91,4	-92,2	-97,8
Liechtenstein	-65,4	-21,3	-72,0	-51,9	-73,0	-57,7	-77,5	-57,7
Norway	-80,0	-55,8	-83,9	-62,8	-86,1	-66,6	-93,0	-76,0
San Marino	-79,3	0,0	-98,0	-91,4	-99,0	-98,8	-99,2	-98,8
Switzerland	-40,7	-19,9	-50,7	-24,1	-52,1	-26,4	-58,6	-31,0
United Kingdom	-61,4	-37,6	-73,1	-48,4	-73,8	-49,6	-83,4	-61,2
Non-EU	**-58,3**	**-42,9**	**-67,9**	**-50,6**	**-69,4**	**-53,2**	**-76,5**	**-62,4**
Albania	-24,1	-19,1	-34,4	-25,4	-54,7	-39,3	-58,8	-42,0
Bosnia and Herzegovina	-58,0	-35,5	-73,7	-51,2	-84,4	-63,6	-92,1	-80,1
Kosovo	-75,5	-79,0	-79,4	-82,6	-85,3	-87,7	-87,5	-88,5
Montenegro	-43,8	-23,7	-53,5	-35,5	-63,5	-42,9	-69,7	-46,9
North Macedonia	-60,4	-54,8	-71,9	-65,3	-81,4	-70,8	-85,0	-74,0
Serbia	-66,2	-42,6	-78,5	-57,9	-87,0	-71,8	-93,4	-82,3
WB countries	**-56,9**	**-38,3**	**-69,5**	**-51,3**	**-80,6**	**-63,5**	**-86,8**	**-73,3**

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
Armenia	62,8	21,5	37,2	8,0	14,5	-3,3	9,6	-5,3
Azerbaijan	64,9	15,9	22,2	4,3	-4,6	-3,5	-17,6	-11,4
Belarus	-30,2	-12,4	-44,5	-26,6	-59,9	-45,9	-73,1	-59,5
Georgia	29,9	15,3	-2,8	2,0	-41,3	-25,5	-51,2	-35,0
Kazakhstan	84,8	46,0	29,3	20,3	-4,6	-0,2	-33,6	-9,6
Kyrgyzstan	60,6	33,9	22,0	18,0	-6,0	0,9	-13,1	-4,1
Moldova	-15,0	2,7	-65,9	-52,5	-93,2	-82,8	-97,6	-94,9
Russia	-14,6	-7,5	-65,6	-20,0	-75,4	-23,5	-91,6	-45,0
Tajikistan	85,9	17,7	39,8	10,6	10,9	5,1	6,6	3,6
Turkey	78,6	30,2	41,7	22,2	-16,0	-6,1	-20,0	-8,5
Turkmenistan	140,8	74,1	64,3	32,4	10,6	-4,5	-1,5	-13,8
Ukraine	-30,5	-16,6	-54,8	-33,5	-64,2	-50,9	-74,9	-64,6
Uzbekistan	61,6	16,5	17,1	2,5	-9,8	-5,0	-15,7	-7,8
EECCA countries & Turkey	**79,5**	**3,0**	**19,0**	**-10,5**	**-38,1**	**-22,0**	**-44,9**	**-37,3**

Table 47 AAE [kg ha^{-1} a^{-1}] and AAR [%] for EUNIS Level-3 grassland ecosystems (R) evaluating exceedance of harmonised minimum Empirical Critical Loads for different scenarios for 2040 (only those R grasslands being part of and displayed in Annex A)

	receptor area	Base 2015		CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	km²	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]	AAE [kg ha^{-1} a^{-1}]	AAR [%]
Semi-dry perennial calcareous grassland (meadow steppe) (R1A)	55.931	0,4	15,4	0,3	10,1	0,2	7,4	0,1	4,3	0,1	3,5
Mediterranean closely grazed dry grassland (R1D)	1.861	3,1	92,4	3,9	81,5	3,1	77,0	1,9	69,3	1,7	65,4
Mediterranean tall perennial dry grassland (R1E)	514.915	0,6	26,3	1,0	34,0	0,8	28,9	0,6	24,7	0,5	23,2
Mediterranean annual-rich dry grassland (R1F)	4.521	2,1	79,4	1,8	59,1	1,5	55,8	1,1	41,9	0,9	32,5
Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta (R1M)	202	0,1	5,1	0,1	2,4	0,1	2,4	0,1	1,8	0,1	1,5
Oceanic to subcontinental inland sand grassland on dry acid and neutral soils (R1P)	40	2,9	98,1	5,0	98,6	3,7	96,9	1,8	94,0	1,6	91,0
Inland sanddrift and dune with siliceous grassland (R1Q)	2	1,2	100,0	0,1	81,9	0,0	38,6	0,0	0,7	0,0	0,7
Low and medium altitude hay meadow (R22)	286.710	2,4	49,3	1,2	28,5	0,9	23,6	0,8	18,3	0,6	14,4
Mountain hay meadow (R23)	4.010	0,4	12,9	0,7	18,0	0,6	16,5	0,3	11,2	0,3	10,9
Moist or wet mesotrophic to eutrophic hay meadow (R35)	255.254	0,0	0,9	0,0	0,7	0,0	0,5	0,0	0,3	0,0	0,1
Temperate and boreal moist or wet oligotrophic grassland (R37)	1.997	4,5	69,5	1,2	29,9	1,0	24,4	0,9	23,0	0,5	17,6
Boreal and arctic acidophilous alpine grassland (R42)	142.690	0,0	0,1	0,0	0,2	0,0	0,2	0,0	0,1	0,0	0,1
Temperate acidophilous alpine grassland (R43)	122.437	1,8	61,2	2,5	66,9	2,1	61,0	1,6	55,9	1,5	51,5
Arctic-alpine calcareous grassland (R44)	43.008	3,0	84,1	2,9	84,2	2,3	78,3	1,8	73,4	1,5	56,7

Table 48 Relative change in AAE and AAR for $CL_{emp}N$ (min) under the different scenarios for 2040 in comparison to the baseline scenario 2015 (only those R grassland ecosystem types being part of and displayed in Annex A)

	CLE 2040		Opt 2040		Opt_hv 2040		MTFR 2040	
	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]	AAE [%]	AAR [%]
Semi-dry perennial calcareous grassland (meadow steppe) (R1A)	-27,7	-34,7	-49,8	-51,8	-72,9	-72,2	-77,8	-77,0
Mediterranean closely grazed dry grassland (R1D)	25,1	-11,8	-1,7	-16,7	-39,8	-25,1	-45,0	-29,2
Mediterranean tall perennial dry grassland (R1E)	62,1	29,3	21,1	10,1	-8,9	-6,1	-17,3	-11,7
Mediterranean annual-rich dry grassland (R1F)	-12,6	-25,6	-26,8	-29,8	-49,2	-47,2	-56,3	-59,0
Lowland to montane, dry to mesic grassland usually dominated by Nardus stricta (R1M)	20,8	-52,5	-8,9	-53,8	-41,3	-65,6	-45,3	-70,0
Oceanic to subcontinental inland sand grassland on dry acid and neutral soils (R1P)	74,3	0,5	29,3	-1,2	-39,2	-4,2	-43,8	-7,3
Inland sanddrift and dune with siliceous grassland (R1Q)	-91,3	-18,1	-97,7	-61,4	-98,9	-99,3	-99,4	-99,3
Low and medium altitude hay meadow (R22)	-52,7	-42,1	-62,1	-52,1	-69,1	-62,8	-77,1	-70,8
Mountain hay meadow (R23)	72,1	39,8	40,9	27,7	-19,1	-12,9	-26,6	-15,6
Moist or wet mesotrophic to eutrophic hay meadow (R35)	-65,7	-27,2	-79,6	-42,8	-89,6	-64,8	-97,0	-85,2
Temperate and boreal moist or wet oligotrophic grassland (R37)	-72,4	-57,0	-78,2	-65,0	-79,2	-66,9	-88,6	-74,7
Boreal and arctic acidophilous alpine grassland (R42)	300,0	87,6	77,8	26,2	11,1	-9,2	11,1	-24,4
Temperate acidophilous alpine grassland (R43)	40,8	9,3	17,7	-0,3	-9,3	-8,8	-17,4	-15,9
Arctic-alpine calcareous grassland (R44)	-1,3	0,1	-21,0	-6,9	-40,0	-12,7	-50,7	-32,5

D.3 Country table evaluating exceedance of Critical Levels for ammonia

Table 49 Relative change in AAE and AAR for Critical Levels for ammonia under the different scenarios for 2040 in comparison to the baseline scenario 2015

	CLE 2040		**Opt 2040**		**Opt_hv 2040**		**MTFR 2040**	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
Austria	-6,3	10,3	-28,2	-8,6	-38,3	-18,2	-77,1	-54,7
Belgium	9,8	9,1	-10,3	-2,7	-12,8	-5,5	-34,5	-27,3
Bulgaria	96,5	228,3	48,0	124,0	-61,7	-64,9	-66,4	-69,1
Croatia	182,7	157,3	95,6	89,8	-32,2	-21,2	-90,5	-82,6
Cyprus	122,7	110,2	103,3	96,2	28,9	68,5	-1,7	11,3
Czech Republic	7,2	15,4	-20,4	-8,7	-24,6	-12,3	-40,2	-24,2
Denmark	-4,8	-0,7	-28,4	-20,1	-46,3	-31,5	-54,3	-37,4
Estonia	52,2	47,9	35,2	40,9	26,3	12,0	-79,8	-70,7
Finland	-46,1	-39,9	-49,1	-45,1	-53,6	-46,9	-87,2	-90,7
France	-10,8	-0,8	-32,9	-16,9	-50,3	-31,0	-75,3	-64,5
Germany	-32,2	-12,8	-42,3	-20,0	-43,5	-21,5	-68,8	-44,9
Greece	116,1	88,8	34,1	41,6	-35,0	-34,2	-52,6	-49,3
Hungary	41,3	59,7	-6,2	7,4	-39,5	-31,9	-60,0	-52,3
Ireland	78,1	42,5	67,6	36,1	62,8	35,0	-36,9	-19,9
Italy	7,2	13,8	-14,0	-3,3	-25,6	-17,1	-42,5	-29,1
Latvia	63,0	69,8	35,2	45,7	24,3	32,3	-31,5	-32,7
Lithuania	54,8	32,4	21,9	18,6	-9,7	-0,6	-62,8	-48,1
Luxembourg	2,0	11,3	-23,3	-5,8	-39,9	-18,2	-84,8	-60,0
Malta	-3,5	0,0	-49,4	-68,2	-61,1	-68,2	-67,3	-68,2

	CLE 2040		**Opt 2040**		**Opt_hv 2040**		**MTFR 2040**	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
Netherlands	2,5	0,2	0,0	0,2	-1,0	0,2	-7,2	0,0
Poland	121,6	60,8	55,7	33,1	5,1	7,2	-37,9	-21,9
Portugal	21,9	19,5	-1,5	-0,9	-37,7	-43,6	-83,0	-66,8
Romania	24,2	38,0	5,2	23,0	-39,7	-38,7	-48,8	-45,5
Slovakia	37,9	36,5	-10,8	8,3	-51,9	-57,0	-65,8	-62,6
Slovenia	13,8	28,7	-16,9	-2,2	-26,9	-8,8	-72,4	-42,4
Spain	-7,2	-1,4	-16,9	-9,0	-57,8	-47,1	-74,5	-64,3
Sweden	52,7	32,2	16,1	12,9	-7,8	-1,2	-76,0	-68,0
EU-27	**-1,1**	**11,4**	**-17,1**	**-2,6**	**-31,1**	**-18,0**	**-54,1**	**-44,2**
Andorra	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Iceland	-19,8	-21,4	-22,5	-21,4	-22,5	-21,4	-68,4	-67,1
Liechtenstein	21,6	0,0	-9,4	-2,4	-12,2	-2,4	-35,9	-2,4
Norway	38,4	26,1	31,5	21,1	21,8	16,6	-59,8	-47,9
San Marino	35,9	0,0	-56,4	0,0	-100,0	-100,0	-100,0	-100,0
Switzerland	5,1	6,6	-13,4	-2,4	-14,2	-2,4	-23,5	-9,5
United Kingdom	32,6	36,7	-33,7	-19,4	-33,6	-19,5	-70,9	-58,4
Non-EU	**14,5**	**22,3**	**-17,0**	**-9,0**	**-18,0**	**-9,4**	**-39,3**	**-37,5**
Albania	96,9	71,4	78,9	71,4	23,8	43,4	17,0	39,7
Bosnia and Herzegovina	1262,7	1053,9	748,1	759,9	225,2	271,1	20,4	32,0
Kosovo	358,2	265,5	374,2	269,2	160,1	109,5	130,3	109,1
Montenegro	430,6	1312,0	443,7	1647,9	189,1	475,0	125,9	340,2
North Macedonia	122,8	138,8	77,3	60,5	35,2	26,5	31,3	24,0

	CLE 2040		**Opt 2040**		**Opt_hv 2040**		**MTFR 2040**	
	Δ AAE [%]	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**	**Δ AAE [%]**	**Δ AAR [%]**
Serbia	158,6	131,8	71,9	84,0	-8,8	10,2	-48,2	-33,2
WB countries	**169,0**	**166,4**	**99,3**	**123,1**	**14,7**	**38,8**	**-15,6**	**0,0**
Armenia	330,8	164,0	141,6	105,0	58,7	39,1	73,7	64,2
Azerbaijan	124,4	66,7	2,1	3,7	-29,5	-25,9	-23,8	-17,8
Belarus	59,7	13,0	39,8	10,0	-22,0	-4,8	-46,6	-15,9
Georgia	7,8	6,7	-28,4	-19,4	-50,6	-31,1	-51,0	-31,1
Kazakhstan	246,1	171,1	168,8	104,6	151,6	87,9	170,9	100,5
Kyrgyzstan	304,6	323,5	122,3	157,7	105,1	150,2	120,8	163,8
Moldova	715,7	764,9	403,9	436,6	24,1	-0,2	4,5	-0,5
Russia	218,1	181,1	81,4	88,7	74,3	78,2	74,1	83,2
Tajikistan	120,0	89,4	25,6	21,0	2,4	3,2	6,1	4,4
Turkey	336,6	171,7	217,8	147,6	60,4	50,0	65,3	54,5
Turkmenistan	-2,0	17,6	-67,3	-22,5	-73,6	-37,6	-72,9	-35,3
Ukraine	291,9	112,7	98,0	60,4	41,3	30,9	-9,8	6,2
Uzbekistan	42,8	29,8	-23,4	-17,6	-34,2	-25,1	-32,0	-23,6
EECCA countries & Turkey	**156,8**	**95,7**	**67,7**	**52,5**	**5,6**	**18,1**	**5,1**	**18,5**

E Annex 5: Country Reports CfD 24/24 Modelled Critical Loads – SMB CL

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E.1.1 Regional Data Produced

Critical loads data have been produced for forests (coniferous, deciduous, mixed forests) and natural vegetation in Wallonia.

E.1.2 Mapping procedure Wallonia

From Corine Land Cover 2018, 5095 forest ecosystems area (>1 ha) were extracted and overlaid with thematic maps in order to calculate critical loads parameters. The total forest area covers 516.758 ha.

Four natural ecosystem types (representing 136 ecosystems area) were extracted and assigned to a theoretical value according to ecosystem type. The intersections of these areas with NATURA 2000 habitats have been identified. Then, critical loads maps were overlaid with EMEP grid (0,10° x 0,05° Longitude-Latitude grid cell) in order to load CCE database as requested.

E.1.3 Calculation methods & results Wallonia

A. Forest Soils

Calculation methods

Critical loads for forest soils were calculated according to the method as described in UBA (CCE, 1996) and Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risk, and trends (109/2023):

$$CL_{max}(S) = BCwe + BC_{dep} - BC_u - ANC_{le(crit)}$$

Equation 6

$$CL_{max}(N) = N_i + N_u + CL_{max}(S)$$

Equation 7

$$CL_{nut}(N) = N_i + N_u + N_{le} + N_{de}$$

Equation 8

$$ANC_{le(crit)} = -Q_{le}\ ([Al^{3+}] + [H^+] - [RCOO^-])$$

Equation 9

Where:

$[Al^{3+}] = 0.2$ eq/m^3 if [H+] is less than 6.3E-2 eq/m^3 (pH >4.2) using the equation $K = [Al^{3+}]/[H+]^3$ otherwise the [H+] = 6.3 E-2 eq/m^3 and $[Al^{3+}]$ is calculed using the equation $K = [Al^{3+}]/[H^+]^3$

[RCOO-]= 0.044 molc/molC x DOCmeasured (Table 50)

The equilibrium $K = [Al^{3+}]/[H^+]^3$ criterion: The Al^{3+} concentration was estimated by 1) experimental speciation of soil solutions to measure rapidly reacting aluminium, Alqr (Clarke *et al.*,1992); 2) calculation of Al3+ concentration from Alqr using the SPECIES speciation software. The K values established for 10 representative Walloon forest soils (Table 50) were more relevant than the gibbsite equilibrium constant recommended in the manual (CCE, 1996). The difference between the estimated Al3+ concentrations and concentration that causes damage to root system (0,2 eq Al^{3+}/m^3 ; (De Vries et al., 1994)) gives the remaining capacity of the soil to neutralise the acidity. For the majority of Walloon soils, the range of critical pH is 4,3-4,4. For the soil of Bande, Chimay, Eupen (2) and Louvain-la-Neuve, the pHcrit equal to 4.2 is applied to protect and guarantee a concentration to Al less than 0,2 eq/m^3.

The Table 50 summarise the values given to some of the parameters.

Table 50 Aluminium equilibrium, weathering rates and critical pH limit calculated with [Al3+] = 0.2 eq/m3 for Walloon soils. pH and DOC measured in 1999 (Brahy & Delvaux, 2000)

Sites	Soil types	K	BCwe eq ha^{-1} yr^{-1}	Critical pH limit calculated	pH mesured	DOC g/m^3
Bande (1-2)	Podzol	140	610	*3.95*	5.16	42.59
Chimay (1)	Cambisol	414	1443	*4.10*	5.61	64.81
Eupen (1)	Cambisol	2438	2057	4.36	4.81	29.6

Sites	Soil types	K	BCwe eq ha^{-1} yr^{-1}	Critical pH limit calculated	pH mesured	DOC g/m^3
Eupen (2)	Cambisol	25	852	*3.70*	3.5	26.47
Hotton (1)	Cambisol	2736	4366	4.38	8.19	45.47
Louvain-la-Neuve (1)	Luvisol	656	638	*4.17*	4.37	99.35
Meix-dvt-Virton (1)	Cambisol	2329	467	4.35	5.4	32.21
Ruette (1)	Cambisol	5335	3531	4.47	6.12	26.12
Transinne (1)	Cambisol	3525	560	4.41	4.61	26.38
Willerzie (2)	Cambisol	2553	596	4.37	4.67	29.91

(1) deciduous or (2) coniferous forest

Soils : *In Wallonia*, 47 soil types were distinguished according to the soil associations map of the Walloon territory, established by Maréchal and Tavernier (1970). Each ecosystem is characterised by a soil type and a forest type.

Weathering rate: In *Wallonia*, the base cation weathering rates (BCwe) were estimated for 10 different representative soil types (Table 50) through leaching experiments. Increasing inputs of acid were added to soil columns and the cumulated outputs of lixiviated base cations (Ca, Mg, K, Na) were measured. Polynomial functions (Table 51) were used to describe the input-output relationship.

To estimate BC_{we}, a acid input was fixed at 900 eqH^{+} ha^{-1} yr^{-1} in order to keep a long term balance of base content in soils.

Table 51 Polynomial functions used in critical loads calculations in Wallonia

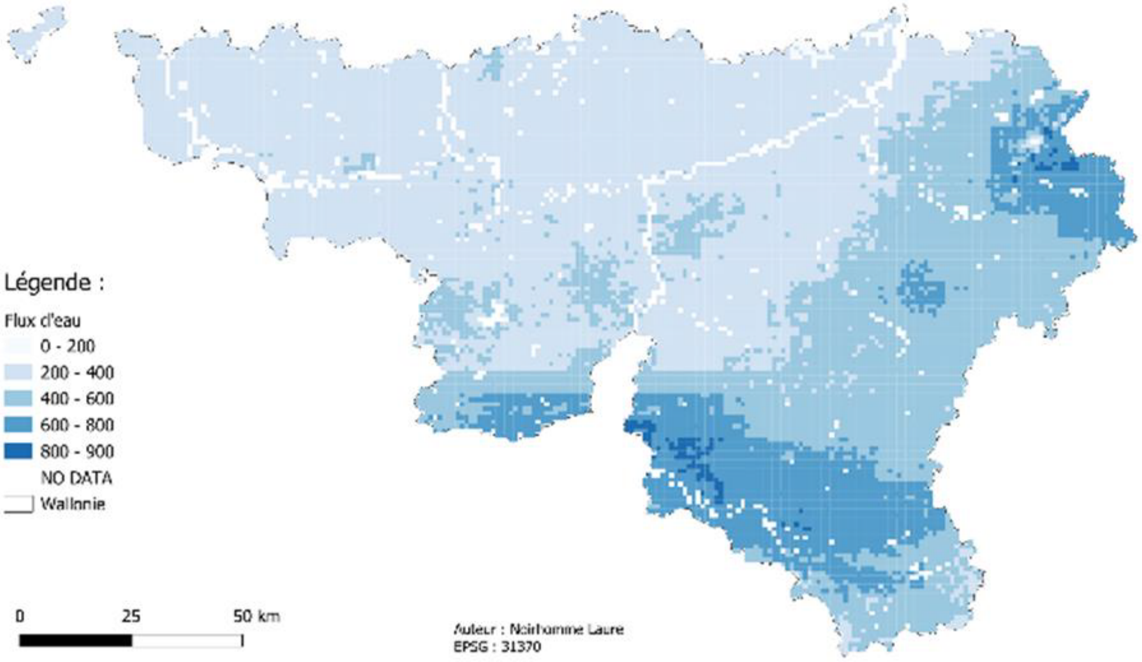
Sites	Polynomial functions y = BC (eq ha^{-1} yr^{-1}) ; x = input d'H^{+} (eq ha^{-1} yr^{-1})	Depth considered to establish the functions
Bande (2)	y = -5.509E-10x3 + 7.023E-06x2 + 0.6721x R2 = 0.9999	0,5 m
Chimay (1)	y = -1.075E-09x3 + 2.510E-05x2 + 1.261x R2 = 0.9991	0,40
Eupen (1)	y = -3.294E-10x3 - 4.338E-06x2 + 1.147x R2 = 0.9998	0,25
Eupen (2)	y = 1.581E-10x3 - 1.130E-05x2 + 0.4835x R2 = 0.9989	0,25
Hotton (1)	y = 8.288E-10x3 - 4.336E-05x2 + 4.889x R2 = 0.9998	0,5m

Sites	Polynomial functions y = BC (eq ha^{-1} yr^{-1}) ; x = input d'H^{+} (eq ha^{-1} yr^{-1})	Depth considered to establish the functions
Louvrain-la-Neuve (1)	y = 3.614E-10x3 - 2.054E-05x2 + 0.7267x R2 =0.9985	0,5m
Meix-dvt-Virton	y = -3.545E-10x3 + 1.675E-06x2 + 0.5180x R2 = 0.9976	0,5m
Transinne (1)	y = 3.729E-10x3 - 2.627E-05x2 + 0.6454x R2 = 0.9818	0,5m
Ruette (1)	y = 1.111E-09x3 - 5.334E-05x2 + 3.970x R2 = 0.9995	0,5m
Wallerzie (2)	y = 6.326E-10x3 - 3.396E-05x2 + 0.6921x R2 = 0.9976	0,5m

(1) deciduous or (2) coniferous forest

The flux of drainage water leaching, Qle, from the soil layer (entire rooting depth) was estimated from EPICgrid model (Faculté Universitaire des Sciences Agronomiques de Gembloux). The results of the EPICgrid model are illustrated at the Figure 37 Flux of drainage at 50 cm depth in Wallonia for the 2019-2023 periods. The flux drainage of the 2019-2023 period was used.

Figure 37 **Flux of drainage at 50 cm depth in Wallonia for the 2019-2023 periods**



The critical (acceptable) N concentration (cNacc) comes from the CCE/Alterra Report (De Vries et al., 2007):

Coniferous forest: 2.5-4 mgN L^{-1}

Deciduous forest: 3.5-6.5 mgN L^{-1}

The minimum recommended values (Table 52) are applied for calculation CLnutN

Table 52 Constants used in critical loads calculations in Wallonia

Parameter	Value
Ni	5.6 kg N ha-1 yr-1 coniferous forest 7.7 kg N ha-1 yr-1 deciduous forest 6.65 kg N ha-1 yr-1 mixed forest
Nle (acc)	2.5 mg N L-1 for coniferous forest 3,5 mg N L-1 for deciduous forest 3 mg N L-1 for mixed forest
Nde	Fraction of (Ndep – Ni – Nu)

Net growth uptake of Base cations and nitrogen: *In Wallonia*, the net nutrient uptake (equal to the removal in harvested biomass) was calculated using the average growth rates measured in 25 Walloon ecological territories and the chemical composition of coniferous and deciduous trees. The chemical composition of the trees (*Picea abies, fagus sylvatica, Quercus robus*, *Carpinus betulus)* appears to be linked to the soil type (acidic or calcareous) (André & Ponette, 2003; André, 2010; Bosman B. et al., 2001; Duvigneaud P. et al., 1969; Unité des Eaux et Forêts, 2001).

The net growth uptake of nitrogen ranges between 288 and 972 eq ha-1 yr-1, while base cations uptake values vary between 280 and 736 eq ha^{-1} yr^{-1} depending on trees species and location in Belgium.

Base cations deposition: In *Wallonia*, actual throughfall data collected in 6 sites, between 2017 and 2023, were used to estimate BCdep parameters. The marine contribution to Ca^{2+}, Mg^{2+} and K^{+} depositions was estimated using sodium deposition according to the method described in UBA (CCE, 1996). The BCdep data of the 6 sites (Eupen (1), Eupen (2), Gedinne, Virton, Chimay, Louvain-la-Neuve) was extrapolated to all Walloon ecosystems depending on the location and the tree species.

Results

In Wallonia, the highest CL values were found in calcareous soils under deciduous or coniferous forests. The measured release rate of base cations from soil weathering processes is high in these areas, and thus provides a high long-term buffering capacity against soil acidification.

Updating the parameters (Nu, BCu, BCdep, Qle, Nle, ANCle) and using the Corine Land Cover 2018 map instead of Walphot 1990 contributed to an increase in the critical load values.

B. Natural vegetations

For Walloon ecosystems, considering the lack of accurate input data, we use critical values established in Flanders with SMB method (Meykens & Vereecken, 2001). The critical loads for N and S deposition to natural vegetations are reported in Table 53.

Table 53 Critical loads for natural vegetations in Wallonia

Ecosystem type	EUNIS code	CLmax N	CLmax S	CL nut
Natural grassland	E1	4572	1893	1286
Moors and heathland	F4.2	2185	1645	643
Inland marshes	D5	2339	1655	786
Peat bogs-Fens	D2	2339	1655	786

E.2 Bulgaria

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The comparison of the amount of precipitation under the assembly of tree vegetation in the forest plantations and in the experimental sample sites covered by other types of vegetation shows that the largest amounts of precipitation were measured in the sites 7310 (902.30 mm) and 7187 (796.98 mm).

The average annual pH values of the precipitation ranged from 5.29 (site 7257) to 5.99 (site 7415). It is established that acid precipitation is recorded in sample sites 7257 (5.29), 7470 (5.35) and 7184 (5.50).

The highest value for the annual inorganic nitrogen-containing deposits (2705.04 eq.ha^{-1}.yr^{-1}) was found for the shrub vegetation in the 7310 site, while the main share of the deposits is being due to the input of nitrate deposits (2485.82 eq. ha^{-1}.yr^{-1}).

The highest sulfate deposits which income with precipitation were found for wetland site C677275 and for the shrub ecosystem in site 7257, 531.82 and 531.50 eq. ha^{-1}.yr^{-1}, respectively. The amounts recorded in the agricultural sites C677101 (496.78 eq. ha^{-1}.yr^{-1}), C677494 (484.98 eq. ha^{-1}.yr^{-1}) and 7187 (448.49 eq. ha^{-1}.yr^{-1}) are also high.

The highest total amount of acidifying deposits of nitrogen and sulfur compounds was found for experimental site 7310 characterized by shrub vegetation cover (3059.22 eq. ha^{-1}.yr^{-1}), which is mainly due to the reported high amount of inorganic nitrogen-containing deposits and the most-large amounts of precipitation.

Deposited basic cations with precipitation are one of the main components of the balance equation in the positive-sign Steady State Mass Balance critical loads method, contributing significantly to increasing the tolerance of different types of ecosystems to acid deposition as they neutralize it. Regarding the annual deposition of basic cations, it is found that the most neutralizing ions are deposited in the site 7187 covered by meadow vegetation (3207.23 eq. ha^{-1}.yr^{-1}). High values were also recorded for the meadow vegetation in the site 7295 (2793.33 eq. ha^{-1}.yr^{-1}) and in the agricultural area 7494 (2638.30 eq. ha^{-1}.yr^{-1}). The lowest values of the deposition of basic ions were found in 2004 (313.99 eq. ha^{-1}.yr^{-1}) and for the spruce forest ecosystem in 2005 (348.97 eq. ha^{-1}.yr^{-1}).

High values are reported for lead and cadmium deposits in the studied forest sites. In terms of cadmium deposits, the highest amounts were found for meadow vegetation in site 7295 (938.30 g. ha^{-1}.yr^{-1}). The values for lead deposits found for shrub ecosystem in 7310 (902.30 g. ha^{-1}.yr^{-1}) are high, followed by those for meadow ecosystem in site 7187 (796.98 g. ha^{-1}.yr^{-1}). The lowest deposits of the two heavy metals, lead and cadmium, are observed in grassland site 7176 and in 2004.

In half of the investigated sample areas, it was found that the deposits of basic cations were in greater quantities and successfully compensated the acid deposits coming with the precipitation. The ratio of basic and acidic deposits is unfavorable in the four forest ecosystems, in the grasslands of 7469 and 7176, in the agricultural areas of 7423 and 7187, as well as in the shrub ecosystem in 7310, for which higher levels of acidifying deposits were reported, compared to those of alkalizing deposits.

E.3 Finland

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E.3.1 Introduction

Simple mass balance critical loads of eutrophication and acidification for terrestrial ecosystems for protected areas in Finland were calculated in response to the 2024–25 Call for Data.

The critical loads of nutrient nitrogen were calculated for a total ecosystem area of 38027 km^2, which corresponds to the area of all 41 terrestrial EUNIS habitat classes that were successfully classified for the protected areas based on Annex I habitat types (see chapter C.6) with the exception of small habitat parcels (< 0.5 hectares) outside of the Natura 2000 -network.

Lakes (C1) were not considered for analyses of critical loads of acidification. Critical loads for acidification in lakes have been previously published and submitted (Posch et al., 2012). Peatlands were also excluded as the determination of a meaningful chemical criterion is more complicated and could not be conducted within the timeframe of the Call for Data.

E.3.2 Mapping of ecosystem types

The habitat classification was identical to that described for empirical critical loads of nitrogen (chapter C.6). But habitats were analysed within the 0.10°×0.05° grid separately for each parcel in the *Protected area compartment information system* (SAKTI) to account for parcel specific variation in site factors.

E.3.3 Site climate

The average excess annual rainfall was calculated for 1962–2024 per soil type (sand, till, rock, silt, clay, organic) as the difference between water influx and evapotranspiration using the hydrological model WSFS-P for the 3rd level of watershed delineation in Finland used in the hydrological model (Kolhinen et al., 2025). The watershed-level results were smoothed per soil type using inlabru (Bachl et al., 2019). The habitat sites were assigned their corresponding estimated excess rainfall based on the assigned soil type information in SAKTI. The soil thickness (rooting depth) was assumed to be 0.5 m for all soils excepts rock outcrops and shallow rocky soils for which 0.1 m was assumed. Annual precipitation and annual average temperature were calculated as the average for the years 1961-2020 derived from gridded 1km×1km climate data for Finland (Aalto et al., 2016).

E.3.4 Critical loads of nutrient nitrogen in terrestrial ecosystems

The approach followed the Mapping Manual (CCE, 2024b) with slight adaptations. Where the calculated critical load for nutrient nitrogen was higher than the empirical critical load for the corresponding EUNIS habitat class, the empirical critical load was used.

For the calculation of the critical load the nutrient uptake of nitrogen (N_u) was set to be zero based on the assumption that no removal of biomass takes place on the protected areas. For some forms of management and especially restoration actions this assumption might not hold over shorter time spans, for example removal of spruce from herb rich forests.

The acceptable nitrogen immobilization (N_i) rate was set to 0.5 kg ha^{-1} a^{-1} which is the upper range of the estimated natural background rate in Nordic forest ecosystems based on studies in Swedish forests (Rosén et al., 1992). Contemporary rates of nitrogen retention and immobilization are likely much higher (Nilsson & Grennfelt, 1988).

The rate of denitrification f_{de} was set based on soil type ((CCE, 2024b), Table 5.7, references therein).

The acceptable N concentration $[N]_{acc}$ was determined by utilizing information on the site fertility index based on Finnish the forest site type system (Cajander, 1926) by linking the representative vegetation to changes in vegetation as established from Swedish data ((CCE, 2024b), Table 5.5). This corresponds to higher acceptable concentrations on more fertile sites (Table 54). For lack of more discerning criteria, the fertility index was also used to set the acceptable criterion for non-forest ecosystems.

Table 54 Acceptable N concentration based on site fertility

Site index[1]	Forest type	[N]acc2 (mgN/L)	Change[2]
1	herb rich forest	3.0	Grass to herbs
2	herb rich heath forest	2.0	Blueberry to grass
3	mesic forest	1.0	Blueberry to grass
4	sub-xeric forest	0.6	Cranberry to blueberry
5	xeric forest	0.4	Cranberry to blueberry
6	barren forest	0.2	Lichens to cranberry
> 6	poorly productive forest land	0.2	Lichens to cranberry

[1] Lower index number is more fertile.

[2] As in Mapping Manual Table 5.5. Here interpreted blueberry as bilberry (Vaccinum myrtillus), cranberry as lingonberry (Vaccinum vitis-idae).

E.3.5 Changes in deposition and exceedance

The exceedances were calculated as for $CL_{emp}N$ (chapter C.6.4). The largest differences compared to using the empirical critical loads only are for the coastal habitat types N1 – N3, which either have no empirical critical loads available (N2 and N3) or they are higher (5 – 10 kg-N ha^{-1} a^{-1}) than the critical loads derived from the simple mass balance. The total area covered by protected areas in these habitat types is small (under 15 km^2) and most of the lie along the southwestern coast of Finland – an area coinciding with the highest nitrogen deposition rates. Other notable differences are found for deciduous forests (T1) which show historically much higher exceedances for the SMB-derived critical loads, inland cliffs and outcrops (U3) for which no empirical critical loads were available but show over 10 % area exceeded with contemporaneously and under currently legislated emission reductions by 2040, as well as raised bogs (Q11) which under the nutrient nitrogen CL_{eut} is also predicted to have over 10 % exceedance in 2040.

Table 55 Habitat area, CL_{eut} and area exceedances for terrestrial protected areas in Finland

EUNIS code	Area km²	CL_{eut}[1] kg ha⁻¹ a⁻¹	AE (1990) km²	AE (2005) km²	AE (2020) km²	AE (2040) km²	AAE (2020) kg ha⁻¹ a⁻¹
N1	12.0	3.9 (1.2 – 45.3)	10.3	9.3	8.3	5.3	1.05
N2	1.1	2.9 (1.1 – 14.4)	1.0	0.9	0.9	0.6	1.40
N3	1.1	1.2 (1.1 – 3.6)	1.1	1.1	1.1	1.1	2.80
Q1	1296.2	4.2 (1.4 – 5)	943.7	786.0	323.7	145.3	0.2
Q2	10035.3	4.8 (1 – 5)	372.7	201.1	29.5	4.6	0.00
Q3	421.6	3	0.0				
Q4	380.9	15 (1.4 – 15)	0.1	0.1	0.0	0.0	0.00
Q5	0.2	11.8 (1.7 – 30.3)					
R2	7.2	7.2 (1.1 – 20.1)	5.4	3.7	1.8	0.33	0.20
R3	20.8	6.6 (1.3 – 15)	0.4	0.3	0.1		0.00
R4	368.6	1.6 (1.1 – 5)	4.2	4.7			
R5	3.37	14.0 (1.2 – 62.5)	1.1	0.9	0.2	0.0	0.04
S2	6735.4	1.4 (1 – 5)	747.7	579.3	0.4		0.00
S4	19.5	2.2 (1.1 – 5)	18.5	17.9	16.4	13.5	0.84
S9	1.1	30.6 (17.6 – 37.7)					
T1	5664.0	2.0 (1 – 15)	1649.3	866.5	8.1	1.8	0.00
T3	12390.0	2.3 (0.9 – 3)	3752.2	3473.1	1243.1	603.7	0.11
U3	668.9	1.5 (1 – 28.8)	272.9	251.1	77.6	65.9	0.31
Total	**38027.5**	**2.9**	**7780.7**	**6196.3**	**1711.3**	**842.2**	**0.05**

Values summarized at EUNIS level 2. AE area with CL_{eut} exceeded. AE (2040) is for the January 2025 GP_WGE scenario for Current Legislation 2040. AAE: average accumulated exceedance; calculation includes areas not in exceedance. [1]CL_{eut} as the area weighted mean over the ecosystems included. Ranges in parentheses. show the range of CL_{eut} among the EUNIS level 3 classes included.

E.3.6 Critical loads of acidification in terrestrial ecosystems

Calculation of critical loads of acidification of terrestrial ecosystems follows the Modeling and Mapping manual (CCE, 2024b) with some simplifications.

Deposition of sea-salt corrected base cations were estimated from monitoring data (Ruohola-Airola et al., 2003) and assigned based on a simple linear south-north gradient. The deposition of non-sea-salt Na and Cl was assumed negligible.

Weathering rates for mineral soils were estimated from concentrations of Ca, Mg, K, and Na in till C-horizon samples and effective temperature sums at 1057 plots (Johansson & Tarvainen, 1997; Joki-Heiskala et al., 2003). Values were interpolated using inlabru (Bachl et al., 2019).

The uptake of base cations was assumed to be zero as only protected sites were considered. Denitrification rates, nitrogen uptake and acceptable immobilization of nitrogen were the same as in the calculation for critical loads of nutrient nitrogen using the simple mass balance model.

The criteria for determining the critical leaching of acid neutralizing capacity is the base cation to aluminium ratio ($(Bc/Al)_{crit}$) with a value of 10. The value is quite conservative in that e.g. significant growth reductions in forests usually observed at mostly considerably lower values (Sverdrup & Warfvinge, 1993) but has been used for forest on minerals soils in Canada based on the relationship between pH and base cation saturation implied. The equilibrium constant for the Al-H relationship was set to 8 for all soil types.

For the chosen values, the critical loads of acidification for terrestrial protected areas, (hence with no net uptake of base cations) have not been exceeded anywhere since before 2000 in terms of sulphur deposition and since 2010 for nitrogen deposition. This is consistent with recovery of in Finland acidified lakes by the early 2000s as shown by detailed studies of lake chemistry and fish populations (Rask et al., 2014). The attainment of non-exceedance of sites with intensive forestry, as is the case for most forested areas in Finland, will likely have been delayed compared to protected areas due to the uptake of base cations under the prevailing high harvest intensities (Joki-Heiskala et al., 2003), but given the rather high $(Bc/Al)_{crit}$ criterion used, it does not imply that significant effects on growth have necessarily been experienced in recent decades if at all.

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E.4.1 Introduction

Nitrogen deposition in the Netherlands is recognised as a large threat to protected nature areas (Autoriteit, 2024; Wamelink et al., 2013). Various policy measures are taken to reduce this threat (Reinds et al., 2024) Critical loads play an important role in these policies. In recent national legislation targets are set based on critical load exceedance in Natura 2000 areas:

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

These critical loads are an combination of empirical critical load ranges and modelling (Van Dobben et al., 2012). In 2022 new empirical critical loads were set for (semi)natural vegetations by Bobbink et al. (Bobbink et al., 2022). This new information has been used in this study to calculate new critical load maps for CLTRAP, using a methodology similar to the method used in 2022 (van Hinsberg & Reinds, 2022). The maps for Natura 2000 areas is the same as used in Dutch legislation. Outside Natura 2000 areas the information is based on nature targets of Dutch provinces (van Beek et al., 2018).

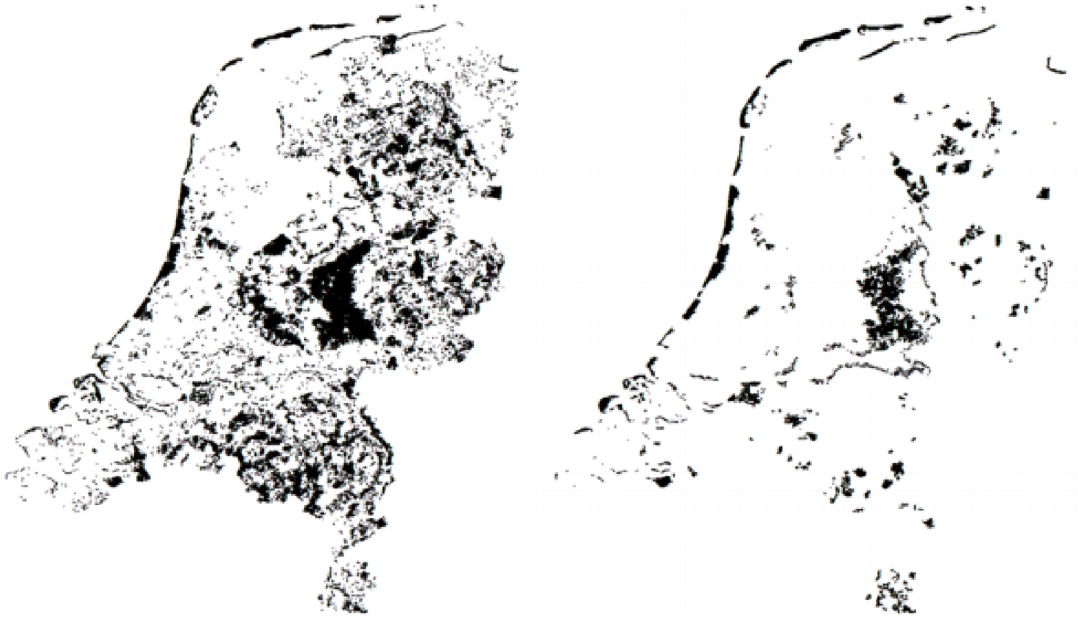
E.4.2 General methodology

The Netherlands has a long history of using soil vegetation models for setting critical loads withing the empirical critical load ranges (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 new update, critical loads were calculated for all terrestrial nature areas in the National Ecological Network (NEN; Figure 38, left) using the new European empirical critical load ranges. Empirical critical load levels were calculated, separately, for protected habitats in Natura 2000 areas (Figure 38, right) and for nature management types in other nature areas (Figure 38, left).

Inside Natura 2000 areas critical loads were set using the information of Wamelink et al. (2023) together with maps of protected habitattypes. Outside Natura 2000 areas critical loads were calculated with VSD+ (Bonten L. et al., 2009) using the same methods as in van Hinsberg and Reinds (2022). Outside Natura 2000 areas the information is based on nature targets of Dutch provinces and their sensitivity (van Beek et al., 2018).

Figure 38 **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).**



E.4.3 Input data

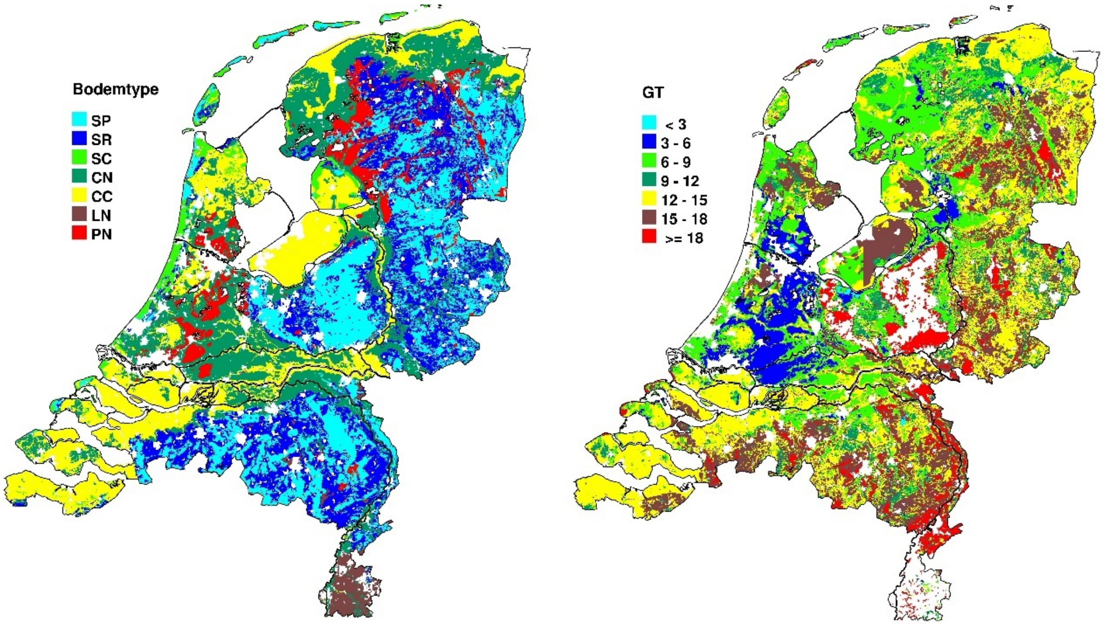
For each 250 x 250-metre grid, we determined all nature management types and habitat types based on polygon maps from the provinces and the Dutch Ministry of Agriculture, Nature and Food Quality. Within Natura 2000 areas (right) we used the habitat map and Wamelink et al. (2023) to map critical loads.

Outside Natura 2000 areas critical loads were calculates with VSD+, with an updated approach as compared to van Hinsberg and Reinds (2022) we now used a direct link between nature management types and habitat types to derive critical values instead of the more complex linking through plant associations used previously. The soil types for which VSD+ has been parametrised were mapped based on the updated version of the soil map 1:50000 (Steur & Heijink, 1991). Information on groundwater levels was derived from a the groundwater level map of the

Netherlands (Van Heesen, 1970). Seepage fluxes stem from the National Water Model[18] 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 (Figure 39). 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 (Figure 39).

Figure 39 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.



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 (N_{avail}) were derived from indication values for trophic conditions (Holtland et al., 2010). The trophic index was transformed into values of N_{avail}, using a regression with data from 2017 on N_{avail} and trophic index calculated for the same nature target types as used in the submission of 2017, according to:

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

Equation 10

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)).

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[18] https://data.nhi.nu/

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.

E.4.4 Critical load function

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

$$CL(N) = N_{availcrit} - N_{upt} - N_{lf} - N_{fix} - N_{seep}$$

Equation 11

With $N_{availcrit}$ = critical N availability, N_{upt} = N uptake, N_{lf} = total litterfall of N (above and below soil surface), N_{fix} = N fixation (set to zero), N = N flux via upward seepage.

For each 250 x 250 metre grid, we compared the calculated $CL_{eut}N$ with the empirical critical range. When $CL_{eut}N$ was within this range, the calculated value was used. When $CL_{eut}N$ was outside the empirical critical loads we used the nearest empirical critical load for the given range. For CLNmax, we always used the value computed with Equation 11. 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 N_{avail}) and CLmaxN (based on pH) was used for CLmaxN.

E.4.5 Results

Cumulative frequencies for $CL_{eut}N$ (Figure 40) show that $CL_{eut}N$ 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, $CL_{eut}N$ is determined by the empirical value, not the (higher) SMB value. Comparison with the previous submission (from 2021, using the 2012 empirical critical loads), shows that the distribution has shifted a towards lower values (Figure 40a), due to the lower empirical critical loads for especially heathland and forests and the new procedure to link nature management types to critical values (Figure 40b,c).

Figure 40 **Cumulative frequencies of CLeutN in eq.ha-1.yr-1 for all vegetations (a) and for heathlands and forest seperately (b,c) for the 2021 and the current submission.**

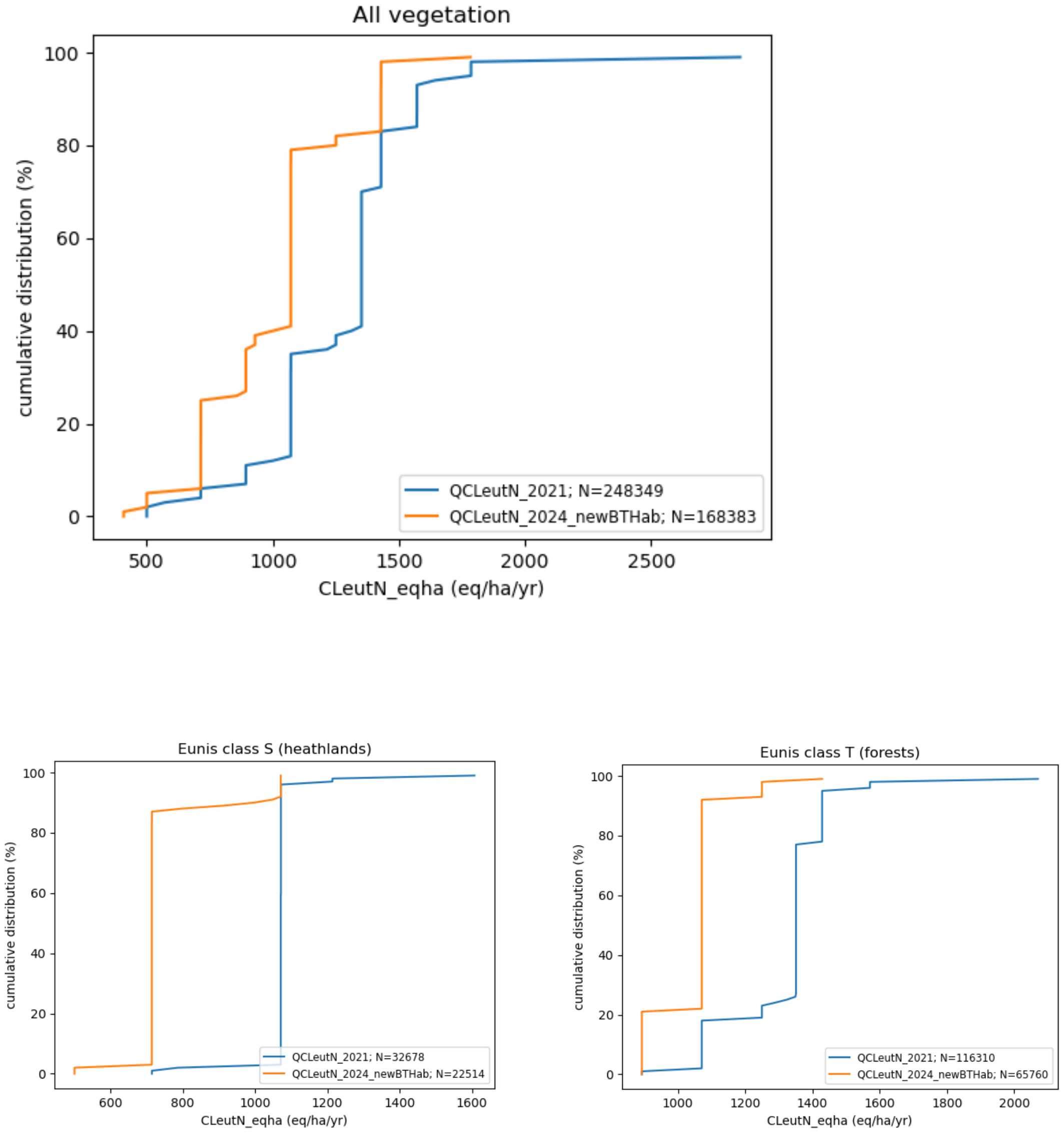
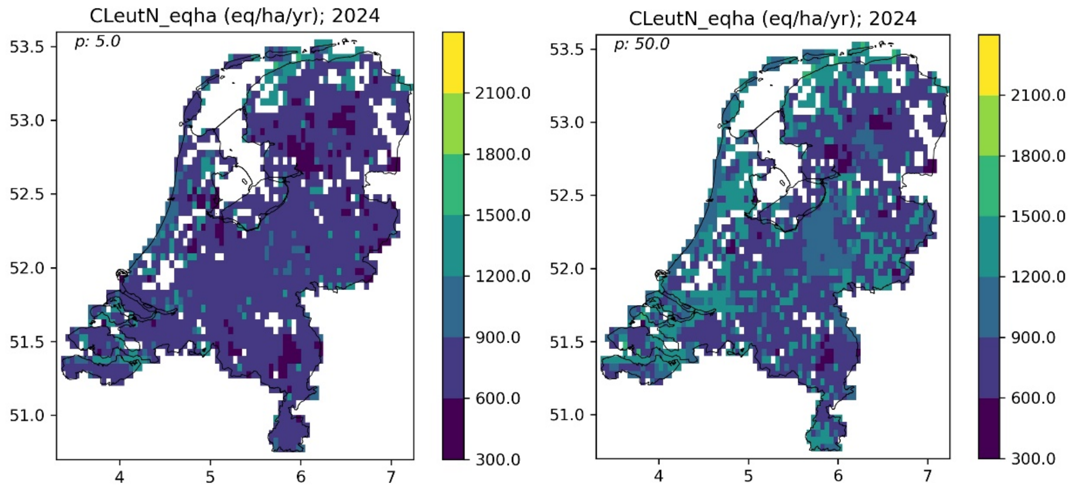


Figure 41 Maps of CLeutN on 0.05 × 0.05° resolution; 5 percentile (left) and median values (right) per grid cell.



The lowest $CL_{eut}N$ values can be found in raised bogs and dune areas (Figure 41), 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 40a).

E.4.6 Assigning nature and habitat types to 250 x 250 metre grid cells

In this assessment of critical loads we 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 $CL_{eut}N$ should not be used on a local scale.

E.4.7 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. For forests, the difference has become larger than in the previous submission due to the lower empirical critical loads that have been used. 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 (Van Dobben et al., 2012). As empirical values are broadly accepted, and the model results are considered a further specification, Wamelink et al. (2023) 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.

E.5 Norway

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E.5.1 Introduction

Norway applies modelled critical loads for acidification of surface waters (CL_{acid}). There have been some updates since the last submission in 2017:

- TOC concentration
- Differentiation of nitrogen removal constants
- Proportion of water and forest area
- Mean annual runoff

Several of the updates were made based on the findings by Austnes et al. (2020), in which the effects from varying parameter values on critical loads and exceedances were assessed.

Norway submits empirical critical loads as critical loads for eutrophication (CL_{eut}), see appendix A.

E.5.2 Critical loads for acidification of surface waters

The critical loads were calculated using the FAB model (Henriksen & Posch, 2001) and largely in accordance with the ICP Modelling and Mapping manual (CCE, 2024b). The methodology for Norway was described by Henriksen (1998) and the application later updated in Larssen et al. (2005), Larssen et al. (2008), Austnes et al. (2018), and (Austnes et al., 2023).

The original 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 for each 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 surface water body 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).

A variable ANC_{limit} as described by Henriksen and Posch (2001) is used but adjusted for the strong acid anion contribution from organic acids (Hindar & Larssen, 2005; Lydersen et al., 2004). Previously, total organic carbon (TOC) concentration data from the national lake survey in 1995 (Skjelkvåle et al., 1996) was used in the calculation of the organic acid adjusted, variable ANC_{limit}. However, over the past decades an increase in organic acid concentrations in surface waters has been observed, in particular in southern and eastern Norway (de Wit et al., 2016). Since the increase to a large degree is caused by decreasing acid deposition, the current levels are considered the most “natural”. Hence, the TOC concentrations have been updated to 2019 levels. A statistical model was applied to assign gridded TOC concentration values to all of Norway. Two different datasets were used as input data: The 2019 national lake survey (de Wit et al., 2023; Hindar et al., 2020) and 2019 data from the annual trend lake monitoring (Vogt & Skancke, 2023). The former represents 758 lakes that are nationally distributed and with minimal impact from anthropogenic activities. The latter represents 78 acid-sensitive lakes, mainly located in southern Norway, which is the region most heavily impacted by acid deposition. Generalised additive modelling (GAM) was selected as statistical method. This method is suitable for spatial modelling as it flexibly describes different shapes of non-linear relations between variables. The GAM model was developed by first testing different variables and combinations of interactions. In the final model UTM coordinates were included as interactions and a cubic spline function was applied along with a Gamma-distribution with log-link[19]. The model estimated TOC concentrations with a 1 x 1 km resolution, which were averaged to fit the original grid.

$[BC]_0^*$ was originally calculated by the F-factor approach, using the sine function of Brakke et al. (Brakke et al., 1990), but in recent applications $[BC]_0^*$ has instead been estimated from MAGIC model (Cosby et al., 2001; Cosby et al., 1985) 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.

Nitrogen removal in harvested biomass was estimated by (Frogner et al., 1994) and mapped for the entire Norway according to forest cover and productivity. Previously nitrogen immobilisation and the denitrification fraction were set constant for all land cover types (0.5 kg N ha^{-1} yr^{-1} and 0.1, respectively), except for water where they were both zero. These constants have now been updated to vary across land cover types (Table 56). Nitrogen immobilisation was set to zero for bare land and 0.5 kg N ha^{-1} yr^{-1} for remaining land, as 0.5 kg N ha^{-1} yr^{-1} is estimated based on forest soil data, and in the FAB model it is assumed that nitrogen deposited on bare land and water enters the surface water unchanged (CCE, 2024b). The denitrification fraction was set to zero for bare land, 0.8 for wetlands, and to 0.1 for the remaining (CCE, 2024b). The land cover map AR50[20] was used to enable this differentiation for each grid cell.

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[19] For further details, see: https://github.com/JamesSample/critical_loads_2/blob/master/notebooks/workflow_update_2023/02b_statistical_models.ipynb

[20] Dokumentasjon av AR50 - Nibio

The AR50 map was also used to update the proportion of water and forest in the catchment. These were formerly constant (5% and 95%, respectively), but were now set equal to the actual proportion per grid cell.

Table 56 **Overview of the different land cover types and the selected values for nitrogen immobilisation and denitrification fraction**

Area type	Category	N immobilisation (kg N ha^{-1} yr^{-1})	Denitrification fraction
Water	Freshwater: River and lake	0.0	0.0
Bare land	No vegetation, impediment Glacier: Ice and snow that does not melt during summer	0.0	0.0
Wetland	Wetland: Area that on the surface appears as wetland	0.5	0.8
Other/remaining		0.5	0.1

Mass transfer coefficients were kept constant at 5 m yr^{-1} and 0.5 m yr^{-1} for N and S, respectively, and chosen as the mid-value of the ranges proposed by Dillon and Molot (Dillon & Molot, 1990) and Baker and Brezonik (1988), respectively. Mean annual runoff data was from runoff maps prepared by the Norwegian Water Resources and Energy Directorate (NVE). These data were updated from the previously used 1961-1990 normal to the new 1991-2020 normal, which better fits the time period for which exceedances are calculated.

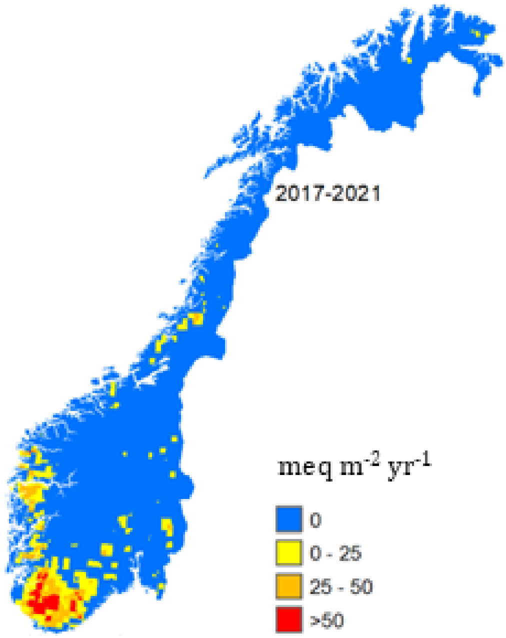
The critical loads calculated for the original grid were assigned to the EMEP 0.10°×0.05° longitude-latitude grid without further data collection. The mid-point critical load values of the EMEP grid cells were used as critical load for the entire EMEP grid cell. When the mid-point was at the border between 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.

E.5.3 Key findings from the update of the critical loads

The updates had only minor effects on the critical loads. The changes went in both directions, but notably the critical loads were slightly higher in the south of Norway, where deposition is generally higher. This was probably mainly due to the updated TOC concentrations, which were usually higher than the former. Other changes can have opposing effects and thereby giving little effect overall.

Using Norwegian deposition data (average 2017-2021) and the updated critical loads, the area with exceedance of critical loads for acidification of surface waters in Norway is 11%, with an average exceedance of 23 meq m^{-2} yr^{-1} (Austnes et al., 2023) (Figure 42).

Figure 42 Exceedance of critical loads for acidification of surface waters for the period 2017-2021



E.6 Poland

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E.6.1 Introduction

In response to the CCE “call for data 2024-25”, the Polish NFC is submitting an updated critical loads database (CL2025), to be used by CIAM as environmental receptors for integrated assessment modelling with GAINS-Europe.

E.6.2 Ecosystems database

As in the previous CL’s databases the calculation grid for Polish ecosystems was based on 0.1x0.05 degree lon/lat EMEP spatial reference.

Terrestrial ecosystem database, was based on CLC18 (Giós, 2019), and combined with spatial dataset of wetland and non-forest ecosystems (IMUZ, 2012). The revised EUNIS Habitat classification was used (Chytry, 2020) with linkage to previous version classes (Davies et al., 2004) with extension to 2nd level of 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 97098,2 km^2 of ecosystems, with one or more habitats in each grid cell and contains 239913 records with ecosystems limit area set ≥0.5 ha (“EcoArea”≥5000 m^2). Forests cover 98.4% of total ecosystems.

Table 57 CL2025 Ecosystem database for Poland

EUNIS code 2020	EUNIS code 2004	EUNIS habitat name	Ecosystem Area		
			Total	Covered by Natura 2000	
			[km²]	[km²]	% of Total
Q1	D1	Raised and blanket bogs	47.2	39.7	83.8
Q2	D2	Valley mires, poor fens and transition mires	105.5	59.1	55.9
Q4	D4	Base-rich fens and calcareous spring mires	1038.0	763.9	73.6
Q45	D4.2	Arctic–alpine rich fen	3.1	1.8	58.1
R22	E2.2	Low and medium altitude hay meadow	245.8	211.4	86.0
R23	E2.3	Mountain hay meadow	57.4	55.1	95.8
R43	E4.3	Temperate acidophilous alpine grassland	21.3	21.3	100.0
S2	F2	Arctic, alpine and subalpine scrub	36.4	36.4	99.7
S42	F4.2	Dry heath	4.8	4.5	93.8
T1	G1	Broadleaved deciduous forests	15163.8	7903.5	52.1
T31	G3.1	Temperate mountain *Picea* forest	3785.2	2747.2	72.6
T35	G3.5	Temperate continental *Pinus sylvestris* forest	52195.7	35676.9	68.3
(T)	G4	Mixed forests	24394.0	11434.9	46.9
TOTAL			**97098.2**	**58955.7**	**60.7**

E.6.3 Critical Loads of Acidity

Critical loads of acidity calculations were based on the SMB model as it was described in ch.5 of UBA Manual (CCE, 2023).

The spatial distribution and soils properties were obtained from European Soils Database (European Commission and the European Soil Bureau Network, 2004), with additional data taken from Polish ICP Forest II-level monitoring system (CCE, 2017; IBL, 2019; Wawrzoniak J. & al., 2005) and other published data (Brożek & Zwydak, 2003). Base cation weathering were calculated from weathering rates classes (WRc) obtained from soil texture. 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].

CL_{acid} calculated for EUNIS ecosystem classes are provided in Table 58. Cumulated distribution function for forests and non-forest ecosystem are shown in Figure 43. Spatial distribution of $CL_{max}(S)$ is presented in Figure 44.

Table 58 CL_{acid} for terrestrial ecosystems in Poland

EUNIS code 2020	**EUNIS code 2004**	**CL_{acid} – Critical Load Function of Acidity [eq/ha/yr]**		
		$CL_{min}N$	$CL_{max}N$	$CL_{max}S$
Q1	D1	138.7	3361.1	1843.0
Q2	D2	124.5	2587.1	1458.0
Q4	D4	119.6	3455.9	1884.9
Q45	D4.2	166.8	3145.8	1953.2
R22	E2.2	112.4	2869.8	1856.9
R23	E2.3	185.7	2850.3	1847.0
R43	E4.3	370.9	4075.7	2431.6
S2	F2	461.6	4002.5	2316.4
S42	F4.2	411.0	3060.3	1770.2
T1	G1	546.8	2397.5	1178.7
T31	G3.1	585.5	2829.7	1494.2
T35	G3.5	411.5	2359.6	1268.0
(T)	G4	498.2	2413.8	1248.0
Average		**467.6**	**2424.5**	**1264.5**

Figure 43 CDF of CL_{acid} for forest and non-forest ecosystems.

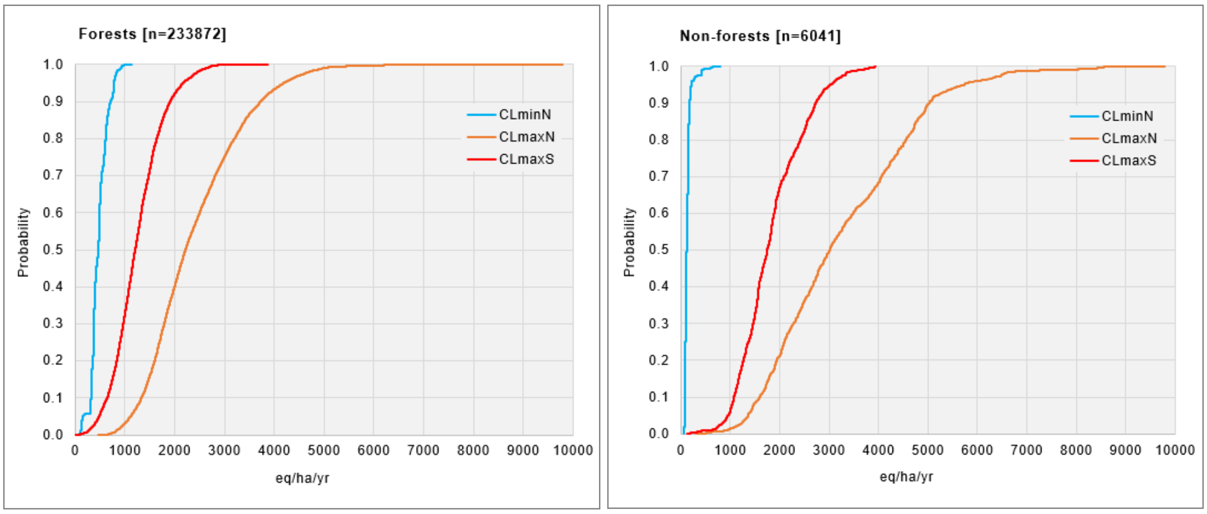
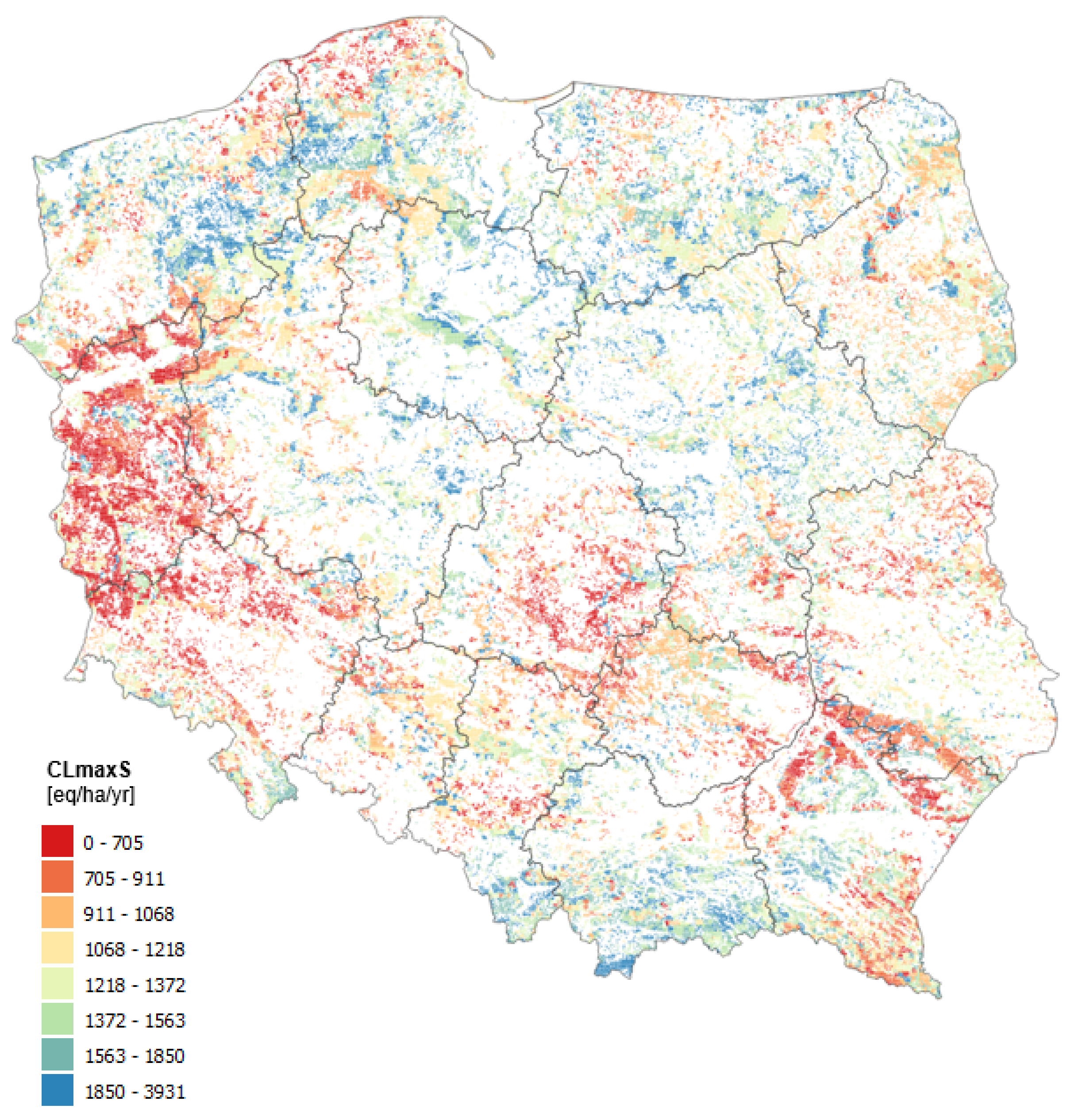


Figure 44 Spatial distribution of $CL_{max}(S)$ values for terrestrial ecosystems in Poland.



E.6.4 Critical Loads of Eutrophication

Critical loads of eutrophication (CL_{eut}) were derived from $CL_{nut}(N)$ calculation methods based on SMB model in ch.5 of UBA Manual (CCE, 2023) and 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 (CCE, 1996). The polynomial equation was used for interpolate temperature range values.

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 59,(CCE, 2023)). 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., 2022) and multiplied by 71.428 to obtain eq/ha/year for further $CL_{emp}(N)$ and $CL_{nut}(N)$ comparisons to derive final CL_{eut}.

CL_{eut} was derived as $CL_{nut}N$, but not lower than $CL_{emp}N$ lower limit ($CL_{emp}N\_LL$) and not higher than the $CL_{emp}N$ upper limit ($CL_{emp}N\_UL$). It helps to avoid low/high precipitation and temperature influence on the $CL_{nut}N$ for mountain and alpine areas (extremely high Q) as well as water deficit areas (zero or negative Q).

CL_{eut} derivation method for EUNIS ecosystem classes are provided in Table 59. Cumulated distribution function for forests and non-forest ecosystem are shown in Figure 45. Spatial distribution of CL_{eut} is presented in Figure 46.

Table 59 CL_{eut} calculation method and values derived for terrestrial ecosystems in Poland [eq/ha/yr]

EUNIS code 2020	EUNIS code 2004	$CL_{nut}N$	$CL_{emp}N$	$Cl_{emp}N$ _LL (lower limit)	$Cl_{emp}N$ _UL (upper limit)	CL_{eut}	CL_{eut} derivation method
D1	Q1	845.1	535.7	357.1	714.3	571.3	$CL_{eut} = CL_{nut}N$
D2	Q2	531.3	892.9	714.3	1071.4	768.3	For cases: when $CL_{nut}N \leq CL_{emp}N\_LL$ then $CL_{emp}N\_LL$ when $CL_{nut}N \geq CL_{emp}N\_UL$ then $CL_{emp}N\_UL$ else $CL_{nut}N$
D4	Q4	464.0	1607.1	1071.4	2142.8	1101.8	
D4.2	Q45	808.6	1607.1	1071.4	2142.8	1115.3	
E2.2	R22	919.6	714.3	357.1	1071.4	798.0	
E2.3	R23	1492.1	535.7	357.1	714.3	712.2	
E4.3	R43	2102.1	535.7	357.1	714.3	710.5	
F2	S2	2669.4	714.3	357.1	1071.4	1035.0	
F4.2	S42	1211.2	1071.4	714.3	1428.6	1053.4	
G1	T1	1129.2	1071.4	714.3	1428.6	1070.5	
G3.1	T31	1595.7	714.3	357.1	1071.4	1051.7	
G3.5	T35	770.1	714.3	357.1	1071.4	741.3	
G4	(T)	1022.9	892.9	535.7	1250.0	932.6	
Average		**954.7**	**862.8**			**890.4**	

Figure 45 CDF of CL_{eut} for forest and non-forest ecosystems.

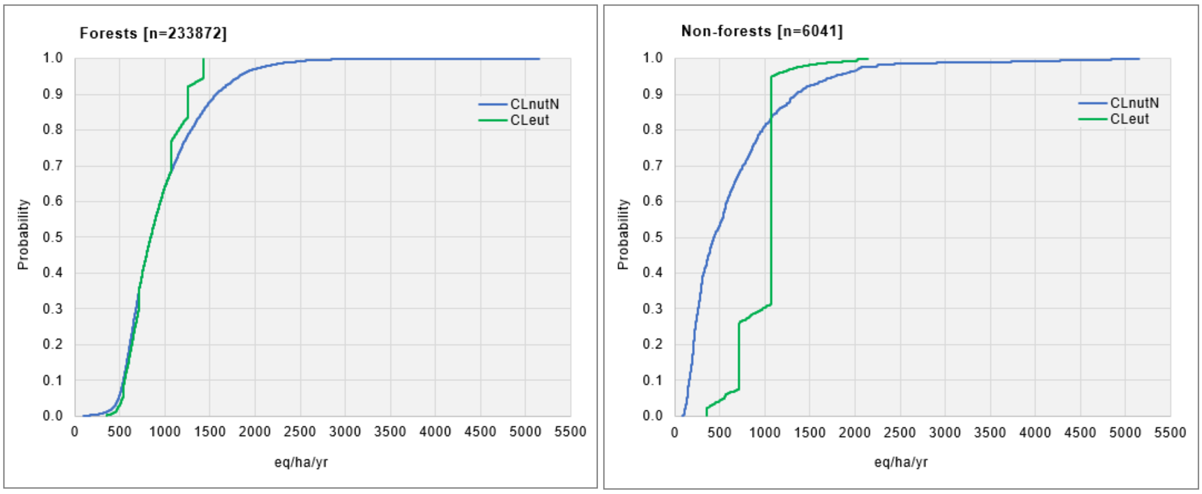
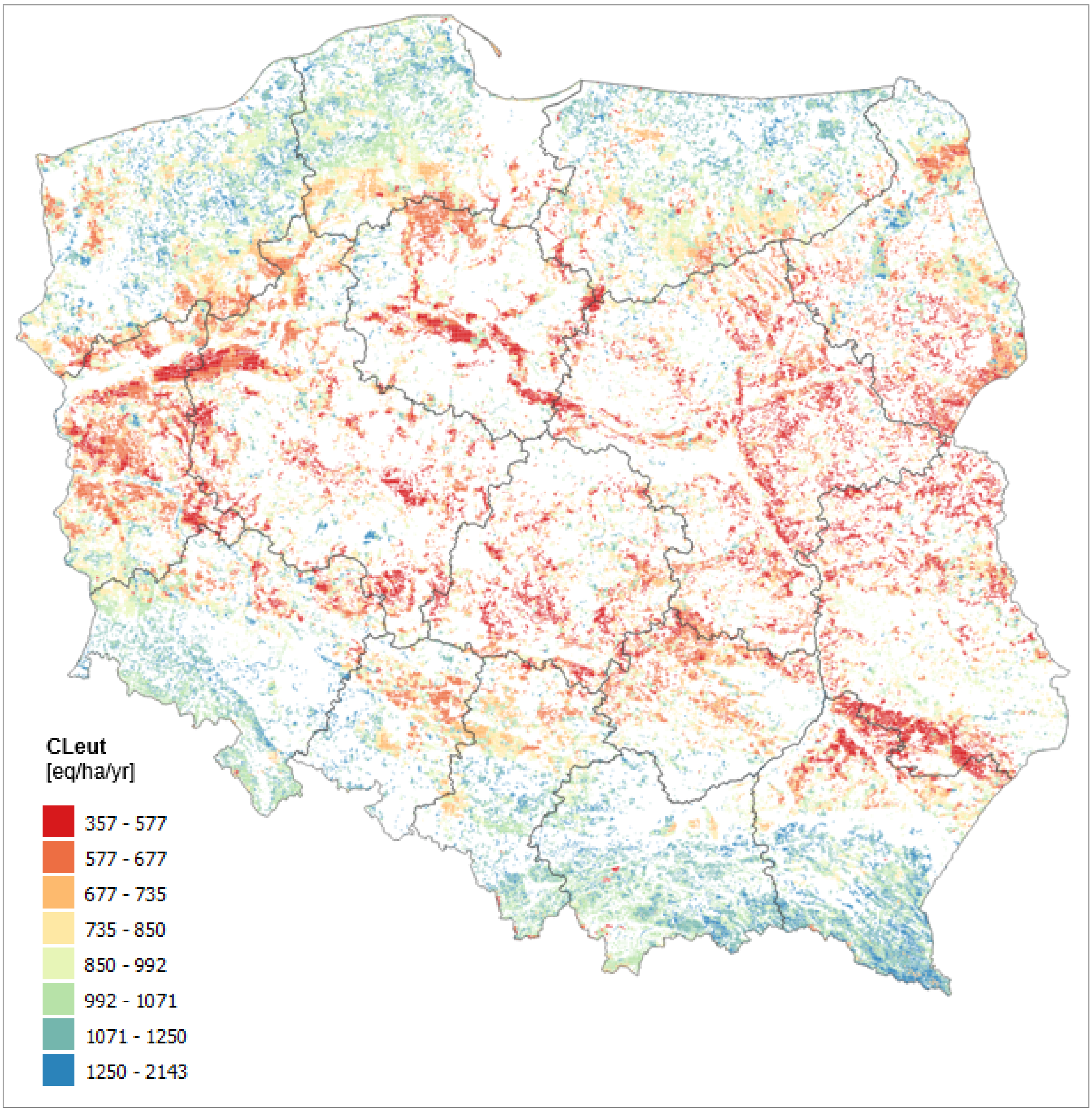


Figure 46 Spatial distribution of CL_{eut} for terrestrial ecosystems in Poland.



F Annex 6: Assignment of Ammonia Critical Level to the EUNIS classes of the receptor map at Level 3

Table 60 Receptor Table for assignment of NH$_3$ Critical Level

Abbreviations for the species category of mosses and liverworts: di = diagnostic species; co = constant species; do = dominant species

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EU-NIS C1	EU-NIS C2	EU-NIS C3	EU-NIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
1000	Marine benthic habitats	Fact Sheet	M				1000			no					
1022	Atlantic littoral biogenic habitat	Fact Sheet	M	MA2			1022			no					
2101	Atlantic, Baltic and Arctic sand beach	Fact Sheet	N	N1	N11		2000	2100	2101	no	no	no	no	N.A.	N.A.
2102	Mediterranean and Black Sea sand beach	Fact Sheet	N	N1	N12		2000	2100	2102	no	no	no	no	N.A.	N.A.
2103	Atlantic and Baltic shifting coastal dune	Fact Sheet	N	N1	N13		2000	2100	2103	no	no	no	no	N.A.	N.A.
2104	Mediterranean, Macaronesian and Black Sea shifting coastal dune	Fact Sheet	N	N1	N14		2000	2100	2104	no	no	no	no	N.A.	N.A.
2105	Atlantic and Baltic coastal dune grassland (grey dune)	Fact Sheet	N	N1	N15		2000	2100	2105	yes	no	yes	no	Syntrichia ruralis (co), Hypnum cupressiforme (co)	N.A.

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
														Ceratodon purpureus (co)	
2106	Mediterranean and Macaronesian coastal dune grassland (grey dune)	Fact Sheet	N	N1	N16		2000	2100	2106	no	no	no	no	N.A.	N.A.
2107	Black Sea coastal dune grassland (grey dune)	Fact Sheet	N	N1	N17		2000	2100	2107	yes	no	yes	no	Syntrichia ruralis (co)	N.A.
2110	Atlantic and Baltic coastal dune scrub	Fact Sheet	N	N1	N1A		2000	2100	2110	yes	no	yes	no	Pseudoscleropodium purum (co)	N.A.
2111	Mediterranean and Black Sea coastal dune scrub	Fact Sheet	N	N1	N1B		2000	2100	2111	no	no	no	no	N.A.	N.A.
2112	Macaronesian coastal dune scrub	Fact Sheet	N	N1	N1C		2000	2100	2112	no	no	no	no	N.A.	N.A.
2113	Atlantic and Baltic broad-leaved coastal dune forest	Fact Sheet	N	N1	N1D		2000	2100	2113	yes	no	yes	no	Pseudoscleropodium purum (co Kindbergia praelonga (co)	N.A.
2116	Mediterranean coniferous coastal dune forest	Fact Sheet	N	N1	N1G		2000	2100	2116	no	no	no	no	N.A.	N.A.
2117	Atlantic and Baltic moist and wet dune slack	Fact Sheet	N	N1	N1H		2000	2100	2117	yes	no	yes	yes	Calliergonella cuspidata (co, do)	N.A.

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	**diagnostic species**	**constant species**	**dominant species**	**name(s) mosses/liverworts**	**name(s) lichens (fungi)**
2118	Mediterranean and Black Sea moist and wet dune slack	Fact Sheet	N	N1	N1J		2000	2100	2118	no	no	no	no	N.A.	N.A.
2201	Atlantic, Baltic and Arctic coastal shingle beach	Fact Sheet	N	N2	N21		2000	2200	2201	no	no	no	no	N.A.	N.A.
2202	Mediterranean and Black Sea coastal shingle beach	Fact Sheet	N	N2	N22		2000	2200	2202	no	no	no	no	N.A.	N.A.
2302	Mediterranean and Black Sea rocky sea cliff and shore	Fact Sheet	N	N3	N32		2000	2300	2302	no	no	no	no	N.A.	N.A.
2303	Macaronesian rocky sea cliff and shore	Fact Sheet	N	N3	N33		2000	2300	2303	no	no	no	no	N.A.	N.A.
2305	Mediterranean and Black Sea soft sea cliff	Fact Sheet	N	N3	N35		2000	2300	2305	no	no	no	no	N.A.	N.A.
4101	Raised bogs	Fact Sheet	Q	Q1	Q11	D1.1	4000	4100	4101	yes	Further details in G Annex 7				
4102	Blanket bogs	Fact Sheet	Q	Q1	Q12	D1.2	4000	4100	4102	yes	Further details in G Annex 7				
4202	Poor fens and soft-water spring mires	Fact Sheet	Q	Q2	Q22	D2.2a	4000	4200	4202	yes	Further details in G Annex 7				
4203	Apennine acidic fens	Fact Sheet	Q	Q2	Q23	D2.2b	4000	4200	4203	yes	Further details in G Annex 7				
4204	Intermediate fen and soft-water spring mire	Fact Sheet	Q	Q2	Q24	D2.2c	4000	4200	4204	yes	Further details in G Annex 7				

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
4205	Non-calcareous quaking mire	Fact Sheet	Q	Q2	Q25	D2.3	4000	4200	4205	yes	Further details in G Annex 7				
4300	Palsa and polygon mires	Fact Sheet	Q	Q3	Q31	D3.1	4000	4300		yes	Further details in G Annex 7				
4401	Alkaline, calcareous, carbonate-rich small-sedge spring fen	Fact Sheet	Q	Q4	Q41	D4.1a	4000	4400	4401	yes	Further details in G Annex 7				
4402	Extremely rich moss-sedge fen	Fact Sheet	Q	Q4	Q42	D4.1a	4000	4400	4402	yes	Further details in G Annex 7				
4404	Calcareous quaking mire	Fact Sheet	Q	Q4	Q44	D4.1c	4000	4400	4404	yes	Further details in G Annex 7				
4405	Arctic-alpine rich fen	Fact Sheet	Q	Q4	Q45	D4.2	4000	4400	4405	yes	Further details in G Annex 7				
4501	Tall-helophyte bed	Fact Sheet	Q	Q5	Q51	C3.2	4000	4500	4501	no	Further details in G Annex 7				
4502	Small-helophyte bed	Fact Sheet	Q	Q5	Q52	C3.1	4000	4500	4502	no	Further details in G Annex 7				
4503	Tall-sedge bed	Fact Sheet	Q	Q5	Q53	C3.2	4000	4500	4503	no	Further details in G Annex 7				
4504	Inland saline or brackish helophyte bed		Q	Q5	Q54	C5.4	4000	4500	4504	no	Further details in G Annex 7				
4600	Inland saline and brackish marshes and reedbeds	Fact Sheet	Q	Q6		C3.5	4000	4600		no	Further details in G Annex 7				

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EU-NIS C1	EU-NIS C2	EU-NIS C3	EU-NIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
5101	Pannonian and Pontic sandy steppe	Fact Sheet	R	R1	R11		5000	5100	5101	yes	no	yes	yes	Syntrichia ruralis (co, do)	
5102	Cryptogam- and annual-dominated vegetation on siliceous rock outcrops	Fact Sheet	R	R1	R12		5000	5100	5102	yes	no	yes	no	Ceratodon purpureus (co)	
5103	Cryptogam- and annual-dominated vegetation on calcareous and ultramafic rock outcrops	Fact Sheet	R	R1	R13		5000	5100	5103	yes	yes	yes	no	Abietinella abietina (di), Homalothecium sericeum (di), Syntrichia ruralis (co)	
5105	Continental dry rocky steppic grassland and dwarf scrub on chalk outcrops	Fact Sheet	R	R1	R15		5000	5100	5105	no	no	no	no		
5106	Perennial rocky grassland of Central and South-Eastern Europe	Fact Sheet	R	R1	R16		5000	5100	5106	no	no	no	no		
5108	Perennial rocky calcareous grassland of subatlantic-submediterranean Europe	Fact Sheet	R	R1	R18		5000	5100	5108	no	no	no	no		
5109	Dry steppic submediterranean	Fact Sheet	R	R1	R19		5000	5100	5109	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EU-NIS C1	EU-NIS C2	EU-NIS C3	EU-NIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
	pasture of the Amphi-Adriatic region														
5110	Semi-dry perennial calcareous grassland (meadow steppe)	Fact Sheet	R	R1	R1A		5000	5100	5110	no	no	no	no	N.A.	N.A.
5111	Continental dry grassland (true steppe)	Fact Sheet	R	R1	R1B		5000	5100	5111	no	no	no	no		
5112	Desert steppe	Fact Sheet	R	R1	R1C		5000	5100	5112	no	no	no	no		
5113	Mediterranean closely grazed dry grassland	Fact Sheet	R	R1	R1D		5000	5100	5113	no	no	no	no		
5114	Mediterranean tall perennial dry grassland	Fact Sheet	R	R1	R1E		5000	5100	5114	no	no	no	no		
5115	Mediterranean annual-rich dry grassland	Fact Sheet	R	R1	R1F		5000	5100	5115	no	no	no	no		
5116	Iberian oromediterranean siliceous dry grassland	Fact Sheet	R	R1	R1G		5000	5100	5116	no	no	no	no		
5117	Iberian oromediterranean basiphilous dry grassland	Fact Sheet	R	R1	R1H		5000	5100	5117	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EU-NIS C1	EU-NIS C2	EU-NIS C3	EU-NIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
5118	Cyrno-Sardean oromediterranean siliceous dry grassland	Fact Sheet	R	R1	R1J		5000	5100	5118	no	no	no	no		
5119	Balkan and Anatolian oromediterranean dry grassland	Fact Sheet	R	R1	R1K		5000	5100	5119	no	no	no	no		
5121	Lowland to montane, dry to mesic grassland usually dominated by *Nardus stricta*	Fact Sheet	R	R1	R1M		5000	5100	5121	yes	no	yes	no	Pleurozium schreberi (co), Rhytidiadelphus squarrosus (co)	
5122	Open Iberian supramediterranean dry acid and neutral grassland	Fact Sheet	R	R1	R1N		5000	5100	5122	yes	no	yes	no	Polytrichum piliferum (co)	
5123	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils	Fact Sheet	R	R1	R1P		5000	5100	5123	yes	yes	yes	no	Brachythecium albicans (di), Polytrichum piliferum (di, co), Ceratodon purpureus (di, co)	
5124	Inland sanddrift and dune with siliceous grassland	Fact Sheet	R	R1	R1Q		5000	5100	5124	yes	yes	yes	yes	Polytrichum piliferum (di, co, do), Ceratodon purpureus (di, co)	Cladonia cervicornis (di), Cladonia glauca (di), Cladonia zopfii (di), Cladonia subulata (di), Cladonia pyxidata (co), Cladonia uncialis (co), Cladonia furcata (co)

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
5125	Mediterranean to Atlantic open, dry, acid and neutral grassland	Fact Sheet	R	R1	R1R		5000	5100	5125	no	no	no	no		
5127	Azorean open, dry, acid to neutral grassland	Fact Sheet	R	R1	R1T		5000	5100	5127	no	no	no	no		
5201	Mesic permanent pasture of lowlands and mountains	Fact Sheet	R	R2	R21		5000	5200	5201	no	no	no	no		
5202	Low and medium altitude hay meadow	Fact Sheet	R	R2	R22		5000	5200	5202	no	no	no	no		
5203	Mountain hay meadow	Fact Sheet	R	R2	R23		5000	5200	5203	no	no	no	no		
5204	Iberian summer pasture (vallicar)	Fact Sheet	R	R2	R24		5000	5200	5204	no	no	no	no		
5301	Mediterranean tall humid inland grassland	Fact Sheet	R	R3	R31		5000	5300	5301	no	no	no	no		
5302	Mediterranean short moist grassland of lowlands	Fact Sheet	R	R3	R32		5000	5300	5302	no	no	no	no		
5303	Mediterranean short moist grassland of mountains	Fact Sheet	R	R3	R33		5000	5300	5303	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
5304	Submediterranean moist meadow	Fact Sheet	R	R3	R34		5000	5300	5304	no	no	no	no	N.A.	N.A.
5305	Moist or wet mesotrophic to eutrophic hay meadow	Fact Sheet	R	R3	R35		5000	5300	5305	no	no	no	no	N.A.	N.A.
5306	Moist or wet mesotrophic to eutrophic pasture	Fact Sheet	R	R3	R36		5000	5300	5306	no	no	no	no	N.A.	N.A.
5307	Temperate and boreal moist or wet oligotrophic grassland	Fact Sheet	R	R3	R37		5000	5300	5307	no	no	no	no	N.A.	N.A.
5401	Snow-bed vegetation	Fact Sheet	R	R4	R41		5000	5400	5401	no	no	no	no	N.A.	N.A.
5402	Boreal and arctic acidophilous alpine grassland	Fact Sheet	R	R4	R42		5000	5400	5402	yes	yes	yes	yes	Kiaeria starkei (di), Oligotrichum hercynicum (di), Pogonatum urnigerum (di), Polytrichastrum alpinum (di, co), Racomitrium heterostichum (di), Racomitrium fasciculare (di), Racomitrium lanuginosum (do), Sanionia uncinata (do)	N.A.
5403	Temperate acidophilous alpine grassland	Fact Sheet	R	R4	R43		5000	5400	5403	no	no	no	no	N.A.	N.A.

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	RecMap G1	RecMap G2	RecMap G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
5404	Arctic-alpine calcareous grassland	Fact Sheet	R	R4	R44		5000	5400	5404	yes	no	yes	no	Tortella tortuosa (co)	N.A.
5405	Alpine and subalpine calcareous grassland of the Balkans and Apennines	Fact Sheet	R	R4	R45		5000	5400	5405	no	no	no	no	N.A.	N.A.
5501	Thermophilous forest fringe of base-rich soils	Fact Sheet	R	R5	R51		5000	5500	5501	no	no	no	no		
5503	Macaronesian thermophilous forest fringe	Fact Sheet	R	R5	R53		5000	5500	5503	no	no	no	no		
5504	Pteridium aquilinum vegetation	Fact Sheet	R	R5	R54		5000	5500	5504	no	no	no	no		
5505	Lowland moist or wet tall-herb and fern fringe	Fact Sheet	R	R5	R55		5000	5500	5505	no	no	no	no		
5506	Montane to subalpine moist or wet tall-herb and fern fringe	Fact Sheet	R	R5	R56		5000	5500	5506	no	no	no	no		
5507	Herbaceous forest clearing vegetation	Fact Sheet	R	R5	R57		5000	5500	5507	no	no	no	no		
5601	Mediterranean inland salt steppe	Fact Sheet	R	R6	R61		5000	5600	5601	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
5602	Continental inland salt steppe	Fact Sheet	R	R6	R62		5000	5600	5602	no	no	no	no		
5603	Temperate inland salt marsh	Fact Sheet	R	R6	R63		5000	5600	5603	no	no	no	no		
5604	Semi-desert salt pan	Fact Sheet	R	R6	R64		5000	5600	5604	no	no	no	no		
5605	Continental subsaline alluvial pasture and meadow	Fact Sheet	R	R6	R65		5000	5600	5605	no	no	no	no		
5700	Sparsely wooded grasslands	Fact Sheet	R	R7			5000	5700		no	no	no	no		
6020	Heathland, scrub and tundra	Fact Sheet	S				6020	6020	6020	no					
6101	Shrub tundra	Fact Sheet	S	S1	S11		6000	6100	6101	yes	yes	yes	yes	Dicranum fuscescens (di, do), Dicranum scoparium (co), Hylocomium splendens (do), Pleurozium schreberi (co, do)	Cetraria ericetorum (di, co), Cladonia bellidiflora (di, co), Cladonia gracilis (di, co), Cladonia mitis (di, co), Cladonia coccifera (di, co), Cladonia rangiferina (di, co), Cladonia unitialis (co), Nephroma arcticum (di, co), Ochrolechia frigida (di, co), Stereocaulon paschale (di)
6102	Moss and lichen tundra	Fact Sheet	S	S1	S12		6000	6100	6102	yes	yes	yes	yes		

Rec_ID	**EUNIS LABEL**	**EUNIS Factsheet**	**EUNIS C1**	**EUNIS C2**	**EUNIS C3**	**EUNIS 2012**	**Rec-Map G1**	**Rec-Map G2**	**Rec-Map G3**	**Indicator species moss/lichen in Level C3**					
										Species	**diagnostic species**	**constant species**	**dominant species**	**name(s) mosses/liverworts**	**name(s) lichens (fungi)**
6201	Subarctic and alpine dwarf *Salix* scrub	Fact Sheet	S	S2	S21		6000	6200	6201	no	no	no	no	N.A.	N.A.
6202	Alpine and subalpine ericoid heath	Fact Sheet	S	S2	S22		6000	6200	6202	yes	no	yes	no	N.A.	Cetraria islandica (co)
6203	Alpine and subalpine *Juniperus* scrub	Fact Sheet	S	S2	S23		6000	6200	6203	no	no	no	no	N.A.	N.A.
6205	Subalpine and subarctic deciduous scrub	Fact Sheet	S	S2	S25		6000	6200	6205	no	no	no	no	N.A.	N.A.
6206	Subalpine *Pinus mugo* scrub	Fact Sheet	S	S2	S26		6000	6200	6206	yes	no	yes	yes	Dicranum scoparium (co), Hylocomium splendens (co, do), Pleurozium schreberi (co), Rhytidiadelphus triquetrus (co)	N.A.
6301	Lowland to montane temperate and submediterranean *Juniperus* scrub	Fact Sheet	S	S3	S31		6000	6300	6301	yes	no	yes	no	Pleurozium schreberi (co), Dicranum scoparium (co)	
6302	Temperate *Rubus* scrub	Fact Sheet	S	S3	S32		6000	6300	6302	no	no	no	no		
6303	Lowland to montane temperate and	Fact Sheet	S	S3	S33		6000	6300	6303	no	no	no	no		

Rec_ID	**EUNIS LABEL**	**EUNIS Factsheet**	**EU-NIS C1**	**EU-NIS C2**	**EU-NIS C3**	**EU-NIS 2012**	**Rec-Map G1**	**Rec-Map G2**	**Rec-Map G3**	**Indicator species moss/lichen in Level C3**					
										Spe-cies	**diagno-stic spe-cies**	**con-stant species**	**domi-nant species**	**name(s) mosses/liver-worts**	**name(s) lichens (fungi)**
	submediterranean genistoid scrub														
6304	Balkan-Anatolian submontane genistoid scrub	Fact Sheet	S	S3	S34		6000	6300	6304	no	no	no	no		
6305	Temperate and submediterranean thorn scrub	Fact Sheet	S	S3	S35		6000	6300	6305	no	no	no	no		
6306	Low steppic scrub	Fact Sheet	S	S3	S36		6000	6300	6306	no	no	no	no		
6307	*Corylus avellana* scrub	Fact Sheet	S	S3	S37		6000	6300	6307	no	no	no	no		
6308	Temperate forest clearing scrub	Fact Sheet	S	S3	S38		6000	6300	6308	no	no	no	no		
6401	Wet heath	Fact Sheet	S	S4	S41		6000	6400	6401	yes	yes	yes	no	Sphagnum compactum (di, co), Pleurozium schreberi (co), Dicranum scoparium (co)	
6402	Dry heath	Fact Sheet	S	S4	S42		6000	6400	6402	yes	no	yes	yes	Pleurozium schreberi (co, do), Dicranum scoparium (co)	
6501	Mediterranean maquis and arborescent matorral	Fact Sheet	S	S5	S51		6000	6500	6501	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
6502	Submediterranean pseudomaquis	Fact Sheet	S	S5	S52		6000	6500	6502	no	no	no	no		
6503	*Spartium junceum* scrub	Fact Sheet	S	S5	S53		6000	6500	6503	no	no	no	no		
6504	Thermomediterranean arid scrub	Fact Sheet	S	S5	S54		6000	6500	6504	no	no	no	no		
6601	Western basiphilous garrigue	Fact Sheet	S	S6	S61		6000	6600	6601	no	no	no	no		
6602	Western acidophilous garrigue	Fact Sheet	S	S6	S62		6000	6600	6602	no	no	no	no		
6603	Eastern garrigue	Fact Sheet	S	S6	S63		6000	6600	6603	no	no	no	no		
6604	Macaronesian garrigue	Fact Sheet	S	S6	S64		6000	6600	6604	no	no	no	no		
6605	Mediterranean gypsum scrub	Fact Sheet	S	S6	S65		6000	6600	6605	no	no	no	no		
6606	Mediterranean halo-nitrophilous scrub	Fact Sheet	S	S6	S66		6000	6600	6606	no	no	no	no		
6607	Aralo-Caspian semi-desert	Fact Sheet	S	S6	S67		6000	6600	6607	no	no	no	no		
6608	Semi-desert sand dune with sparse scrub	Fact Sheet	S	S6	S68		6000	6600	6608	no	no	no	no		
6701	Western Mediterranean spiny heath	Fact Sheet	S	S7	S71		6000	6700	6701	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
6702	Eastern Mediterranean spiny heath (phrygana)	Fact Sheet	S	S7	S72		6000	6700	6702	no	no	no	no		
6703	Western Mediterranean mountain hedgehog-heath	Fact Sheet	S	S7	S73		6000	6700	6703	no	no	no	no		
6704	Central Mediterranean mountain hedgehog-heath	Fact Sheet	S	S7	S74		6000	6700	6704	no	no	no	no		
6705	Eastern Mediterranean mountain hedgehog-heath	Fact Sheet	S	S7	S75		6000	6700	6705	no	no	no	no		
6706	Canarian mountain hedgehog-heath	Fact Sheet	S	S7	S76		6000	6700	6706	no	no	no	no		
6801	Canarian xerophytic scrub	Fact Sheet	S	S8	S81		6000	6800	6801	no	no	no	no		
6901	Temperate riparian scrub	Fact Sheet	S	S9	S91		6000	6900	6901	no	no	no	no		
6902	*Salix* fen scrub	Fact Sheet	S	S9	S92		6000	6900	6902	yes	no	yes	no	Calliergonella cuspidata (co)	
6903	Mediterranean riparian scrub	Fact Sheet	S	S9	S93		6000	6900	6903	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	RecMap G1	RecMap G2	RecMap G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
6904	Semi-desert riparian scrub	Fact Sheet	S	S9	S94		6000	6900	6904	no	no	no	no		
7101	Temperate *Salix* and *Populus* riparian forest	Fact Sheet	T	T1	T11		7000	7100	7101	no	no	no	no		
7102	*Alnus glutinosa-Alnus incana* forest on riparian and mineral soils	Fact Sheet	T	T1	T12		7000	7100	7102	no	no	no	no		
7103	Temperate hardwood riparian forest	Fact Sheet	T	T1	T13		7000	7100	7103	no	no	no	no		
7104	Mediterranean and Macaronesian riparian forest	Fact Sheet	T	T1	T14		7000	7100	7104	no	no	no	no		
7106	Broadleaved mire forest on acid peat	Fact sheet	T	T1	T16		7000	7100	7106	yes	yes	yes	yes	Sphagnum palustre (di), Sphagnum fimbriatum (di), Polytrichum commune (co), Pleurozium schreberi (co), Sphagnum recurvum (co), Sphagnum palustre (co), Dicranum scoparium (co), Aulacomnium palustre (co), Sphagnum recurvum (do), Sphagnum palustre (do),	

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
														Polytrichum commune (do)	
7107	*Fagus* forest on non-acid soils	Fact Sheet	T	T1	T17		7000	7100	7107	no	no	no	no		
7108	*Fagus* forest on acid soils	Fact Sheet	T	T1	T18		7000	7100	7108	yes	yes	yes	no	Polytrichastrum formosum (di, co),	
7109	Temperate and submediterranean thermophilous deciduous forest	Fact Sheet	T	T1	T19		7000	7100	7109	no	no	no	no		
7110	Mediterranean thermophilous deciduous forest	Fact Sheet	T	T1	T1A		7000	7100	7110	no	no	no	no		
7111	Acidophilous *Quercus* forest	Fact Sheet	T	T1	T1B		7000	7100	7111	yes	yes	yes	no	Polytrichastrum formosum (di, co), Dicranum scoparium (co)	

Rec_ID	**EUNIS LABEL**	**EUNIS Factsheet**	**EUNIS C1**	**EUNIS C2**	**EUNIS C3**	**EUNIS 2012**	**RecMap G1**	**RecMap G2**	**RecMap G3**	**Indicator species moss/lichen in Level C3**					
										Species	**diagnostic species**	**constant species**	**dominant species**	**name(s) mosses/liverworts**	**name(s) lichens (fungi)**
7112	Temperate and boreal mountain *Betula* and *Populus tremula* forest on mineral soils	Fact Sheet	T	T1	T1C		7000	7100	7112	yes	yes	yes	yes	Sciuro-hypnum reflexum (di), Dicranum scoparium (co), Pleurozium schreberi (co), Hylocomium splendens (co), Hylocomium splendens (do)	
7113	Southern European mountain *Betula* and *Populus tremula* forest on mineral soils	Fact Sheet	T	T1	T1D		7000	7100	7113	no	no	no	no		
7114	*Carpinus* and *Quercus* mesic deciduous forest	Fact Sheet	T	T1	T1E		7000	7100	7114	no	no	no	no		
7115	Ravine forest	Fact Sheet	T	T1	T1F		7000	7100	7115	no	no	no	no		
7117	Broadleaved deciduous plantation of non site-native trees	Fact Sheet	T	T1	T1H		7000	7100	7117	no	no	no	no		
7201	Mediterranean evergreen *Quercus* forest	Fact Sheet	T	T2	T21		7000	7200	7201	no	no	no	no		
7202	Mainland laurophyllous forest	Fact Sheet	T	T2	T22		7000	7200	7202	no	no	no	no		
7203	Macaronesian laurophyllous forest	Fact Sheet	T	T2	T23		7000	7200	7203	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	RecMap G1	RecMap G2	RecMap G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
7204	*Olea europaea-Ceratonia siliqua* forest	Fact Sheet	T	T2	T24		7000	7200	7204	no	no	no	no		
7205	*Phoenix theophrasti* vegetation	Fact Sheet	T	T2	T25		7000	7200	7205	no	no	no	no		
7208	Macaronesian heathy forest	Fact Sheet	T	T2	T28		7000	7200	7208	no	no	no	no		
7209	Broadleaved evergreen plantation of non site-native trees	Fact Sheet	T	T2	T29		7000	7200	7209	no	no	no	no		
7301	Temperate mountain *Picea* forest	Fact Sheet	T	T3	T31		7000	7300	7301	yes	yes	yes	yes	Polytrichastrum formosum (di, co), Dicranum scoparium (co), Hylocomium splendens (co, do)	
7302	Temperate mountain *Abies* forest	Fact Sheet	T	T3	T32		7000	7300	7302	yes	no	yes	yes	Polytrichastrum formosum (co), Hylocomium splendens (do)	
7303	Mediterranean mountain *Abies* forest	Fact Sheet	T	T3	T33		7000	7300	7303	no	no	no	no		
7304	Temperate subalpine *Larix, Pinus cembra* and *Pinus uncinata* forest	Fact Sheet	T	T3	T34		7000	7300	7304	yes	no	no	yes	Hylocomium splendens (do)	

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
7305	Temperate continental *Pinus sylvestris* forest	Fact Sheet	T	T3	T35		7000	7300	7305	yes	yes	yes	yes	Dicranum polysetum (di), Pleurozium schreberi (co, do), Dicranum scoparium (co), Hylocomium splendens (co, do), Dicranum polysetum (co)	
7306	Temperate and submediterranean montane *Pinus sylvestris-Pinus nigra* forest	Fact Sheet	T	T3	T36		7000	7300	7306	no	no	no	no		
7307	Mediterranean montane *Pinus sylvestris-Pinus nigra* forest	Fact Sheet	T	T3	T37		7000	7300	7307	no	no	no	no		
7308	Mediterranean montane *Cedrus* forest	Fact Sheet	T	T3	T38		7000	7300	7308	no	no	no	no		
7309	Mediterranean and Balkan subalpine *Pinus heldreichii-Pinus peuce* forest	Fact Sheet	T	T3	T39		7000	7300	7309	no	no	no	no		
7310	Mediterranean lowland to submontane *Pinus* forest	Fact Sheet	T	T3	T3A		7000	7300	7310	no	no	no	no		
7311	*Pinus canariensis* forest	Fact Sheet	T	T3	T3B		7000	7300	7311	no	no	no	no		

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	Rec-Map G1	Rec-Map G2	Rec-Map G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
7313	Mediterranean Cupressaceae forest	Fact Sheet	T	T3	T3D		7000	7300	7313	no	no	no	no		
7314	Macaronesian *Juniperus* forest	Fact Sheet	T	T3	T3E		7000	7300	7314	no	no	no	no		
7315	Dark taiga	Fact Sheet	T	T3	T3F		7000	7300	7315	yes	yes	yes	yes	Hylocomium splendens (di, co, do), Pleurozium schreberi (di, co, do), Ptilium crista-castrensis (di, co), Polytrichum commune (co)	
7316	*Pinus sylvestris* light taiga	Fact Sheet	T	T3	T3G		7000	7300	7316	yes	yes	yes	yes	Pleurozium schreberi (di, co, do), Hylocomium splendens (di, co, do), Ptilium crista-castrensis (di, co), Polytrichum commune (co)	
7318	*Pinus* and *Larix* mire forest	Fact Sheet	T	T3	T3J		7000	7300	7318	yes	yes	yes	yes	Sphagnum magellanicum (di, co, do), Sphagnum recurvum (di, co, do), Aulacomnium palustre (di, co), Pleurozium schreberi (di, co, do), Sphagnum fuscum (di, do), Polytrichum strictum (di,	

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	RecMap G1	RecMap G2	RecMap G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
														co), Hylocomium splendens (co)	
7319	*Picea* mire forest	Fact Sheet	T	T3	T3K		7000	7300	7319	yes	yes	yes	yes	Sphagnum girgensohnii (di, co, do), Polytrichum commune (di, co, do), Pleurozium schreberi (di, co, do), Bazzania trilobata (di), Hylocomium splendens (di, co, do), Sphagnum russowii (di), Dicranum scoparium (co), Sphagnum recurvum (co, do), Sphagnum capillifolium (do)	
7320	Coniferous plantation of non site-native trees	Fact Sheet	T	T3	T3M		7000	7300	7320	yes	no	yes	yes	Pseudoscleropodium purum (co, do), Polytrichastrum formosum (co), Dicranum scoparium (co)	
7500	Mixed deciduous and coniferous woodland		T	T5			7000	7500		no					
8201	Boreal and arctic siliceous scree and block field		U	U2	U21		8000	8200	8201	yes	Expert judgment without checking EUNIS factsheets				

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	RecMap G1	RecMap G2	RecMap G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
8202	Temperate high-mountain siliceous scree		U	U2	U22		8000	8200	8202	yes	Expert judgment without checking EUNIS factsheets				
8204	Mediterranean siliceous scree		U	U2	U24		8000	8200	8204	yes	Expert judgment without checking EUNIS factsheets				
8205	Boreal and arctic base-rich scree and block field		U	U2	U25		8000	8200	8205	yes	Expert judgment without checking EUNIS factsheets				
8206	Temperate high-mountain base-rich scree and moraine		U	U2	U26		8000	8200	8206	yes	Expert judgment without checking EUNIS factsheets				
8207	Temperate, lowland to montane base-rich scree		U	U2	U27		8000	8200	8207	yes	Expert judgment without checking EUNIS factsheets				
8208	Western Mediterranean base-rich scree		U	U2	U28		8000	8200	8208	yes	Expert judgment without checking EUNIS factsheets				
8209	Eastern Mediterranean base-rich scree		U	U2	U29		8000	8200	8209	yes	Expert judgment without checking EUNIS factsheets				
8210	Crimean base-rich screes		U	U2	U2A		8000	8200	8210	yes	Expert judgment without checking EUNIS factsheets				
8301	Temperate high-mountain siliceous inland cliff		U	U3	U32		8000	8300	8301	yes	Expert judgment without checking EUNIS factsheets				

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	RecMap G1	RecMap G2	RecMap G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
8302	Temperate, lowland to montane siliceous inland cliff		U	U3	U33		8000	8300	8302	yes	Expert judgment without checking EUNIS factsheets				
8303	Mediterranean siliceous inland cliff		U	U3	U34		8000	8300	8303	yes	Expert judgment without checking EUNIS factsheets				
8304	Boreal and arctic base-rich inland cliff		U	U3	U35		8000	8300	8304	yes	Expert judgment without checking EUNIS factsheets				
8305	Temperate high-mountain base-rich inland cliff		U	U3	U36		8000	8300	8305	yes	Expert judgment without checking EUNIS factsheets				
8306	Temperate, lowland to montane base-rich inland cliff		U	U3	U37		8000	8300	8306	yes	Expert judgment without checking EUNIS factsheets				
8307	Mediterranean base-rich inland cliff		U	U3	U38		8000	8300	8307	yes	Expert judgment without checking EUNIS factsheets				
8308	Temperate ultramafic inland cliff		U	U3	U3A		8000	8300	8308	yes	Expert judgment without checking EUNIS factsheets				
8310	Macaronesian inland cliff		U	U3	U3C		8000	8300	8310	yes	Expert judgment without checking EUNIS factsheets				
8311	Wet inland cliff		U	U3	U3D		8000	8300	8311	yes	Expert judgment without checking EUNIS factsheets				
8400	Snow or ice-dominated habitats		U	U4			8000	8400		yes	Expert judgment without checking EUNIS factsheets				
8500	Miscellaneous inland habitats usually with very sparse or no vegetation		U	U5	U52		8000	8500	8500	yes	Expert judgment without checking EUNIS factsheets				

Rec_ID	EUNIS LABEL	EUNIS Factsheet	EUNIS C1	EUNIS C2	EUNIS C3	EUNIS 2012	RecMap G1	RecMap G2	RecMap G3	Indicator species moss/lichen in Level C3					
										Species	diagnostic species	constant species	dominant species	name(s) mosses/liverworts	name(s) lichens (fungi)
8600	Recent volcanic features		U	U6			8000	8600		yes	Expert judgment without checking EUNIS factsheets				

G Annex 7: Assignment of Sensitivity to Ammonia for Wetlands (EUNIS class Q) with the help of descriptions of typical species according to the habitats of the EU Habitats Directive

Table 61 **Assignment of Sensitivity to Ammonia for Wetlands (EUNIS class Q) with the help of descriptions of typical species according to the habitats of the EU Habitats Directive (EIONET, 2018)**

Relationships EUNIS to Annex I: = The revised EUNIS habitat is equal to the Annex I habitat type; **#** The revised EUNIS habitat overlaps with the Annex I habitat type; **<** The revised EUNIS habitat is narrower than the Annex I habitat type; **>** The revised EUNIS habitat is wider than the Annex I habitat type; **blank -** The revised EUNIS habitat is not linked to an Annex I type or is outside EU. No links are given to levels 1 and 2 as these are too numerous; **Italics** - indicate relationships of low importance, in the sense that only a very small part of the Annex I habitat is crosslinked with the EUNIS habitat.

revised EUNIS Code	Revised EUNIS name	relationship EUNIS to Annex I	Annex I code	Annex I name (EU Habitats Directive)	non-vascular plants as typical species (Yes/No)	$Cl_{emp}N$ available	typical species
Q11	Raised bog	#	7110	Active raised bogs	Yes	Q1	Sphagnum compactum, Cladonia arbuscula, Aulacomnium palustre, Calypogeia sphagnicola, Mylia anomala, Polytrichum strictum, Sphagnum angustifolium, Sphagnum fuscum, Sphagnum magellanicum, Sphagnum papillosum, Sphagnum rubellum, Sphagnum tenellum, Kurzia pauciflora, Sphagnum balticum, Sphagnum pulchrum, Sphagnum capillifolium, Odontoschisma sphagni, Cephalozia macrostachya, Warnstorfia fluitans
Q11	Raised bog	>	7120	Degraded raised bogs still capable of natural regeneration	Yes	Q1	Calliergon stramineum, Cephalozia macrostachya, Sphagnum angustifolium, Sphagnum balticum, Sphagnum flexuosum, Sphagnum obtusum, Calypogeia neesiana, Lepidozia reptans, Cephalozia connivens, Cladopodiella fluitans, Gymnocolea inflata, Sphagnum pulchrum, Sphagnum riparium
Q12	Blanket bog	=	7130	Blanket bogs (* if active bog)	Yes	Q1	Sphagnum balticum, Sphagnum fuscum, Sphagnum magellanicum, Sphagnum majus, Sphagnum rubellum, Sphagnum tenellum
Q13	Ombrotrophic percolation mire	*#*	*7110*	*Active raised bogs*	Yes	Q1	See above

revised EUNIS Code	**Revised EUNIS name**	**relationship EUNIS to Annex I**	**Annex I code**	**Annex I name (EU Habitats Directive)**	**non-vascular plants as typical species (Yes/No)**	**$Cl_{emp}N$ available**	**typical species**
Q13	Ombrotrophic percolation mire	#	*7140*	*Transition mires and quaking bogs*	Yes	Q1	Dicranum bergeri , Cinclidium stygium, Cephalozia connivens, Calypogeia sphagnicola, Calliergon giganteum, Brachythecium mildeanum, Kurzia pauciflora, Sphagnum cuspidatum, Sphagnum balticum, Meesia triquetra, Drepanocladus, Warnstorfia fluitans, Calliergon stramineum, Calliergon cordifolium, etc.
Q21	Oceanic valley mire	#	7150	Depressions on peat substrates of the Rhynchosporion	Yes	Q2	See above
Q21	Oceanic valley mire	#	*7140*	*Transition mires and quaking bogs*	Yes	Q2	See above
Q22	Poor fen	#	7140	Transition mires and quaking bogs;	Yes	Q2	See above
Q22	Poor fen	#	7150	Depressions on peat substrates of the Rhynchosporion	Yes	Q2	See above
Q22	Poor fen	#	*7130*	*Aapa mires*	Yes	Q2	Sphagnum balticum, Sphagnum fuscum, Sphagnum magellanicum, Sphagnum majus, Sphagnum rubellum, Sphagnum tenellum
Q23	Relict mire of Mediterranean mountains	#	7140	Transition mires and quaking bogs;	Yes	Q2	See above
Q23	Relict mire of Mediterranean mountains	#	*6160*	*Oro-Iberian Festuca indigesta grasslands;*	No	Q2	
Q23	Relict mire of Mediterranean mountains	#	*6170*	*Alpine and subalpine calcareous grasslands*	Yes	Q2	Cetraria tilesii, Vulpicida tubulosus, Thamnolia vermicularis
Q24	Intermediate fen and soft-water spring mire	#	7140	Transition mires and quaking bogs	Yes	Q2	See above

revised EUNIS Code	Revised EUNIS name	relationship EUNIS to Annex I	Annex I code	Annex I name (EU Habitats Directive)	non-vascular plants as typical species (Yes/No)	$Cl_{emp}N$ available	typical species
Q24	Intermediate fen and soft-water spring mire	#	7150	Depressions on peat substrates of the Rhynchosporion	Yes	Q2	See above
Q24	Intermediate fen and soft-water spring mire	#	7130	Aapa mires	Yes	Q2	Sphagnum balticum, Sphagnum fuscum, Sphagnum magellanicum, Sphagnum majus, Sphagnum rubellum, Sphagnum tenellum
Q24	Intermediate fen and soft-water spring mire	*#*	*7160*	*Fennoscandian mineral-rich springs and springfens*	Yes	Q2	Rhizomnium magnifolium, Rhizomnium pseudopunctatum, Sarmentypnum exannulatum, Sarmentypnum procerum, Sarmentypnum sarmentosum, Scorpidium scorpioides, Sphagnum riparium, etc.
Q25	Non-calcareous quaking mire	#; #	7140	Transition mires and quaking bogs;	Yes	Q2	See above
Q25	Non-calcareous quaking mire	#	7130	Aapa mires	Yes	Q2	Sphagnum balticum, Sphagnum fuscum, Sphagnum magellanicum, Sphagnum majus, Sphagnum rubellum, Sphagnum tenellum
Q31	Palsa mire	=	7320	Palsa mires	Yes	Q3	Cladonia spp., Ochrolechia spp., Tetraphis pellucida
Q41	Alkaline, calcareous, carbonate-rich small-sedge spring fen	<	7230	Alkaline fens	Yes	Q41-Q44	Drepanocladus cossonii, Plagiomnium elatum, Scorpidium turgescens, Cinclidium stygium, Calliergon giganteum, Sphagnum teres, Scorpidium scorpioides, Philonotis calcarea, Palustriella commutata, Fissidens adianthoides, Campylium stellatum, Bryum pseudotriquetrum, Tomentypnum nitens, Aulacomnium palustre, Climacium dendroides, Cratoneuron filicinum, etc
Q42	Extremely rich moss-sedge fen	<	7230	Alkaline fens	Yes	Q41-Q44	See above
Q43	Tall-sedge base-rich fen	#	7210	Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*	Yes	Q41-Q44	Sphagnum contortum, Calliergon cuspidatum,, Plagiomnium elatum, Scorpidium scorpioides, Calliergon giganteum, Calliergon trifarium, Campylium stellatum, Drepanocladus cossonii, Drepanocladus lycopodioides, Fissidens

revised EUNIS Code	Revised EUNIS name	relationship EUNIS to Annex I	Annex I code	Annex I name (EU Habitats Directive)	non-vascular plants as typical species (Yes/No)	$Cl_{emp}N$ available	typical species
							adianthoides, Sphagnum warnstorfii, Sphagnum subnitens, Palustriella commutata etc.
Q43	Tall-sedge base-rich fen	#	*7230*	*Alkaline fens*	Yes	Q41-Q44	See above
Q44	Calcareous quaking mire	#; #	7230; *7140*	Alkaline fens;	Yes	Q41-Q44	See above
Q44	Calcareous quaking mire	#	*7140*	*Transition mires and quaking bogs*	Yes	Q41-Q44	See above
Q45	Arctic-alpine rich fen	=	7240	* Alpine pioneer formations of *Caricion bicoloris-atrofuscae*	Yes	Q45	Campylium stellatum, Drepanocladus cossonii, Bryum pseudotriquetrum, Drepanocladus revolvens
Q46	Carpathian travertine fen with halophytes	<	7230	Alkaline fens	Yes		See above
Q51	Tall-helophyte bed		x	No Annex I type			
Q52	Small-helophyte bed		x	No Annex I type			
Q53	Tall-sedge bed		x	No Annex I type			
Q53	Tall-sedge bed	#	6450	Northern boreal alluvial meadows	No		
Q54	Inland saline or brackish helophyte bed		x	No Annex I type			
Q54	Inland saline or brackish helophyte bed	#	1340	Inland salt meadows	No		
Q61	Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation	#	3270	Rivers with muddy banks with Chenopodion rubri p. p.	No		

revised EUNIS Code	Revised EUNIS name	relationship EUNIS to Annex I	Annex I code	Annex I name (EU Habitats Directive)	non-vascular plants as typical species (Yes/No)	$Cl_{emp}N$ available	typical species
				and Bidention p. p. vegetation;			
Q61	Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation	#	3280	Constantly flowing Mediterranean rivers of the Paspalo-Agrostidion species and hanging curtains of Salix and Populus alba;	No		
Q61	Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation	#	3290	Intermittently flowing Mediterranean rivers of the Paspalo-Agrostidion	No		
Q62	Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation	<	3130	3130 Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoeto-Nanojuncetea	Yes		Aphanorrhegma patens, Archidium alternifolium, Bryum cyclophyllum, Chara delicatula, Chara globularis, Drepanocladus aduncus, Fossombronia wondraczekii, Micromitrium tenerum, Nitella capillaris, Nitella mucronate, Nitella opaca, Nitella syncarpa, Nitella translucens, Phaeoceros carolinianus, Physcomitrium eurystomum, Pohlia bulbifera, Pohlia camptotrachela, Pseudephemerum nitidum, Riccardia chamaedryfolia, Riccia beyrichiana, Riccia canaliculate, Riccia cavernosa, Riccia fluitans, Riccia glauca, Riccia huebeneriana, Ricciocarpos natans, Vaucheria dichotoma, etc.
Q63	Periodically exposed saline shore with pioneer or ephemeral vegetation	#	3170	Mediterranean temporary ponds	No		