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Report No. **197**

Development of Critical Loads for Ireland: Simulating Impacts on Systems (SIOS)

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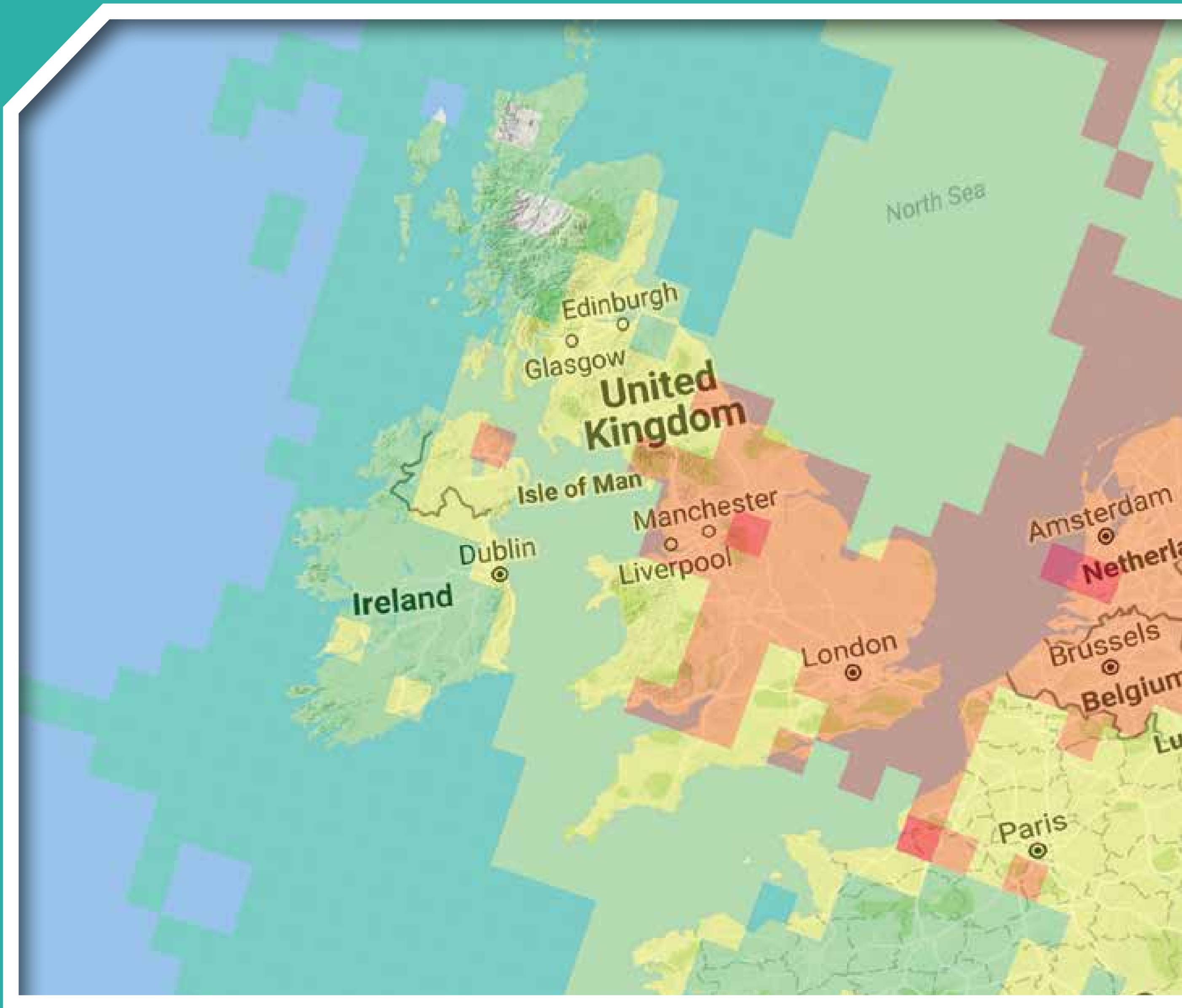

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

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ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

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- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
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- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2014–2020

Development of Critical Loads for Ireland: Simulating Impacts on Systems (SIOS)

(2008-CCRP-4.1a)

EPA Research Report

Prepared for the Environmental Protection Agency

by

Trent University

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The EPA Research Programme addresses the need for research in Ireland to inform policy and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Air pollution can have unacceptable impacts on the natural environment; pollutants, such as sulphur and nitrogen oxides, can travel several hundred or even thousands of kilometres before damage, for example acidification and eutrophication, occurs. Initial efforts to reduce the extent of environmental damage led to national and international legislation aimed at controlling emissions of long-range transboundary air pollution. However, this legislation was generally deficient as it was not established on biological or ecological principles.

Emphasis on a cost-effective abatement strategy, based on scientific criteria, led to the development of the critical loads concept. In simple terms, this concept indicates how much pollutant deposition an ecosystem can tolerate without unacceptable long-term damage. Critical loads are widely used as a tool for assessing the sensitivity of terrestrial and aquatic habitats; exceedance, whereby atmospheric pollutant deposition is greater than the habitat critical load, is used as an indicator of unacceptable effects. The critical loads approach is used under the United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution and the European Union National Emission Ceilings Directive (2001/81/EC) to quantify the impacts of acidifying and eutrophying air pollutant deposition on natural ecosystems, and to guide policy on reducing the environmental impacts of transboundary air pollutants. Under the Convention, each party is obliged to submit national critical loads for natural habitat areas on a regular basis to the Coordination Centre for Effects. In addition, critical loads are widely used by EU Member States to assess the impacts of national policies on the exceedance of critical loads, evaluate the emissions permitting and licensing of industrial and agricultural facilities, and support Appropriate Assessments under Article 6.3 of the Habitats Directive (92/43/EEC).

This report presents results from the EPA-funded research project 2008-CCRP-4.1a, Development of Critical Loads for Ireland. The principal objective of this project was to determine critical loads of acidity and eutrophication for terrestrial and aquatic ecosystems in Ireland. In addition, the project evaluated the potential impacts of nitrogen deposition on plant species diversity in natural grasslands. The project specifically responded to calls for critical load data under the Convention; this report describes the critical load database submitted to the Coordination Centre for Effects in response to the 2011–2012 call for data.

The research outputs directly support international policies under the UNECE Convention and EU Clean Air Policy Package (adopted 18 December 2013):

- The 2012 data submission to the Coordination Centre for Effects estimated critical loads of acidity and eutrophication for natural habitats covering >25% of the land area of Ireland.
- National critical loads are generally consistent with estimates across western and continental Europe; furthermore, there are no border effects between Ireland and the UK (Northern Ireland).
- Areal exceedances of critical loads of acidity are predicted to decrease from 19% in 1990 to 6% in 2020 under the revised Gothenburg Protocol. In contrast, exceedances of critical loads of eutrophication are predicted to increase from 45% in 2000 to 47% in 2020.
- National emissions play a greater role in the exceedance of critical loads of eutrophication than transboundary sources. Therefore, national strategies, such as Food Wise 2025, may lead to increased exceedance.
- Plant species diversity is negatively correlated with nitrogen deposition in semi-natural Irish grasslands, with a loss of one plant species per kilogram of excess nitrogen deposition.

National critical load data have made an important contribution to the abatement of long-range transboundary air pollution; however, critical loads have been virtually ignored under national policy assessments. Therefore, it is recommended that (1) there should be a wider adoption of critical loads in national and international policy assessments (e.g. Article 6.3 of the Habitats Directive); (2) there is a need to build national synergies between the Habitats and Clean Air Directives, given that nitrogen deposition is a serious threat to biodiversity; (3) existing deposition monitoring stations should be augmented to monitor ammonia, the dominant component of nitrogen

deposition, with a view to establishing a long-term nitrogen monitoring network; (4) evidence of the impacts of nitrogen on vegetation across habitats should be collated; (5) the national critical load database should continue to be revised in response to scientific and technical updates; and (6) a national air quality strategy should be developed with the goal of achieving levels of air quality that do not result in unacceptable impacts on human health and the environment.

1 Introduction

1.1 The Effects of Air Pollution on Natural Ecosystems

It is well established that anthropogenic air pollution can have negative impacts on the natural environment, both in terms of direct effects on vegetation and indirectly through effects on the acid and nutrient status of soils and waters (EEA, 2014; WGE, 2014). This report focuses on the effects of sulphur (S) and nitrogen (N) emissions on natural ecosystems. Sulphur and N-containing air pollutants are emitted to the atmosphere primarily as a result of fossil fuel combustion and agricultural activities. These air pollutants can travel several hundred or even thousands of kilometres in the atmosphere before deposition and potential damage, for example acidification and eutrophication, occurs to the environment. As with human health, air quality objectives have been established to protect (or promote) environmental health. The initial efforts to reduce the extent of possible environmental damage led to national and international legislation aimed at controlling emissions of long-range transboundary air pollution (LRTAP). However, this legislation was generally deficient, as it was not established on biological or ecological principles; fixed percentage emission reductions were agreed, irrespective of spatial variation in deposition intensity and ecosystem sensitivity.

1.2 The Critical Loads Concept

Emphasis on cost-effective strategies, based on scientific effects-based criteria, led to the development of the critical loads concept (CLRTAP, 2004; de Vries *et al*., 2015). The concept focuses on the link between atmospheric pollutant deposition and ecosystem response. In principle, it indicates how much pollutant deposition an ecosystem can tolerate before its integrity is compromised. A critical load[1] is defined as "a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt, 1988). Critical loads are widely used as a tool for assessing the sensitivity of terrestrial and aquatic habitats to the harmful effects of airborne pollutants (Hettelingh *et al*., 2007; de Vries *et al*., 2015). Standards expressed in terms of critical loads are derived for habitats, and exceedance of these values, where atmospheric pollutant deposition is greater than the habitat critical load, is used as an indicator of the potential for harmful effects. The critical loads approach is used under the United Nations Economic Commission for Europe (UNECE) Convention on LRTAP and the European Union (EU) National Emission Ceilings (NEC) Directive (2001/81/EC) to quantify the impacts of acidifying and eutrophying air pollutant deposition on ecosystems, and to guide policy on reducing the environmental impacts of transboundary air pollutants, such as S and N oxides. The state of science underpinning critical loads, as well as their use in policy support, is presented in detail in de Vries *et al*. (2015).

1 Critical load relates to the quantity of a pollutant deposited from the atmosphere onto the Earth's surface; in contrast, critical level refers to the gaseous concentration of a pollutant in the atmosphere. A critical level is defined as the "concentration of a pollutant in the atmosphere above which direct adverse effects on receptors occur according to present knowledge". Critical levels are not addressed in this report.

1.3 Convention on Long-range Transboundary Air Pollution

Critical loads have played a central role in the development of effect-based emission reduction strategies under the UNECE Convention on LRTAP. The Convention was the first international legally binding instrument to deal with the problems of air pollution on a broad regional scale. It was signed in 1979, laying down the general principles of international cooperation through an institutional framework, bringing together research and policy (Figure 1.1).

One of the main subsidiary bodies of the Convention is the Working Group on Effects (WGE), which provides information on the degree and geographic extent of the environmental impacts of major air pollutants, such as S and N oxides. Its six International Cooperative Programmes (ICPs) identify the most endangered areas, ecosystems and other receptors by considering damage to terrestrial and aquatic ecosystems. The

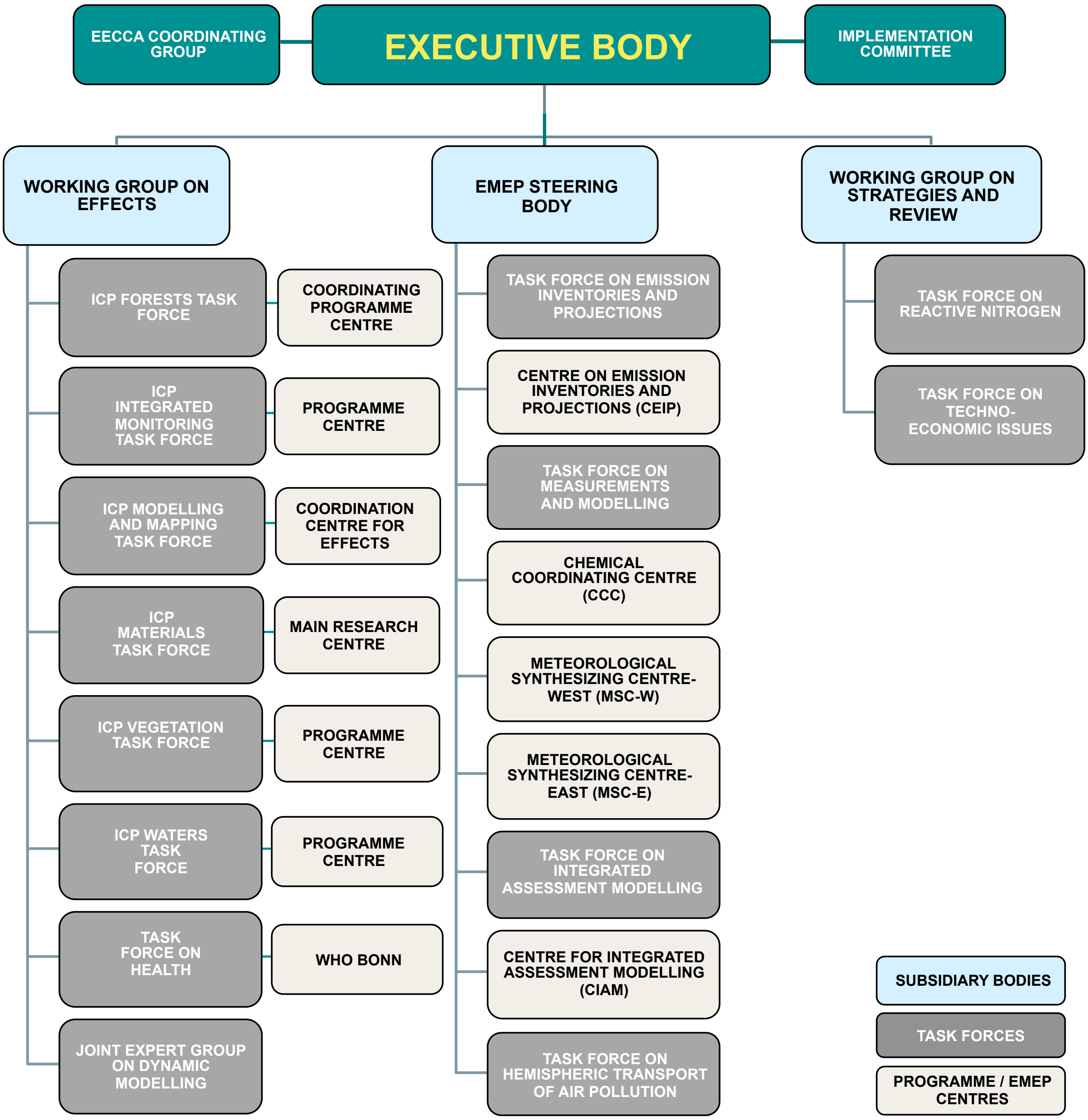


Figure 1.1. The organisational framework of the Convention on Long-range Transboundary Air Pollution. The Executive Body is the governing body of the convention. The Working Group on Strategies and Review is the principal negotiating body for the convention. The Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe provides scientific support in the areas of atmospheric monitoring and modelling; emission inventories and emission projections; and integrated assessment. The Working Group on Effects provides information on the degree and geographic extent of the impacts on human health and the environment of major air pollutants. Its six International Cooperative Programmes and the Task Force on Health identify the most endangered areas, ecosystems and other receptors by considering damage to human health, terrestrial and aquatic ecosystems and materials. Source: www.unece.org/env/lrtap/welcome.html.

work is underpinned by scientific research on dose–response, critical loads and damage evaluation (e.g. ICP Modelling and Mapping, Figure 1.1). A second subsidiary body, the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants [the European Monitoring and Evaluation Programme (EMEP)], provides scientific support to the Convention on atmospheric monitoring and modelling, emission inventories and emission projections, and integrated assessment modelling.

Under the Convention, each party is requested to submit national critical loads for natural habitat areas on a regular basis via their National Focus Centre (NFC) to the Coordination Centre for Effects (CCE; Figure 1.1). The CCE combines these national datasets to produce European-scale critical loads maps (Figure 1.2). For further details see Box 1.1.

These European maps are used to calculate exceedances under modelled deposition fields produced by the EMEP/Meteorological Synthesizing Centre – West (MSC-W) model (Simpson *et al*., 2012), representing a range of potential European emission abatement scenarios to be considered during negotiations supporting the LRTAP Convention.

1.4 Study Objectives and Policy Context

The principal objective of this project was to develop critical loads of acidity and eutrophication for terrestrial and aquatic ecosystems in Ireland. The project built upon the existing national database (Aherne and Farrell, 2000a), incorporating new methodologies and datasets where appropriate. In addition, the project evaluated the potential impacts of N deposition on plant species diversity in natural grasslands. The project specifically responded to calls for critical load data under the LRTAP Convention; this report describes the critical load database submitted to the CCE in response to the 2011–2012 call for data. In addition, the project contributed to the broader development and application of national critical loads, e.g. through provision of water chemistry data to ICP Waters under the Convention, the evaluation of inter-jurisdictional critical loads with the NFC in the UK and discussion of the relevance of N deposition to the Habitats Directive (92/43/EEC) with the National Park and Wildlife Services (NPWS). The project outputs have been published in peer-reviewed journals and presented at international conferences

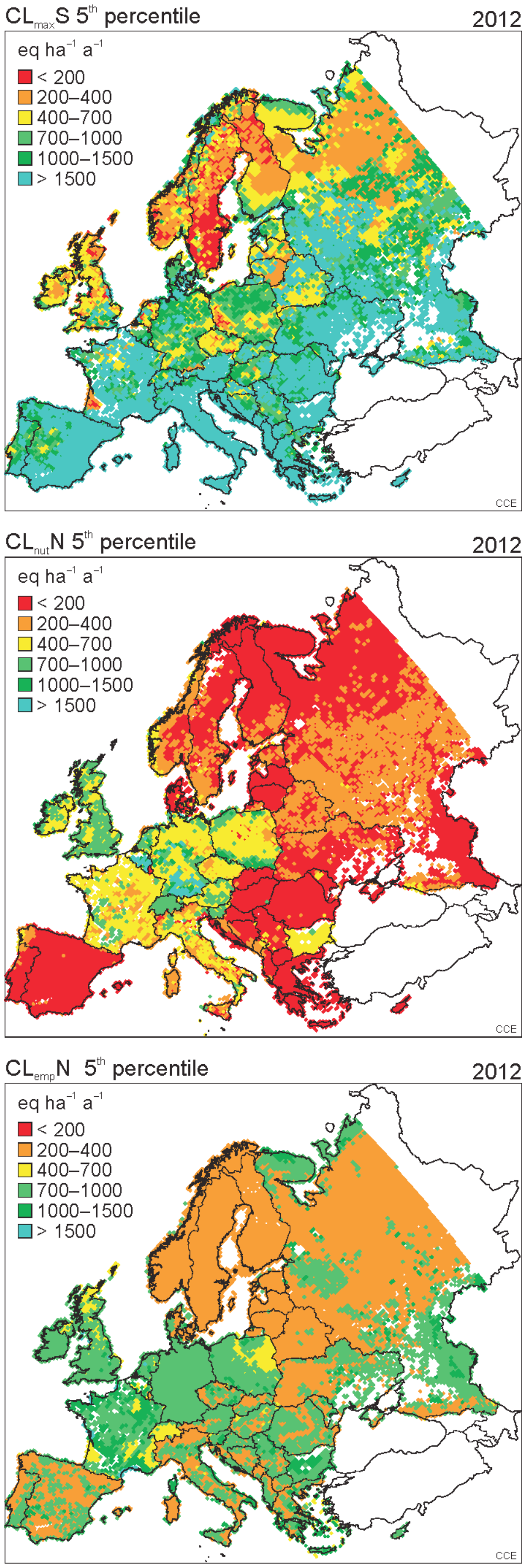


Figure 1.2. Fifth percentile critical loads of acidity (CL$_{max}$S), nutrient nitrogen (CL$_{nut}$N) and empirical nutrient nitrogen (CL$_{emp}$N) produced by the Coordination Centre for Effects following their 2011–2012 call for critical load data (25 km × 25 km grid on the EMEP projection). Source: Posch *et al.* (2012).

Box 1.1. Modelling and mapping of critical loads

Anthropogenic emissions of sulphur (S) and nitrogen (N) oxides result in acidic deposition that can potentially acidify soils and impact vegetation. In addition, N is an essential plant nutrient that is limited in many ecosystems. Elevated N deposition can cause eutrophication, leading to changes in plant community composition and leaching of N into the environment.

Critical loads are widely used to evaluate the potential risks of acidification and eutrophication; a critical load represents the maximum amount of S and N deposition that does not cause harmful effects to natural ecosystems. Where deposition of S and N exceed the critical load there is a risk of damage.

The acidifying impact of S and N deposition defines a critical load function, incorporating the most important biogeochemical processes that affect long-term soil acidification (CLRTAP, 2004). The function is defined by three quantities (see Figure 1.3): the maximum critical load of S ($CL_{max}S$); minimum critical load of N ($CL_{min}N$); and the maximum critical load of N ($CL_{max}N$).

The eutrophying impact of N deposition can be derived from a balance of long-term sources and sinks of N [critical load of nutrient nitrogen ($CL_{nut}N$)], or based on habitat-specific empirical observations of plant diversity change under N deposition [empirical critical load of nutrient nitrogen ($CL_{emp}N$)]. Critical load data are typically reported in the units* of eq (equivalents) $ha^{-1} a^{-1}$.

At the national level, critical loads are determined for numerous ecosystems at multiple locations (100 to > 1000 locations) and typically summarised (and mapped) on the EMEP grid scale (see Figure 1.2). If deposition stays below the minimum critical load value, all ecosystems in an EMEP grid cell are protected. However, to discard outliers, to account for uncertainties in the critical load calculations and to ensure that a sufficient percentage of ecosystems are protected, critical loads are set at the fifth percentile of all critical loads in an EMEP grid (protecting 95% of the ecosystem area in a grid cell).

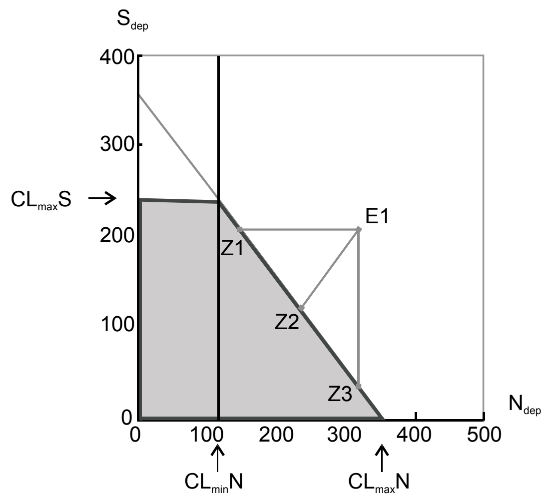


Figure 1.3. Relationship between nitrogen and sulphur acidic deposition and the critical load of acidity; the critical load function. Deposition pairs (N_{dep}, S_{dep}) lying on the function, shown as a thick line, or below in the grey shaded area, do not exceed the critical load. The point E1 denotes acidic deposition of N and S in excess of the critical load function. Reducing N_{dep}, point Z1 is reached and, therefore, non-exceedance without reducing S_{dep}; alternatively non-exceedance can be reached by reducing S_{dep} only (Z3); finally, with a smaller reduction of both S_{dep} and N_{dep} non-exceedance can also be reached (Z2). Source: CLRTAP (2004).

*Empirical critical loads of nutrient nitrogen ($CL_{emp}N$) are often presented in units of kg N $ha^{-1} a^{-1}$; however, consistent units (eq $ha^{-1} a^{-1}$) are used under critical load and exceedance assessments.

(see Appendix 1), submitted to the CCE in response to data calls[2] (see Appendix 2), and the associated databases have been submitted to the Secure Archive For Environmental Research (SAFER)[3] managed by the Environmental Protection Agency (EPA).

Critical loads are used in a policy context to assess the relative benefits of different emissions reduction strategies. Under the LRTAP Convention, critical loads have played a central role in the development of cost-effective effects-based protocols, such as The 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (UNECE, 1999) and its 2012 revision, which was the first multi-pollutant, multi-effect protocol. In addition, critical loads have been used by the EU to support air pollution directives. The EU Thematic Strategy on air pollution under the Framework of the Clean Air For Europe (CAFE) Programme set emission reduction targets for S and N oxides, ammonia (NH_3) and volatile organic compounds, (the NEC Directive) using critical loads. Further, the EU's 7th Environment Action Programme set a target to ensure that by 2020 air pollution and its impacts on ecosystems and biodiversity are further reduced with the long-term aim of not exceeding critical loads.

The outputs of this project directly supported national obligations under the LRTAP Convention and the EU NEC Directive. Nonetheless, there is significant scope for wider adoption of critical loads to support national and European policy: most Member States (excluding Ireland) require Appropriate Assessments under Article 6.3 of the Habitats Directive to incorporate critical loads in the assessment of impacts on Natura 2000 sites.

2 The project responded to two data calls from the CCE: the 2010–2011 call for data announced on 1 November 2010 with a submission date of 7 March 2011 and the 2011–2012 call for data announced on 23 November 2011 with a submission date of 12 March 2012.

3 erc.epa.ie/safer

2 Determination of Critical Loads for Irish Ecosystems

2.1 National Critical Loads

Since 1990, the Irish NFC, coordinated by the EPA[4], has participated in the critical loads mapping programme under the LRTAP Convention (McGettigan, 1992). The first submission of national critical load data was made to the CCE in 1991 (see Irish NFC report in Hettelingh *et al.*, 1991). Update and revision to the national critical loads database was carried out from 1996 to 1999[5] (Aherne and Farrell, 2000a), with minor updates in 2001, 2003 (Aherne, 2003) and 2005 (Aherne, 2007). This project represents the second major update and revision to the national critical loads database, incorporating new spatial information on land cover, soil and sub-soil, a revised spatial description of receptor ecosystems (see Figure 2.1 and Appendix 3), revised nutrient removal in harvested biomass, updated critical loads model parameters and the addition of critical loads for aquatic ecosystems.

Since 1990, the Irish NFC has responded to more than ten calls for critical load data by the CCE[6] under the LRTAP Convention. The last two data submissions, in response to the 2010–2011 and 2011–2012 calls for data, were carried out under the current project; this report describes the national database following the 2011–2012 data submission to the CCE (see Appendix 2). In addition, the data submissions are briefly documented in the CCE status reports (see Posch *et al.*, 2011, 2012). Furthermore, the critical loads and their exceedance (in 1990, 2000 and 2020) are reported in Ireland's Environment 2012 – an Assessment (Lehane and O'Leary, 2012). The 2011–2012 critical load data have also been incorporated into SCAIL Agriculture[7], which is a simple online screening tool for assessing the impact of atmospheric emissions from agricultural sources on semi-natural areas.

In response to the 2011–2012 data call, a database containing approximately 60 variables describing critical loads and the associated model input parameters for natural ecosystems covering more than 25% of Ireland was submitted to the CCE. The data submission included five critical load variables: critical loads of acidity, which is defined by a critical load function composed of three entities[8] (see CLRTAP, 2004), the maximum critical load of S ($CL_{max}S$), the minimum critical load of N ($CL_{min}N$) and the maximum critical load of N ($CL_{max}N$); critical load of nutrient N ($CL_{nut}N$); and empirical critical loads of nutrient N ($CL_{emp}N$), which are defined based on observed or experimentally-induced changes in ecosystems (see Bobbink and Hettelingh, 2011). In contrast, $CL_{nut}N$ is calculated from long-term ecosystem budgets (see Appendix 2 for a detailed description of the data submission). In general, $CL_{nut}N$ and $CL_{emp}N$ are referred to as critical loads of eutrophication ($CL_{eut}N$).

2.2 Modelling and Mapping of Critical Loads

The determination and mapping of critical loads for acidity and eutrophication for Irish ecosystems followed the methods detailed in the "Mapping Manual" published by ICP Modelling and Mapping (CLRTAP, 2004) and documented by de Vries *et al.* (2015). The linking of ecosystem response to deposition levels is the central principle of the critical load approach. For each receptor ecosystem, a biological indicator is chosen, a suitable chemical criterion is selected for that biological indicator and a critical chemical limit is specified, i.e. the desired level of protection. By using appropriate methods, a maximum value of atmospheric deposition (i.e. the critical load) is calculated at which the critical limit will not

4 The Environmental Research Unit coordinated NFC activities between 1990 and 1993.

5 In collaboration with the Forest Ecosystem Research Group, University College Dublin, under the Environmental Monitoring R&D Sub-programme of the Operational Programme for Environmental Services.

6 Data submissions: February 1991, December 1996, March 1997, January 1998, June 1998, June 2001, April 2003, March 2005, May 2007, April 2011 and May 2012. For further details see the Irish NFC reports in the corresponding CCE status reports (available online: wge-cce.org).

7 Simple Calculation of Atmospheric Impact Limits (available online: www.scail.ceh.ac.uk).

8 $CL_{max}S$ is the maximum deposition of S an ecosystem can tolerate assuming all N deposition is zero; similarly, $CL_{max}N$ is the maximum deposition of N an ecosystem can tolerate assuming all S deposition is zero, and $CL_{min}N$ is the minimum removal of N by ecosystem process, i.e. N removal in harvested biomass and immobilisation. These three quantities define the acidity critical load function (see Box 1.1).

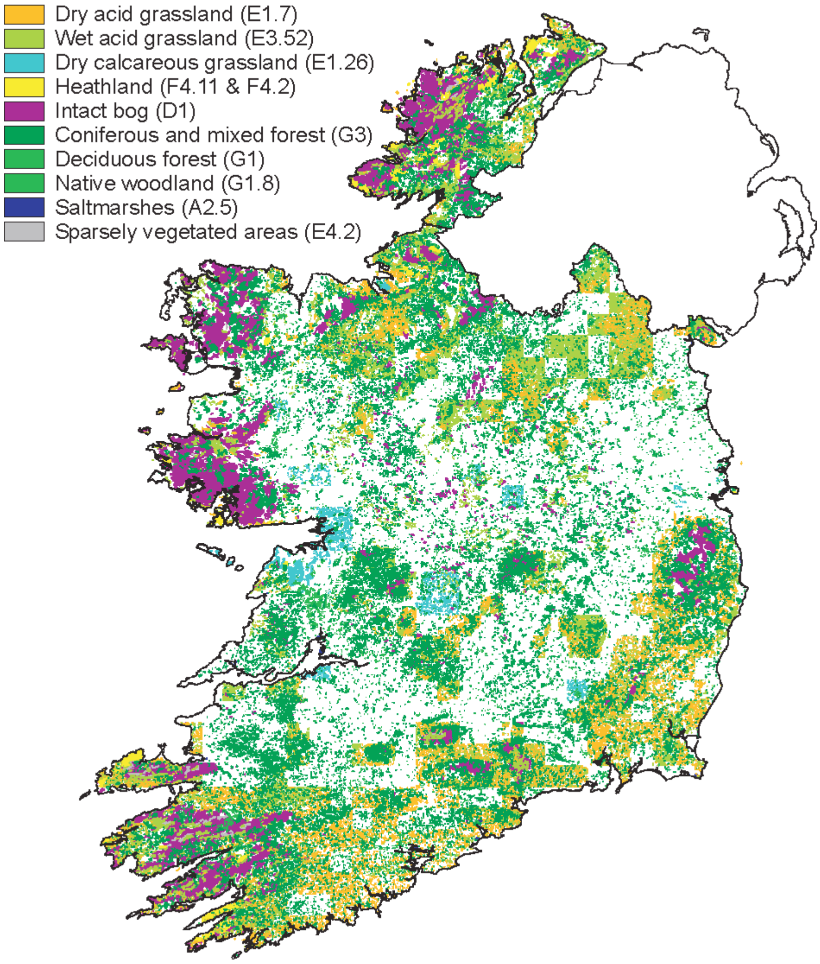


Figure 2.1. Receptor ecosystem map showing the spatial distribution of semi-natural ecosystems for use in long-range transboundary air pollution activities, i.e. determining critical loads. See Table 2.2 for ecosystem areal coverages and Appendix 3 for a detailed description on the mapping procedure. The legend indicates ecosystem name and corresponding European Nature Information System (EUNIS) habitat code. Ecosystem classes were simplified to facilitate visual presentation.

be exceeded. In this way, ecosystem response is linked to atmospheric inputs. An important step is the selection of the chemical criterion and the critical limit (see Table 2.1). In general, critical loads are determined for acid-sensitive nutrient-poor natural (receptor) ecosystems. The 2012 data submission included critical loads of acidity for natural grasslands, heathlands and forest ecosystems covering 12,678 km^2; and critical loads of eutrophication (also included bogs and saltmarshes) covering 17,959 km^2. Critical loads of acidity were also determined for acid-sensitive lake catchments covering 841 km^2 (see Appendix 2).

A national map describing the spatial distribution of receptor ecosystems or habitats for use in effects-based air pollution studies was unavailable. Therefore, a receptor ecosystem map (REM) derived from land cover data in combination with other national data layers, e.g. Coordination of Information on the Environment (CORINE) land cover (CLC), elevation, soil and sub-soil, and plant species richness, was developed for Irish ecosystems (see Appendix 3 for details on the methodology). It is important to note that the resultant map is not a national habitat map, but rather a data layer to support calls for critical load data under the LRTAP Convention. The map is constrained by the quality and resolution of the underlying data, therefore habitat distribution and areal coverage may differ from other national habitat assessments. Moreover, receptor ecosystems were classified according to the EUNIS habitat classification, which is a pan-European system (see Figure 2.1). All ecosystem critical load data submitted to the CCE under the LRTAP Convention are assigned a EUNIS class (see Appendix 2); further, empirical critical loads of nutrient N are structured following the EUNIS

Table 2.1. Links between air pollution impacts, ecological responses, chemical indicators, critical limits and the indicators of exceedance for terrestrial ecosystems

Impact	Ecological response	Indicator	Critical limits	Indicator of exceedance
Acidification	Decreased forest growth; increased susceptibility to disease; decreased soil nutrient status; loss of soil structural integrity; increased export of toxic metals	Molar Bc:Al or molar Ca:Al ratios	<1	Damage to plant fine roots
		Soil solution Al^{3+} concentration	$<0.2\,eq\,m^{-3}$	Damage to plant fine roots
		Soil solution pH	≤ 4.2	Mobilisation of toxic metals and damage to plant roots
		Al mobilisation	$<2\,eq\,eq^{-1}$	Depletion of secondary Al phases and soil structural changes
		Soil base saturation	$<10\%$	Soil acid status and nutrient deficiencies
Nutrient enrichment	Nutrient imbalances; elevated nitrogen leaching; loss of sensitive plant species; increase in invasive plants; increased tree mortality	Nitrogen leaching	$<0.2\,mg\,N\,L^{-1}$	Elevated NO_3^- leaching, nutrient imbalances and vegetation changes
		Nitrogen deposition	$>5–20\,kg\,N\,ha^{-1}\,a^{-1}$	Shift in plant species composition (see Table 2.2)

Ecological thresholds are typical values that vary depending on ecological and environmental conditions, and desired level of protection (for further discussion see de Vries *et al.*, 2015).

Al, aluminium; Bc, base cation; Ca, calcium; NO_3^-, nitrate.

classification (see Table 2.2) as described in Bobbink and Hettelingh (2011).

Critical loads of acidity ($CL_{max}S$, $CL_{min}N$ and $CL_{max}N$) were estimated using the Steady-State Mass Balance (SSMB) model for terrestrial ecosystems (EUNIS habitats E, F and G), and the First-order Acidity Balance (FAB) model for aquatic ecosystems (EUNIS habitat C) following CLRTAP (2004). Similarly, a mass balance approach for nutrient N ($CL_{nut}N$) was applied to managed forest habitats (EUNIS G1, G3.1 and G4.6). Further, empirical critical loads of nutrient N were defined for all mapped terrestrial ecosystems (see Table 2.2; EUNIS habitats A, D, E, F and G) following Bobbink and Hettelingh (2011). A pH level of 4.2 was selected as the acidity critical chemical criterion for terrestrial ecosystems, a variable acid neutralising capacity limit (ANC_{limit}) was used for aquatic ecosystems to account for the concentration of total organic carbon (as described in Curtis *et al.*, 2015) and an acceptable N leaching concentration of $0.3\,mg\,N\,L^{-1}$ was set as the nutrient criterion to avoid imbalance in forests (see Table 2.1 and Appendix 2 for further details). Empirical critical loads of nutrient N for Irish ecosystems were set based on available literature (e.g. Emmett *et al.*, 2011; Hall *et al.*, 2011; Stevens *et al.*, 2011) or as the mid-point of the recommended range (see Table 2.2). Under the Convention, critical load data are generally presented and displayed on the EMEP projection[9], which is a polar-stereographic projection with a cell size of 50 km × 50 km used by the EMEP/MSC-W atmospheric deposition model. The many critical load data within each EMEP cell (i.e. 50 km × 50 km) are typically summarised to ensure that the critical load will protect 95% of the receptor ecosystem area, i.e. the critical load for each grid is set at the 5th percentile of the cumulative distribution function of all critical load data weighted by their ecosystem area (see Figure 1.2). The 2011–2012 data call requested national critical load data on a 5 km × 5 km grid, i.e. a sub-grid of the EMEP 50 km × 50 km grid, to allow assessment of exceedance under higher resolution EMEP/MSC-W dispersion modelling (see Box 1.1 for further description of the critical loads concept).

2.3 Atmospheric Deposition of Sulphur and Nitrogen

Exceedance of critical loads, where atmospheric deposition of S and N is in excess of the ecosystem critical load, is used as an indicator of the long-term harmful effects of air pollution to natural ecosystems.

9 The EMEP/MSC-W model has now moved to a longitude–latitude projection with a grid cell-size of 0.50° × 0.25°; during 2014 the CCE issued a call for data to convert existing national critical loads to a 0.10° × 0.05° longitude–latitude grid.

Table 2.2. European Nature Information System (EUNIS) code, receptor ecosystems, mapped ecosystem area (km²) and percent of total terrestrial area (based on a land mass of 69,438.45 km²) used for critical loads (see Figure 2.1 and Appendix 3), recommended range for critical load of empirical nutrient nitrogen (following Bobbink and Hettelingh, 2011), selected empirical critical loads of nutrient nitrogen for Irish ecosystems and indicators of exceedance

EUNIS code	Receptor ecosystem	Area[a] km² (%)	Range kg N ha^{-1} a^{-1}	$CL_{emp}N$[b]	Indicator of exceedance[c]
A2.5	Saltmarshes	18.1 (0.03)	20–30	25	Increase in dominance of graminoids
D1	Raised and blanket bogs (intact)[d]	5158.4 (7.43)	5–10	10	Increase in vascular plants, altered species composition
E1.26	Sub-Atlantic semi-dry calcareous grassland	360.4 (0.52)	15–25	20	Decline in diversity, increase in mineralisation and N leaching
E1.7	Non-Mediterranean dry acid and neutral closed grassland	3383.8 (4.87)	10–15	10	Increase in graminoids and decrease in species richness
E3.52	Moist and wet oligotrophic grasslands	3261.8 (4.70)	10–20	15	Increase in tall graminoids and decreased diversity
E4.2	Moss and lichen-dominated mountain summits	66.7 (0.10)	5–10	7.5	Effects upon diversity of bryophytes and lichens
F4.11	Northern wet heath	333.4 (0.48)	10–20	15	Transition from heather to grass dominance
F4.2	Dry heath	25.8 (0.04)	10–20	15	As above
G1	Broadleaved deciduous woodland[e]	1459.0 (2.10)	10–20	15	Changes in soil processes, altered ground vegetation
G1.8	Acidophilous *Quercus*-dominated woodland	34.2 (0.05)	10–15	12.5	As above
G3.1	Coniferous forest (managed)	2675.7 (5.42)	10–15	12.5	Changes in soil processes, altered ground vegetation
G4.6	Mixed forest (managed)	1086.3 (2.20)	10–20	15	As above

[a]Total mapped ecosystem area is 19391 km² (28% of the terrestrial area of Ireland).

[b]The empirical critical loads of nutrient nitrogen for Irish ecosystems were selected based on available literature or as the mid-point of the recommended range.

[c]Indicator of exceedance of critical load following Hall *et al.* (2011).

[d]Composed of < 1% raised bogs.

[e]Native and managed.

As noted above, under the LRTAP Convention the deposition of total S and N is taken from the multi-layer Eulerian EMEP/MSC-W model[10] (Tarrasón *et al.*, 2003; Simpson *et al.*, 2012), which consists of relationships (source–receptor matrices) between European country emissions and specific ecosystems (e.g. forests and semi-natural vegetation) at a 50 km × 50 km grid resolution covering Europe. Prior to 2010, historical country-specific emissions were used (see Schöpp *et al.*, 2003, for data sources prior to 1990), whereas for 2020 emissions used are those agreed in May 2012 under the revision of the Gothenburg Protocol. It should be noted that there will be differences between the modelled EMEP deposition data and estimates based on nationally derived deposition observations, which may be available at a finer spatial resolution and generated by different models.

There have been significant decreases in the deposition of atmospheric S and N during the last two decades (see Aherne *et al.*, 2014), most notably for S. During 1990, modelled S deposition was > 1000 mg S m^{-2} a^{-1} in some regions and, in 2020, all EMEP 50 km × 50 km grids are predicted to receive < 400 mg S m^{-2} a^{-1} under the revised Gothenburg Protocol (Figure 2.2, top row). Similarly, oxidised N is predicted to greatly decrease from a dominant regional grid average of 250–300 mg N m^{-2} a^{-1} in 1990 to 150–200 mg N m^{-2} a^{-1} in 2020 under the revised

10 For further details on the EMEP/MSC-W model, including model versions and updated model predictions under revised emissions inventories, see www.emep.int/mscw

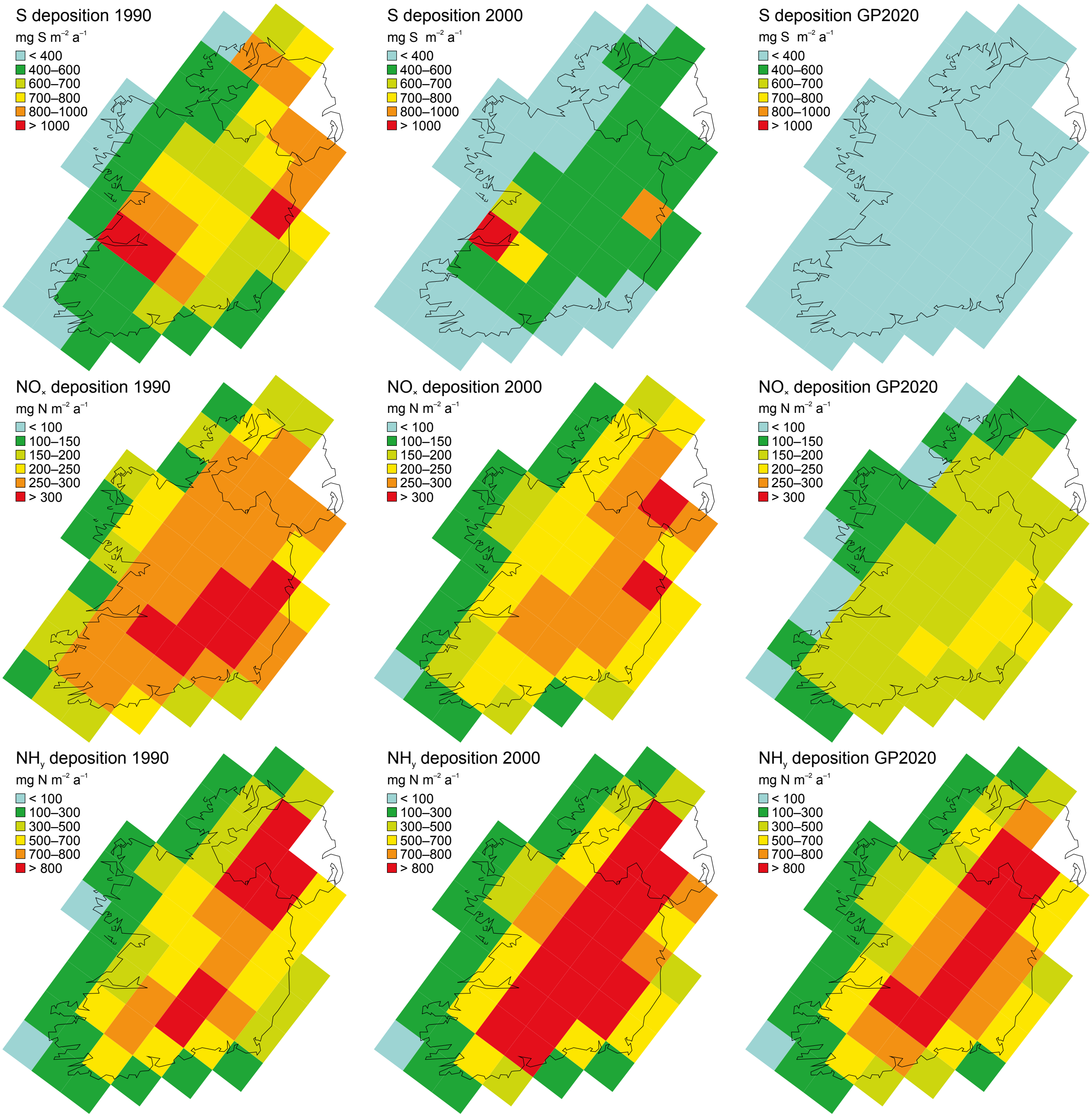


Figure 2.2. Modelled total sulphur (S), oxidised nitrogen (NO_x) and reduced nitrogen (NH_y) deposition for average land cover in 1990, 2000 and 2020 under the revised Gothenburg Protocol (GP2020) on the 50 km × 50 km EMEP grid from the EMEP/MSC-W chemical transport model. For further information see Simpson *et al.* (2012) or online (www.emep.int).

Gothenburg Protocol (Figure 2.2, middle row). In contrast, reduced nitrogen (NH_y) has stayed relatively static, and while deposition is generally predicted to decrease between 2000 and 2020, deposition to the south-east of Ireland is predicted to increase (Figure 2.2, bottom row). Furthermore, N deposition is strongly dominated by NH_y during all periods, i.e. NH_y ranged from 1.8 to 2.6 times the deposition of nitrogen oxides (NO_x).

The exceedance of critical loads is presented as the average accumulated exceedance (AAE), estimated by multiplying exceedance by the respective ecosystem area, summing within each grid cell to yield accumulated exceedance (zero for non-exceedance) and dividing by the total mapped ecosystem area within the grid cell to give the AAE (for further details, see CLRTAP, 2004). It is important to note that while critical load data were

Table 2.3. Statistical summaries for the 5th percentile maximum critical load of sulphur, critical load of nutrient nitrogen, empirical critical load of nutrient nitrogen and exceedance during 1990, 2000 and 2020 under EMEP deposition (see Figure 2.2) for terrestrial ecosystems (and terrestrial and aquatic ecosystems for the maximum critical load of sulphur)

Parameter	Year	$CL_{max}S$[a]	$CL_{nut}N$	$CL_{emp}N$
Ecosystem area (km^2)		12678.2 (13519.2)	5256.7	17958.8
Average critical load ($eq\,ha^{-1}\,a^{-1}$)[b]		787.4 (802.6)	828.0	743.6
Average accumulated exceedance ($eq\,ha^{-1}\,a^{-1}$)[b]	1990	64.2 (63.5)	64.4	16.8
	2000	38.6 (38.5)	113.9	46.0
	2020	9.3 (9.5)	133.0	35.9
Exceeded ecosystem area (km^2)	1990	2410.0 (2573.1)	1845.4	3828.1
	2000	1814.2 (1890.8)	2345.9	5028.6
	2020	779.8 (810.1)	2487.6	4393.9
Exceeded ecosystem area (% of mapped area)	1990	19.0 (19.0)	35.1	21.3
	2000	14.3 (14.0)	44.6	28.0
	2020	6.2 (6.0)	47.3	24.5

[a]Exceedance refers to the average accumulated exceedance for critical loads of acidity (see Figure 2.5) and not exceeedence with respect to sulphur only.

[b]Average of the 5th percentile of critical loads.

submitted at a 5 km × 5 km grid resolution in response to the 2011–2012 data call, exceedance is estimated using deposition on a 50 km × 50 km grid, i.e. each 5 km × 5 km sub-grid cell within the larger 50 km × 50 km grid cell receives the same deposition.

2.4 Critical Loads and Exceedances of Acidity (Sulphur and Nitrogen)

The 5th percentile of $CL_{max}S$[11] for terrestrial and aquatic ecosystems (i.e. critical load to protect 95% of the receptor ecosystem area in a grid cell) ranged from approximately 215 to approximately 4900 $eq\,ha^{-1}\,a^{-1}$; the average $CL_{max}S$ was 802.6 $eq\,ha^{-1}\,a^{-1}$ (Table 2.3 and Figure 2.3). The lowest values were observed in the eastern and central regions as a result of lower critical ANC leaching (see Appendix 2 and Aherne *et al.*, 2001). In general, critical loads of acidity (i.e. $CL_{max}S$) for Irish ecosystems are broadly similar to ecosystems across western and central Europe (see Figure 1.2; Posch *et al.*, 2012); furthermore, $CL_{max}S$ values are consistent in magnitude and spatial variation across Ireland and the UK. It is important to note that the mapped receptor ecosystems do not occupy the entire grid area. The average mapped ecosystem area for $CL_{max}S$ within each EMEP 5 km × 5 km grid square was 4.15 km^2 (16.6% of the grid area; range 0.01–84.16%). The total mapped area of 13,519 km^2 (Table 2.3) was dominated by natural grasslands (51.6%) and forests (39.6%). As already noted, critical load of acidity for aquatic ecosystems (lake catchments) were an addition to the 2012 data submission (not submitted since 1999); however, lakes only represent 6% of the mapped receptor ecosystems (based on catchment area). Aquatic critical loads of acidity were weighted towards acid sensitive lakes[12] (Aherne *et al.*, 2002; Aherne and Curtis, 2003; Aherne *et al.*, 2014); nonetheless, they had limited influence on the average 5th percentile of $CL_{max}S$, which increased from 787.4 $eq\,ha^{-1}\,a^{-1}$ excluding lakes to 802.6 $eq\,ha^{-1}\,a^{-1}$ including lakes (Table 2.3). The spatial variation and magnitude of $CL_{max}S$ for aquatic ecosystems are broadly similar to other jurisdictions in

11 Critical loads of acidity are defined by a critical load function composed of three entities; the maximum critical load of S ($CL_{max}S$), the minimum critical load of N ($CL_{min}N$) and the maximum critical load of N ($CL_{max}N$). For simplicity only $CL_{max}S$ is presented.

12 During 1997, a survey of upland headwater lakes (n = 200) was carried out in predominantly acid-sensitive coastal regions of Ireland; site selection was pseudo-randomly weighted on acid-sensitive regions based on mapped soil characteristics and bedrock geology. A sub-set of these lakes (n = 139) were re-sampled during 2007 and 2008 (Burton and Aherne, 2012; Aherne *et al.*, 2015). In addition, the data submission included “acid lakes” routinely sampled by the Irish EPA under the Water Framework Directive monitoring programme (n = 41) and other national monitoring programmes (n = 41). All lakes (n = 221) were sampled for water chemistry at least once during the period 2000 to 2010.

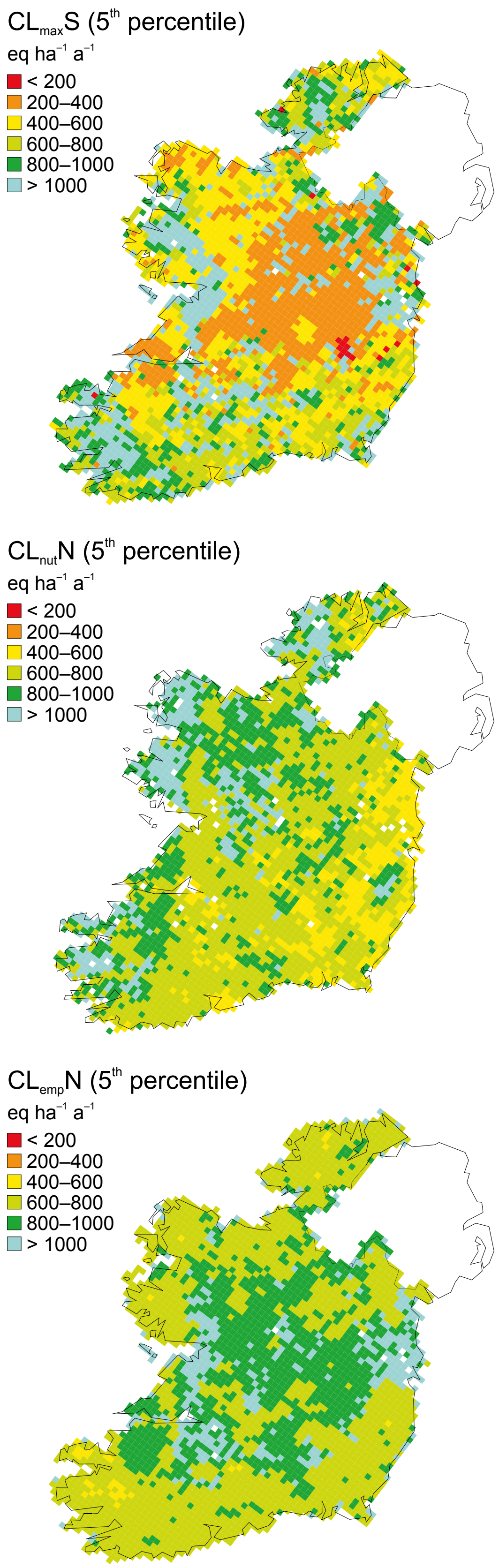


Figure 2.3. Fifth percentile of the maximum critical loads of sulphur ($CL_{max}S$), critical loads of nutrient nitrogen ($CL_{nut}N$) and critical loads of empirical nitrogen ($CL_{emp}N$) submitted to the Coordination Centre for Effects in 2012 (Posch *et al.*, 2012).

northern Europe (see Figure 2.4); further, there were no border effects (or discontinuities) between Ireland and the UK (Northern Ireland).

The areal exceedance of acidity for terrestrial and aquatic ecosystems is predicted to decrease from 2573 km^2 (19% of mapped ecosystems) during 1990 to 1891 km^2 (14%) in 2000 and to 810 km^2 (6%) in 2020 under the revised Gothenburg Protocol (see Table 2.3 and Figure 2.5). The overall AAE was predicted to decrease from 38.5 eq ha^{-1} a^{-1} in 2000 to 9.5 eq ha^{-1} a^{-1} in 2020 under the Gothenburg Protocol, indicating a low magnitude of exceedance across the eastern and south-eastern portion of Ireland (Figure 2.5). The predicted reductions in exceedance are primarily a result of the decrease in S deposition (Figure 2.2). The proportion of lakes with exceedance of acidity decreased from 30.8% in 1980 to 14.9% in 2020 under the Gothenburg Protocol, with the majority of exceedance in 2020 driven by N deposition (see Curtis *et al.*, 2015); nonetheless the pattern of exceedance is broadly similar to other European countries, which is notable given the weighting towards acid sensitive lakes in Ireland (Figure 2.4).

2.5 Critical Loads and Exceedances of Nutrient Nitrogen (Mass Balance and Empirical)

Critical loads of eutrophication were estimated using a nutrient mass balance for managed forest ecosystems ($CL_{nut}N$) covering 5257 km^2 and an empirical approach for nutrient N ($CL_{emp}N$) for all other habitats (see Table 2.2) covering 17,959 km^2 (Table 2.3). The 5th percentile $CL_{nut}N$ for managed forest ecosystems ranged from <450 to >2000 eq ha^{-1} a^{-1} (Figure 2.3), with an overall average of 828 eq ha^{-1} a^{-1} (Table 2.3). The lowest values (400–600 eq ha^{-1} a^{-1}) were predominantly along the east of the country (Figure 2.3). In general, 5th percentile $CL_{nut}N$ values were similar to levels in western and central Europe (see Figure 1.2; Posch *et al.*, 2012). Notably, previous data submissions had lower $CL_{nut}N$ for Ireland compared with the UK (Posch *et al.*, 2011, 2012). The differences were primarily a result of parametric and methodological preferences, i.e. previous $CL_{nut}N$ data submissions for Ireland (e.g. 2008 and 2011) closely followed recommendations in the Mapping Manual (CLRTAP, 2004) using 0.5 kg N ha^{-1} a^{-1} for soil immobilisation and a denitrification fraction (based on soil drainage); in contrast, the UK uses higher fixed values for N immobilisation and denitrification (see Hall *et al.*,

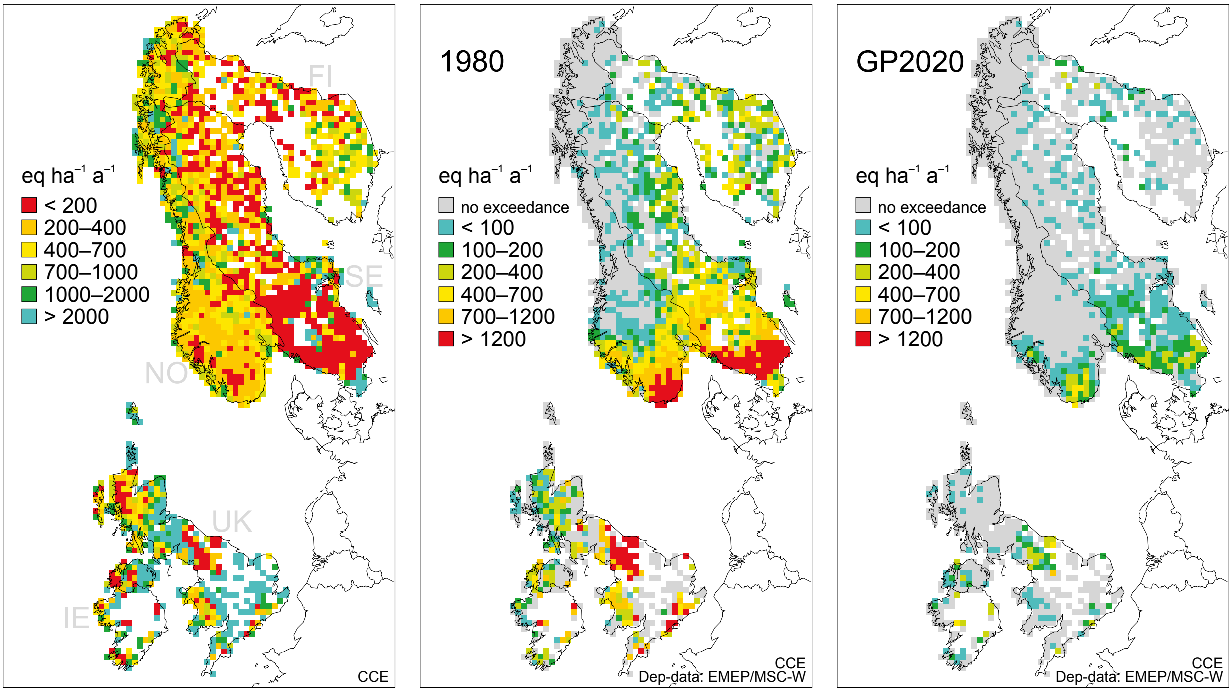


Figure 2.4. The fifth percentile of the maximum critical loads of sulphur for surface waters (left) and the exceedance of acidity under modelled total sulphur and nitrogen deposition during 1980 (centre) and 2020 (right) under the revised Gothenburg Protocol (GP2020) on the 25 km × 25 km EMEP grid across five European countries [Finland (FI), Ireland (IE), Norway (NO), Sweden (SE) and the United Kingdom (UK)] (after Curtis *et al.*, 2015). In Ireland, surface water observations focused on acid sensitive regions (2012 data submission); in contrast, other countries, such as Norway, sampled surface waters in every grid square.

1998)[13]. The 2012 data submission (see Appendix 2) incorporated revised N immobilisation values, which reverted back to previous values of 3 kg N $ha^{-1}a^{-1}$ for podzols and histosols and 1 kg N $ha^{-1}a^{-1}$ for all other soils (Aherne and Farrell, 2000a).

The 5th percentile $CL_{emp}N$ ranged from <550 to >1400 eq $ha^{-1}a^{-1}$ (Figure 2.3), with an overall average of 743.6 eq $ha^{-1}a^{-1}$ (Table 2.3). Despite differences in habitat types (managed forests compared with all habitats) and approaches for $CL_{nut}N$ and $CL_{emp}N$, the distribution of critical loads was quite similar (Figure 2.6). Empirical critical loads are discrete values for a habitat type (i.e. not varying within a habitat, see Table 2.2); nonetheless, $CL_{nut}N$ and $CL_{emp}N$ had similar distributions despite the greater coverage of ecosystems under $CL_{emp}N$ (average mapped ecosystem area within the 5 km × 5 km grids was 0.71 km^2 for $CL_{nut}N$ compared with 5.47 km^2 for $CL_{emp}N$). Furthermore, as with $CL_{nut}N$, $CL_{emp}N$ values were similar to levels in western and central Europe and showed no obvious border discontinuities with Northern Ireland (see Figure 1.2 and Posch *et al.*, 2012).

The areal exceedance of critical loads of eutrophication show a different temporal pattern compared with acidity. The areal exceedance of $CL_{nut}N$ increased from 1845 km^2 (35.1%) in 1990 to 2346 km^2 (44.6%) in 2000, and is predicted to further increase to 2488 km^2 (47.3%) in 2020 under the Gothenburg Protocol (Table 2.3 and Figure 2.5). The AAE is predicted to increase from 113.9 eq $ha^{-1}a^{-1}$ in 2000 to 133.0 eq $ha^{-1}a^{-1}$ in 2020 under the Gothenburg Protocol, indicating larger magnitude and greater areal exceedance (Table 2.3). Despite reductions in oxidised and reduced N, primarily in the midlands (Figure 2.2), an increase in reduced N is predicted along the east and south coast under the Gothenburg Protocol (coinciding with the region of lowest $CL_{nut}N$) resulting in increased exceedance (Figure 2.5). Similarly, areal exceedance of $CL_{emp}N$ increased from 3828 km^2 (21.3%) in 1990 to 5029 km^2 (28.0%) in 2000, and is predicted to decrease slightly

13 Inter-jurisdictional critical loads between Ireland and the UK were evaluated during several bilateral meetings with the UK NFC (Dublin 2010, Wales 2011, and the Netherlands 2011).

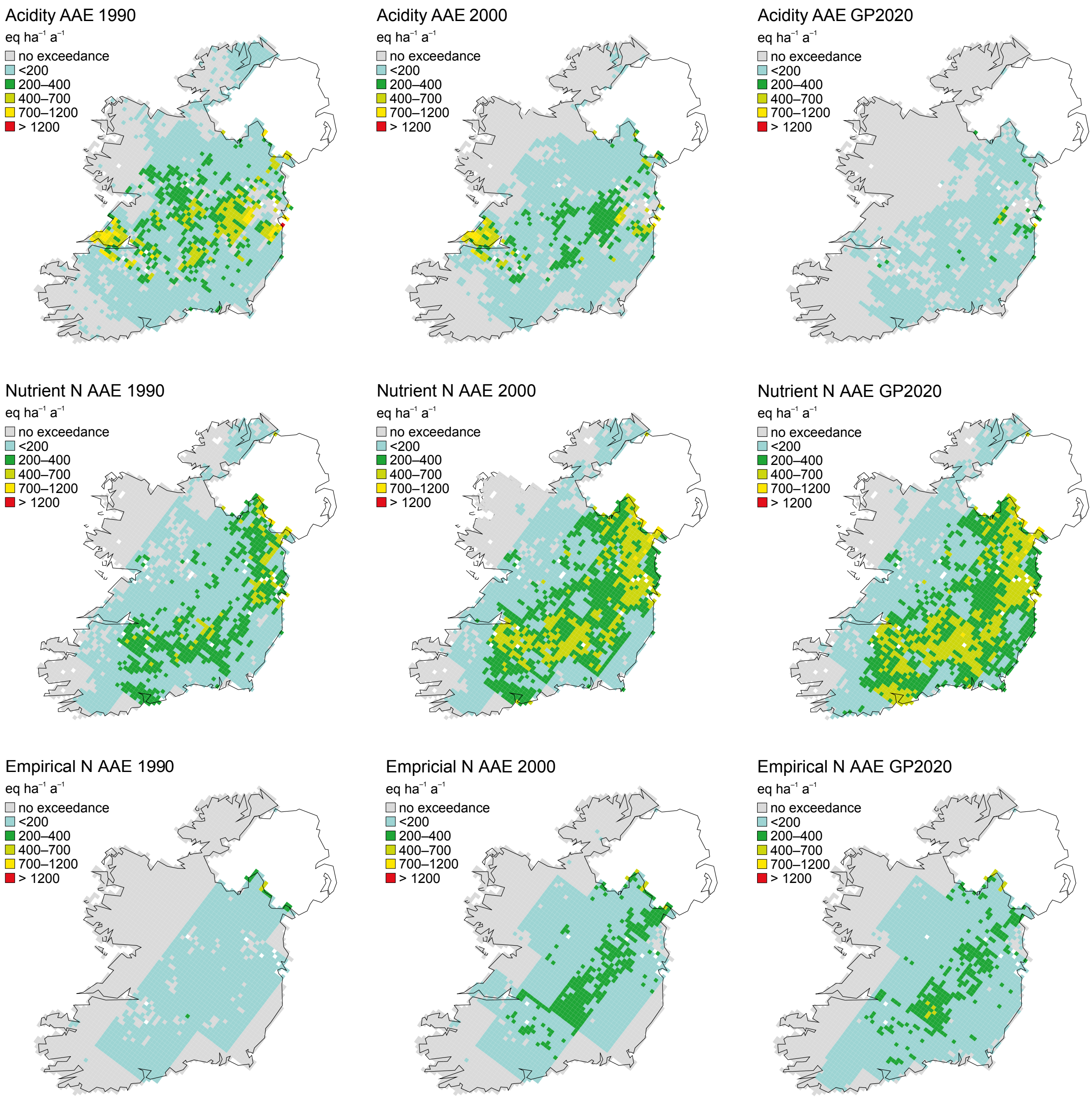


Figure 2.5. Average accumulated exceedance (AEE) on the 5 km × 5 km EMEP grid of critical loads of (from top to bottom): acidity, nutrient nitrogen and empirical nitrogen under modelled total sulphur and nitrogen deposition during 1990, 2000 and 2020 under the revised Gothenburg Protocol (GP2020). The figure shows areas where critical loads on the 5 km × 5 km EMEP grid (2011–2012 data submission, see Figure 2.2) are exceeded (units: eq ha^{-1} a^{-1}) by deposition on the 50 km × 50 km EMEP grid (see Figure 2.1). Note: during GP2020, areal exceedance of nutrient and empirical N increased in the coastal areas along the south and south-east.

to 4394 km^2 (24.5%) in 2020 under the Gothenburg Protocol (Table 2.3). Nonetheless, an increase in areal exceedance was predicted in the east and south under the Gothenburg Protocol (Figure 2.5), despite the overall reduced areal exceedance (owing to reduced exceedance predicted in the west and central regions). Furthermore, it is important to note that predicted deposition in 2020 is based on the revised Gothenburg Protocol and does not consider national policies and strategies in the interim that may influence N emissions (and deposition).

As noted above, N deposition is dominated by NH_y (see Figure 2.2), as a result of high national NH_3 emissions. Agriculture is the dominant source of NH_3 emissions in Ireland (98%), with approximately 80% from the dairy

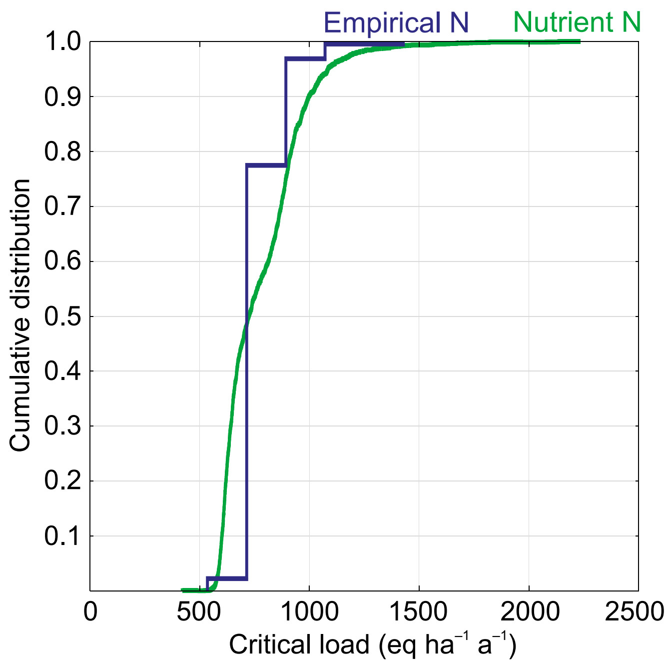


Figure 2.6. Area-weighted cumulative distribution functions of the 5th percentile of critical loads of nutrient nitrogen and critical loads of empirical nitrogen.

and beef sectors (EPA, 2012), specifically 47% from animal housing and storage and 34% associated with land spreading of slurries and manures. Therefore, exceedance of critical loads of eutrophication is predominantly influenced by national rather than long-range transboundary emissions sources. National strategies such as Food Wise 2025[14] set out a vision for the development of the agri-food sector over the next decade. This growth will ultimately lead to increased NH_3 emissions associated with increased livestock numbers, e.g. dairy cow numbers may increase by up to 30% under the strategy. In the absence of greater (national and international) emission controls, exceedance of critical loads of eutrophication from atmospheric N deposition may potentially increase, leading to changes in plant species diversity (see Tables 2.1 and 2.2). In general, many parties to the LRTAP Convention use critical loads to evaluate the impact of national and European policies on natural ecosystems, e.g. many EU Member States (excluding Ireland) use critical loads to evaluate the impacts of emissions from pig and poultry facilities on Natura 2000 sites under Article 6.3 of the Habitats Directive (see Whitfield and McIntosh, 2014). There is considerable scope for the integration of critical loads into national policy assessments.

14 For further details see www.agriculture.gov.ie/foodwise2025

3 Nitrogen Deposition and Plant Species Diversity

3.1 Assessment of Semi-Natural Grasslands

Global emissions of N from agricultural and industrial activities have dramatically increased during the last two centuries, leading to an increase in N deposition to semi-natural ecosystems (Galloway *et al*., 2003, 2004). As a consequence, there are growing concerns that chronically elevated N deposition to terrestrial ecosystems will cause soil acidification and a decrease in plant species diversity (Bobbink *et al*., 1998, 2010; Bobbink and Hettelingh, 2011; EC, 2013). A growing number of studies have focused on impacts on biodiversity in grassland habitats; deposition gradient studies have shown a significant negative relationship between N deposition and plant species diversity on a regional, national (Maskell *et al*., 2010; Power and Collins, 2010; Stevens *et al*., 2004) and continental (Stevens *et al*., 2010) scale. To assess the potential influence of N deposition on plant species diversity in Irish grasslands, a gradient study was conducted using relevé (vegetation plot) data obtained from the NPWS. A high spatial resolution map of N deposition (5 km × 5 km grid), compared with EMEP (50 km × 50 km grid), was developed for Ireland to evaluate the relationship between deposition and site-specific plant species diversity. Site, climate and soil characteristics were also evaluated to determine if these variables had an influence on plant species diversity.

3.2 Plant Species and Deposition Data

A survey of plant species abundance in semi-natural grasslands was coordinated by the NPWS between 2007 and 2012, with field observations and analysis carried out by Botanical, Environmental & Conservation (BEC) Consultants Ltd. The overall purpose of the survey was to spatially identify semi-natural grassland habitats and to identify dominant plant species and plant composition for different grassland types (e.g. acid grasslands and neutral-calcareous grasslands) (O'Neill *et al*., 2010, 2013). Plant relevé data surveyed between 2007 to 2010 (n = 3055) were obtained from the NPWS; the database also included median grass (graminoid) height, topsoil pH and organic matter content in the 0–10 cm soil layer [estimated as loss-on-ignition (LOI)]; for further details see Martin *et al*. (2007, 2008) and O'Neill *et al*. (2009, 2010, 2013).

Plant relevés were classified as acid or neutral-calcareous grasslands based on habitat identifier species; acid grassland identifier species were selected from O'Neill *et al*. (2009): *Agrostis capillaris, Danthonia decumbens, Festuca ovina, Galium saxatile, Hylocomium splendens, Luzula multiflora, Molinia caerulea, Nardus stricta, Potentilla erecta* and *Thuidium tamariscinum*. Similarly, neutral-calcareous grassland identifier species were selected from O'Neill *et al*. (2010): *Carex flacca, Centaurea nigra, Dactylis glomerata, Euphrasia officinalis agg., Festuca rubra, Galium verum, Lotus corniculatus, Plantago lanceolata, Thymus polytrichus* and *Trifolium pratense*. At least 4 out of the 10 identifier species had to be present within a relevé to be classified as acid or neutral-calcareous; topsoil pH was also taken into consideration when classifying habitat type (pH < 5.5 for acid grasslands and pH ≥ 5.5 for neutral-calcareous grasslands). Further, relevés identified as improved grasslands were excluded, as these sites typically represent fertilised areas. A total of 416 relevés were classified as unmanaged acid grasslands and 419 as unmanaged neutral-calcareous grassland from the 2007–2010 survey database (see Figure 3.1). However, only a sub-set of these relevés had topsoil pH and LOI observations for acid (n = 260) and neutral-calcareous (n = 279) grasslands.

Long-term annual climate data (1971–2000) from meteorological stations across Ireland were obtained from Met Éireann and interpolated to develop national-scale long-term mean annual precipitation and air temperature maps (5 km × 5 km grid resolution). In concert, long-term mean annual N deposition was determined from the sum of wet ammonium (NH_4^+) and nitrate (NO_3^-) plus dry NH_3 and NO_x following Henry and Aherne (2014). Wet NH_4^+ and NO_3^- deposition was estimated by combining mapped long-term mean annual precipitation volumes with interpolated concentrations of NH_4^+ and NO_3^- obtained from precipitation chemistry monitoring stations (n = 16) across Ireland and Northern Ireland (Aherne and Farrell, 2002a; Leinert *et al*., 2008; Aherne *et al*., 2014). Monitoring stations were

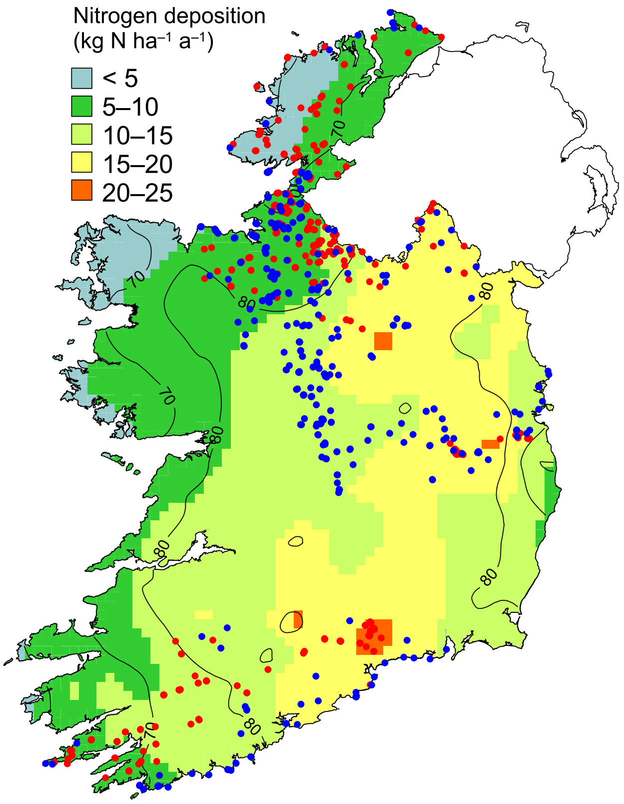


Figure 3.1. Total [wet (NO_3^- plus NH_4^+) and dry (NO_x plus NH_3)] nitrogen deposition (kg N $ha^{-1} a^{-1}$) to semi-natural grasslands at a 5 km × 5 km grid resolution. The contour lines depict reduced N (NH_3 plus NH_4^+) deposition as a percentage of total N. Filled circles show the location of plant relevés: acid grassland in red (n = 416) and neutral-calcareous grassland in blue (n = 419).

included if they had >3 years of precipitation chemistry data during the period 1991–2010. Dry NH_3 deposition was estimated by combining mapped (interpolated) air concentration (µg m^{-3}) with a habitat-specific NH_3 deposition velocity (V_d)[15]. Ammonia air concentration data was obtained from a national network (comprising 40 sites) that operated during 1999–2000 (de Kluizenaar and Farrell, 2000)[16], and V_d was set to 1.5 cm s^{-1} for grasslands (Environment Agency, 2010). Finally, modelled dry deposition of NO_x to semi-natural vegetation (50 km × 50 km) was obtained from EMEP (Simpson *et al*., 2012). It should be noted that the national-scale high-resolution N deposition map (5 km × 5 km compared with EMEP 50 km × 50 km) was only used to evaluate the potential influence of N deposition on plant species diversity in semi-natural grasslands. Exceedance of critical load is estimated using EMEP modelled deposition under the LRTAP Convention and EU directives; however, national-scale studies have used higher resolution deposition for exceedance of critical load (see Henry and Aherne, 2014).

The potential influence of N deposition on plant species diversity, estimated as species richness[17], was assessed using linear regression and principle component analysis (PCA). Principal component analysis is a data exploratory technique used to emphasise variation and visualise strong patterns in a dataset by reducing the dimensions of the dataset. Exploratory data analysis primarily focused on plant relevés with soil chemical data; however, initial linear regression analysis of species richness against N deposition included all relevé data for acid and neutral-calcareous grasslands.

3.3 Nitrogen Deposition Impacts in Grasslands

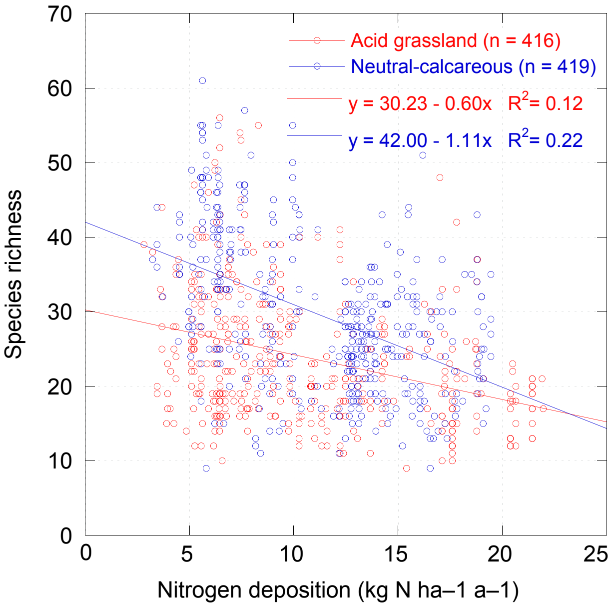
Annual estimated N deposition (wet and dry) to semi-natural grassland habitats ranged from 2 to 22 kg $ha^{-1} a^{-1}$, with an average national deposition of 12.1 kg $ha^{-1} a^{-1}$ (Figure 3.1). The lowest deposition was observed on the west coast and the highest in the central and eastern regions, predominantly associated with intensive livestock farming, i.e. cattle, which are the primary emissions source of NH_3 in Ireland (EPA, 2012). Reduced N deposition (dry NH_3 and wet NH_4^+) represented the dominant form (mean 77% and range approximately 55 to 88%) of total N deposition (Figure 3.1). Average oxidised deposition was only 2.4 kg $ha^{-1} a^{-1}$ compared with reduced deposition of 9.7 kg $ha^{-1} a^{-1}$. In contrast, average total N deposition to grassland habitats in the UK was 15 kg $ha^{-1} a^{-1}$, with roughly 50% from reduced N species (Defra, 2001, 2012).

A significant negative relationship was observed between N deposition and plant species richness in acid (R^2 = 0.12) and neutral-calcareous (R^2 = 0.22) grasslands (Figure 3.2). Although N deposition explained a

15 A deposition velocity describes the rate a gas or particle falls to a particular type of surface; in general, areas of vegetation with high surface roughness have high deposition velocities, e.g. the V_d for NH_3 to forests is higher than for grasslands.

16 A national network also operated during 2013–2014 under the EPA funded project 2012-CCRP-MS.8, Ammonia2 – Baseline Ammonia in Ireland (www.ucd.ie/ammonia).

17 Species richness is simply a count of plant species in an ecological community, landscape or region; it does not take into account the abundances of the species.



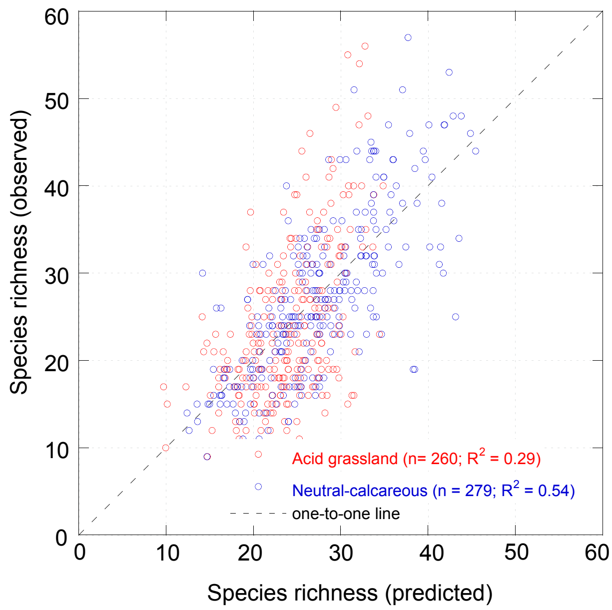


Figure 3.2. Nitrogen deposition versus plant species richness (left) for acid (red) and neutral-calcareous (blue) grasslands for all relevés; predicted plant species richness versus observed (right) for plants relevés with soil chemistry; acid grassland species richness = 0.52 + 0.14 × slope – 1.26 × litter cover – 0.33 × total nitrogen deposition + 6.70 × topsoil pH, and neutral-calcareous grassland species richness = 107.49 –7.40 × annual temperature – 0.19 × median graminoid height – 0.67 × total nitrogen deposition + 0.11 × topsoil organic matter.

low proportion of the variability, Maskell *et al.* (2010) found a similar significant negative relationship between N deposition and species richness in acid grasslands ($R^2 = 0.09$) and heathlands ($R^2 = 0.17$) across Britain. They attributed their low R^2 value to the low resolution of their N deposition map (5 km × 5 km). This suggests that a higher resolution map for N deposition may explain a higher proportion of the variability.

A number of site variables had significant linear relationships with plant species richness in acid and neutral-calcareous grasslands (Table 3.1). Litter cover showed a strong negative relationship, whereas slope and topsoil pH had a positive relationship with acid grasslands; similarly, median graminoid height and annual temperature showed a negative relationship, and topsoil organic matter showed a positive relationship with neutral-calcareous grasslands. These variables were selected during stepwise multiple regression as the best predictors of plant species richness. Overall, 29% of the variability in species richness was explained by four variables for acid grassland and 54% for neutral-calcareous grassland; species richness was negatively related to N deposition for both grasslands (see Figure 3.2).

Principle component analysis for both habitat types, returned eigenvalues[18] greater than 1 for the first four principal components (PCs) (see Figure 3.3 and Table 3.2). In acid grasslands, PC1 and PC2 explained 20% and 18% of the variation (cumulatively 38%) for relevés with soil chemistry (n = 260). The main positive loadings for PC1 were altitude and N deposition; the main negative loads were richness and topsoil pH (Table 3.2). For PC2, the main positive loadings were mean annual precipitation and wet sulphate (SO_4^{2-}) deposition; the main negative loadings were dry sulphur oxides (SO_x) deposition and N deposition. In neutral-calcareous grasslands with soil chemistry (n = 279), PC1 and PC2 explained 26% and 20% of the variation (cumulatively 46%). The main positive loadings for PC1 were mean annual precipitation and richness; the main negative loadings were N deposition and dry SO_x deposition. For PC2, the main positive loadings were wet SO_4^{2-} deposition

18 An eigenvalue indicates how much variance there is in the data along an eigenvector. The eigenvector with the highest eigenvalue is the principal component. In general, factors or components with an eigenvalue > 1 are retained for analysis, as they describe a reasonable proportion of variance in the data.

Table 3.1. Linear regression statistics (direction of relationship, coefficient of determination and significance) between plant species richness and relevé attributes in acid and neutral-calcareous grasslands

Variable	Acid grassland (n = 260)		Neutral-calcareous grassland (n = 279)	
	Direction of change	R^2	Direction of change	R^2
Total nitrogen deposition	–	0.05***	–	0.15***
Wet sulphate deposition	–	0.03**		ns
Dry oxidised sulphur deposition	–	0.02**	–	0.09***
Annual precipitation volume		ns	+	0.14***
Annual air temperature		ns	–	0.26***
Site altitude	–	0.04***	+	0.19***
Slope	+	0.03**	+	0.07***
Litter cover	–	0.09***	–	0.08***
Median graminoid height	–	0.02*	–	0.19***
Topsoil pH	+	0.16***	–	0.02*
Topsoil organic matter	–	0.03**	+	0.04***

*****, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; ns, not significant.**

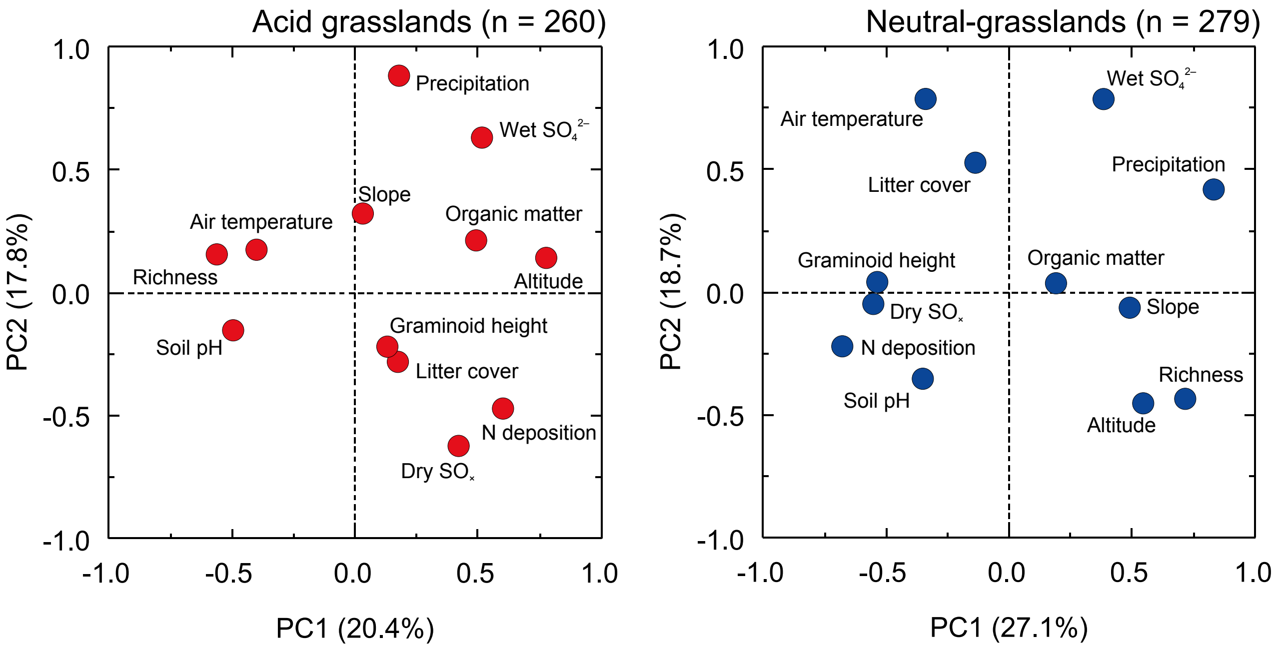


Figure 3.3. Principle component analysis bi-plots; the first and second principal components are plotted on the *x*-axis and *y*-axis, respectively, for acid and neutral-calcareous grasslands. For component loadings, see Table 3.2.

and mean annual air temperature; the main negative loadings were richness and altitude. The PCA indicates that plant species richness in both habitat types had a negative relationship with N deposition (Figure 3.3).

3.4 Reduced Plant Species Richness

Overall, this study indicated that N deposition had a significant negative relationship with plant species richness in semi-natural (acid and neutral-calcareous) grasslands (Figure 3.2). Regression analysis was also supported by the results from the PCA, i.e. where species richness had a negative relationship with N deposition (Figure 3.3). The results suggest that species richness declined as a function of N deposition with a reduction of one species for approximately every 1–1.5 kg N ha^{-1} a^{-1} deposition. Similar results have been observed in acid grasslands in Great Britain along a N

Table 3.2. Component loadings under principle component analysis for acid and neutral-calcareous grasslands

	Acid Grassland				Neutral-calcareous Grassland			
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Eigenvalue	2.45	2.14	1.91	1.23	3.25	2.24	1.37	1.20
Percentage	0.20	0.18	0.16	0.10	0.27	0.19	0.11	0.10
Richness	–0.56	0.15	–0.38	0.01	0.72	–0.44	0.04	–0.15
Altitude	0.77	0.14	–0.38	0.00	0.55	–0.46	0.35	0.35
Slope	0.04	0.32	–0.59	0.02	0.49	–0.07	0.02	0.68
Litter cover	0.17	–0.28	0.53	0.28	–0.14	0.52	0.58	0.05
Graminoid height	0.15	–0.23	0.65	0.14	–0.53	0.03	0.23	–0.20
Nitrogen deposition	0.60	–0.47	–0.27	0.28	–0.67	–0.22	0.28	0.23
Wet sulphate deposition	0.51	0.62	0.02	0.54	0.39	0.78	–0.01	0.25
Dry sulphur deposition	0.42	–0.62	–0.31	0.24	–0.55	–0.06	0.34	0.49
Mean annual precipitation	0.19	0.88	0.08	0.14	0.84	0.41	0.00	–0.02
Mean annual air temperature	–0.41	0.17	0.38	0.48	–0.34	0.78	–0.27	0.11
Topsoil pH	–0.49	–0.15	–0.28	0.59	–0.35	–0.35	–0.40	0.18
Topsoil organic matter (LOI)	0.49	0.22	0.40	–0.31	0.19	0.03	0.65	–0.38

deposition gradient of 5–35 $kg\,ha^{-1}\,a^{-1}$ (Stevens *et al*., 2004).

It is important to note that this was a gradient study; therefore no cause-effect relationship can be inferred from this result. This study provides an indication that N deposition has influenced plant species diversity in semi-natural grasslands at a national scale; therefore, further investigation on the effect of N deposition to semi-natural grasslands in Ireland is warranted. Moreover, future studies should include additional habitats, focusing on Annex 1 habitats under Natura 2000. In the current study, more than 23% of the relevés ($n = 133$) with soil information (Table 3.1) were located in Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). Henry and Aherne (2014) reported that 18% of mapped acid grassland in Natura 2000 areas exceeded their $CL_{emp}N$.

4 Conclusions

The principal objective of this project was to develop critical loads of acidity and eutrophication for terrestrial and aquatic ecosystems in Ireland. The project responded to two calls for critical load data under the LRTAP Convention; these data have been used to support the revised Gothenburg protocol and EU Clean Air Policy Package. In addition, the project evaluated the potential impacts of N deposition on plant species diversity in natural grasslands.

- The 2012 data submission to the CCE represented a significant update to the Irish critical load database incorporating a revised spatial description of receptor ecosystems, revised nutrient removal in harvested biomass, updated critical load model parameter values and the addition of aquatic critical loads. The database includes estimates of critical loads of acidity and eutrophication for natural habitats (grasslands, heathlands, bogs and woodlands) covering > 25% of the land area of Ireland.
- National critical loads of acidity and eutrophication are generally consistent with estimates across western and continental Europe; further, there are no border effects (or discontinuities) between Ireland and the UK (Northern Ireland).
- Areal exceedances of critical loads of acidity are predicted to decrease from 19% in 1990 to 6% in 2020 under the revised Gothenburg Protocol. In contrast, exceedances of critical loads of eutrophication ($CL_{nut}N$) are predicted to increase from 45% in 2000 to 47% in 2020. Predicted deposition in 2020 is based on the revised Gothenburg Protocol and does not consider national policies in the interim that may influence N emissions (and deposition).
- National, rather than transboundary, emissions sources play a greater role in the exceedance of critical loads of eutrophication, owing to the dominance of NH_3 from agricultural sources in N deposition. Therefore, national strategies, such as Food Wise 2025, may lead to increased exceedance of critical loads of eutrophication.
- There is growing evidence that N deposition may have long-term negative impacts on plant species diversity in natural habitats, this is particularly important to national obligations under Natura 2000. Plant species diversity is negatively correlated to N deposition in semi-natural Irish grasslands, with an estimated loss of one plant species per kilogram of N deposited.

5 Recommendations

National critical load data have made an important contribution to the development of effects-based international polices on the abatement of long-range transboundary air pollution. Nonetheless, critical loads have been virtually ignored under national policy assessments, partially owing to the lack of a national strategy on air pollution, and perhaps a lack of awareness on the use of critical loads on a European scale. Therefore, there are several clear and concrete recommendations.

- There should be wider adoption and integration of critical loads into national and international policy assessments, e.g. the impact of elevated emissions under national strategies, such as Food Wise 2025, should be evaluated with respect to their influence on exceedance of critical loads.
- In concert, permitting for new industrial facilities under the Industrial Emissions Directive (2010/75/EU) by the EPA should incorporate a critical load assessment. Further, critical loads should be used to assess impacts to Natura 2000 sites under Article 6.3 of the Habitats Directive (see Whitfield and McIntosh, 2014).
- Nitrogen impacts are considered a serious threat to biodiversity; therefore, there are clear synergies between the Habitats and Clean Air Directives, specifically with respect to Natura 2000 sites. While recently funded EPA research[19] has commenced an assessment of impacts from pig and poultry facilities, N emissions contribute both to local and long-range transboundary impacts, highlighting the need to integrate local policies with international policies. The Programmatic Approach to Nitrogen[20], used in the Netherlands, is an excellent example of good practice in assessing and managing the impacts of critical load exceedance.
- Nitrogen deposition is dominated by atmospheric NH_3; however, there are few national observations. While recently funded EPA research[21] provides a national snapshot of atmospheric NH_3, there is limited long-term monitoring capacity. It is recommended that existing EMEP stations be augmented to monitor NH_3 using passive samplers, with a view to establishing a national N monitoring network.
- Furthermore, quantification of impacts and improvements in natural ecosystems requires systematic monitoring of water, soil and vegetation. Existing long-term networks, such as ICP Waters and ICP Forests sites, should be built upon to meet this need, as noted under The Clean Air Policy Package[22] (see Annex V, Monitoring of effects of pollutants in the environment to the Proposal for a Directive of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants and amending Directive 2003/35/EC). The EPA and other national agencies should (continue to) engage in these ICPs within available resources, so that national monitoring is incorporated and used by the LRTAP Convention for the benefit of all EU Member States.
- Few studies have investigated the effects of N deposition to semi-natural habitats, e.g. natural grasslands, heathlands and native woodlands, in Ireland. Evidence of N impacts on vegetation should be collated, to provide an integrated assessment on plant species diversity, soil chemistry and atmospheric deposition. In addition, long-term experimental N addition studies are required to evaluate cause-effect relationships between current levels of N deposition and plant species diversity in Irish habitats.
- The national critical load database should continue to be revised in response to scientific and technical updates, such as new national soil and land cover data (e.g. CORINE 2012), improved descriptions of habitat distribution and technical revisions to EMEP grid projections. Critical loads will continue to play an important role in European air policy

19 2013-EH-MS-14: Assessment of the Impact of Ammonia Emissions from Intensive Agriculture Installations on SACs and SPAs.

20 The AERIUS calculation tool is one of the cornerstones of the Dutch integrated approach to nitrogen (www.aerius.nl).

21 2012-CCRP-MS.8: Ambient Atmospheric Ammonia in Ireland, 2013–2014.

22 The Clean Air Policy Package: ec.europa.eu/environment/air/clean_air_policy.htm (adopted 18 December 2013).

strategies, especially with respect to the impacts of N deposition on plant species diversity. While recently funded EPA research[23] will respond to CCE data calls until 2016, to date Irish critical load obligations have been addressed through research calls, a more coordinated national approach may potentially support wider adoption of critical loads into national policy assessments. During this project (and project 2012-CCRP-MS.7), collaboration on critical loads between the EPA, NPWS and the Department for Environment, Communities and Local Government was developed. This collaboration should be strengthened and extended to other relevant governmental agencies so that critical loads can be used appropriately for national assessments, similar to other EU Member States.

- Long-term improvements in air quality can only be achieved through a national air quality strategy. In addition to outlining a clear policy framework that integrates ambient and transboundary objectives, a strategy should address monitoring and research to increase understanding. The ultimate goal of a National Strategy should be to achieve levels of air quality that do not result in unacceptable impacts on human health and the environment.

23 2012-CCRP-MS.7: Critical Loads and Dynamic Soil-Vegetation Modelling.

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Abbreviations

AAE	Average accumulated exceedance
ANC	Acid neutralising capacity
CCE	Coordination Centre for Effects
CLC	CORINE Land Cover
$CL_{emp}N$	Empirical critical load of nutrient nitrogen
$CL_{max}N$	Maximum critical load of nitrogen
$CL_{max}S$	Maximum critical load of sulphur
$CL_{min}N$	Minimum critical load of nitrogen
$CL_{nut}N$	Critical load of nutrient nitrogen
CORINE	Coordination of Information on the Environment
DEM	Digital elevation model
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency
EU	European Union
EUNIS	European Nature Information System
FAB	First-order Acidity Balance
ICP	International Cooperative Programme
IFS/ISM	Indicative Forest Soil/Indicative Soil Map
LOI	Loss-on-ignition
LRTAP	Long-range Transboundary Air Pollution
MSC-W	Meteorological Synthesizing Centre – West
N	Nitrogen
Natura 2000	Network of nature protection areas designated under the EU Habitats Directive
NEC	National Emissions Ceilings
NFC	National Focal Centre
NH_3	Ammonia
NH_4^+	Ammonium
NH_y	Reduced nitrogen
NO_3^-	Nitrate
NO_x	Nitrogen oxides
NPWS	National Parks and Wildlife Service
NSNW	National Survey of Native Woodlands
PC	Principle Component
PCA	Principle Component Analysis
REM	Receptor ecosystem map
S	Sulphur
SAC	Special Area of Conservation
SO_4^{2-}	Sulphate
SO_x	Sulphur oxides
SPA	Special Protection Area
SSMB	Steady-State Mass Balance
THIM	Teagasc Habitat Indicator Map
UNECE	United Nations Economic Commission for Europe
V_d	Deposition velocity
WGE	Working Group on Effects

Appendix 1 Project Outputs

A1.1 Peer-Reviewed Publications

Posch, M., Aherne, J. and Hettelingh, J.-P., 2011. Nitrogen critical loads using biodiversity-related critical limits. *Environmental Pollution* 159: 2223–2227.

Henry, J. and Aherne, J., 2014. Nitrogen deposition and exceedance of critical loads for nutrient nitrogen in Irish grasslands. *Science of the Total Environment* 470–471: 216–223.

Henry, J. and Aherne, J., 2016. Potential impacts of nitrogen deposition on plant species richness and soil nitrogen in Irish acid grasslands. *PeerJ* (submitted).

Aherne, J. and Dodd, D., 2010. Ireland: National Focal Centre report. In Posch, M., Slootweg, J. and Hettelingh, J.-P. (eds), *Progress in the Modelling of Critical Thresholds and Dynamic Modelling, Including Impacts on Vegetation in Europe*. CCE Status Report 2010. pp 151–152. Coordination Centre for Effects, Bilthoven, the Netherlands.

Aherne, J., Koseva, I.S. and Dodd, D., 2011. Ireland: National Focal Centre Report. In Posch, M., Slootweg, J. and Hettelingh, J.-P. (eds), *Modelling Critical Thresholds and Temporal Changes of Geochemistry and Vegetation Diversity: CCE Status Report 2011*. pp 117–118. Coordination Centre for Effects, Bilthoven, the Netherlands.

Aherne, J., Wolniewicz, M. and Dodd, D., 2012. Ireland: National Focal Centre report. In Posch, M., Slootweg, J. and Hettelingh, J.-P. (eds), *Modelling and Mapping of* Atmospherically-Induced *Ecosystem Impacts in Europe: CCE Status Report 2012*. pp 89–91. Coordination Centre for Effects, Bilthoven, the Netherlands.

Clair, T.A., Blett, T., Aherne, J. *et al*., 2014. The critical loads and levels approach for nitrogen. In Sutton, M.A., Mason, K.E., Sheppard, L.J. *et al*. (eds), *Nitrogen Deposition, Critical Loads and Biodiversity*. pp 481–491. Springer Netherlands, Dordrecht.

Curtis, C.J., Posch, M., Aherne, J. *et al*., 2015. Assessment of critical loads of acidity and their exceedances for European lakes. In de Vries, W. Hettelingh, J.-P. and Posch, M. (eds), *Critical Loads for Nitrogen, Acidity and Metals for Terrestrial and Aquatic Ecosystems*. Springer Netherlands, Dordrecht.

A1.2 Conferences and Workshops: Oral and Poster Presentations

Aherne, J., 2009. Critical Load Assessments for Ireland: 2009–2012. Transboundary Air Pollution. National Coordination Meeting, Gresham Hotel, Dublin, 19 November 2009 (oral presentation).

Aherne, J., 2010. Modelling and Mapping of Critical Loads for Ireland. Bilateral Meeting of National Focal Centres, UK and IE, Environmental Protection Agency, Richview, Dublin, 13 August 2010 (oral presentation).

Cummins, T. and Aherne, J., 2010. Critical Loads. EPA Transboundary Air Pollution Research Workshop, Radisson Blu Hotel, Galway, 8–9 September 2010 (oral and poster presentation).

Aherne, J., 2011. Critical Loads, Nutrient Nitrogen and Linkages to Habitat Reporting. Joint National Parks and Wildlife Service–Environmental Protection Agency Meeting, Ely Place, Dublin, 14 February 2011 (oral presentation).

Aherne, J., Koseva, I.S. and Dodd, D., 2011. Mapping Critical Loads for Ireland. 21st CCE Workshop and 27th Task Force Meeting of the ICP M&M, Bilthoven, the Netherlands, 18–21 April 2011 (poster presentation).

Henry, J. and Aherne, J., 2011. Impacts of Nitrogen Deposition on Plant Species Richness in Irish Grasslands. 54th Symposium of the International Association for Vegetation Science IAVS, Lyon, France, 20–24 June 2011 (poster presentation).

Aherne, J., 2012. Critical Loads, Nutrient Nitrogen and Linkages to Habitat Reporting. Joint National Parks and Wildlife Service–Environmental Protection Agency meeting, Ely Place, Dublin, 30 January 2012 (oral presentation).

Henry, J. and Aherne, J., 2012. Nitrogen Deposition and Critical Load Exceedance for Irish Grassland and Forest Ecosystems. 22nd CCE Workshop and 28th Task Force Meeting of the ICP M&M, Warsaw, Poland, 16–19 April 2012 (poster presentation).

Henry, J. and Aherne, J., 2012. Impacts of Nitrogen Deposition on Irish Grasslands. 7th International Symposium on Ecosystem Behaviour, BIOGEOMON 2012, Maine, 15–19 July, 2012 (oral and poster presentation).

Aherne, J., 2012. Irish Acid-sensitive lakes. ICP Waters 28th Task Force Meeting, Pallanza, Italy, 8–10 October 2012 (oral presentation).

Henry, J. and Aherne, J., 2013. Potential Impacts of Nitrogen Deposition on Plant Diversity and Soil Chemistry in Acid and Neutral-Calcareous Irish Grasslands. 23rd CCE Workshop and 29th Task Force Meeting of the ICP M&M, Copenhagen, Denmark, 8–11 April 2013 (poster presentation).

A1.3 Research Dissertations

Henry, J., 2012. *Assessment of the Potential Impacts of Reactive Nitrogen Deposition on Irish* Semi-Natural *Grassland Habitat*. MSc Thesis. Environmental & Life Science Graduate Programme, Trent University, Peterborough, Canada.

Appendix 2 The 2012 Data Submission to the Coordination Centre for Effects

A2.1 Instructions for Submitting National Critical Data

This appendix describes the Irish critical loads database submitted to the Coordination Centre for Effects (CCE) in 2012 in response to the 2011–2012 call for data. Detailed instructions for the submission of empirical and modelled critical loads of nitrogen and sulphur were provided by the CCE. The Irish critical loads database contains five data tables (ecords, CLdata, inputs, EmpNload and h2oinputs) composed of approximately 60 variables outlining national critical loads for terrestrial and aquatic ecosystems and their corresponding model input data. The data submission represented a significant update to the Irish critical load database (since the 2010–2011 data submission), incorporating a revised spatial description of receptor ecosystems (see Appendix 3), revised nutrient removal in harvested biomass, updated critical load model parameter values and the addition of aquatic critical loads. In addition, several meetings have been held with the National Focal Centre in the UK to resolve differences in national critical load databases[24]; the current critical loads are broadly in line with those in the UK (see Figure 1.2). The determination of critical loads followed well-established methods as described in the Mapping Manual (CLRTAP, 2004) and more recently by de Vries *et al*. (2015). A description of the structure of each data table and the requested variables is given below.

A2.2 Data Table 1: "ecords"

Variables: Site ID, Lon, Lat, I, J, EcoArea, Protection, EUNIS code

Description: UNIQUE site identifier, site longitude and latitude (in decimal degrees), EMEP5 horizontal coordinate, EMEP5 vertical coordinate, ecosystem area (km^2; only areas larger than 1 ha are included) within each European Monitoring and Evaluation Programme (EMEP) grid cell, protection status and European Nature Information System (EUNIS) code.

The "ecords" table contains eight variables that describe the geographic attributes of the ecosystems with mapped critical load data; 192,628 records were submitted to the CCE in response to the 2011–2012 call for data. Nine receptor ecosystems (Table A2.1), primarily derived from CORINE Land Cover and the Forest07 database, were selected for mapping, including deciduous forests (both native and managed), coniferous forest, mixed forests, sparsely vegetated areas, grasslands (natural and unimproved pastures), heathlands, intact bogs, saltmarshes and surface waters (see Appendix 3 for further details on the distribution of terrestrial receptor ecosystems).

The protection status for each ecosystem record was derived by intersecting each receptor with coverage maps of Nature Reserves, Natural Heritage Areas (NHAs), Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) obtained from the National Parks and Wildlife Service (www.npws.ie).

A2.3 Data Table 2: CLdata

Variables: Site ID, $CL_{max}S$, $CL_{min}N$, $CL_{max}N$, $CL_{nut}N$, $nANC_{crit}$

Description: Unique site identifier (see Data Table 1), maximum critical load of acidifying sulphur ($CL_{max}S$), minimum critical load of nitrogen ($CL_{min}N$), maximum critical load of acidifying nitrogen ($CL_{max}N$), critical load of nutrient nitrogen ($CL_{nut}N$) and critical leaching of alkalinity.

The "CLdata" table contains six variables that describe modelled critical loads; 185,901 records were submitted to the CCE. Critical loads of acidity ($CL_{max}S$, $CL_{min}N$ and $CL_{max}N$) were estimated using the Steady-State Mass Balance (SSMB) model for terrestrial ecosystems (EUNIS habitats E, F and G), and the First-order Acidity Balance (FAB) model for aquatic ecosystems (EUNIS C) as described in the Mapping Manual (CLRTAP,

24 Ireland–United Kingdom Bilateral Critical Loads Meetings: EPA Richview, Dublin, Ireland, 13 August 2010; Centre for Ecology and Hydrology, Bangor, Wales, 16 February 2011; and Hotel Mitland, Utrecht, the Netherlands, 17 April 2011.

Table A2.1. Selected CORINE land cover classes and codes, corresponding receptor ecosystem classes (see Appendix 3 for description) and associated EUNIS code

CORINE land cover class	Code	Receptor ecosystem	EUNIS code
Grassland	321	Dry acid grassland (natural grassland)	E1.7
	231	Dry acid grassland (unimproved pasture)	E1.7
	321	Dry basic grassland (natural grassland)	E1.26
	231	Dry basic grassland (unimproved pasture)	E1.26
	321	Wet acid grassland (natural grassland)	E3.52
	231	Wet acid grassland (unimproved pasture)	E3.52
	321	Wet basic grassland (natural grassland)	E
	231	Wet basic grassland (unimproved pasture)	E
Heathlands	322	Dry heathland	F4.2
	322	Wet heathland	F4.11
Intact bogs	412	Intact bog (lowland blanket)	D1
	412	Intact bog (mountain blanket)	D1
	412	Intact bog (raised blanket)	D1
	412	Intact bog (upland blanket)	D1
Sparsely vegetated areas	333	Moss and lichen-dominated mountains (> 300 m)	E4.2
Saltmarshes	421	Saltmarshes	A2.5
Deciduous forest	311	Native woodland	G1
	311	Acidophilous *Quercus*-dominated woodland	G1.8
	311	Deciduous forest (managed)	G1
Coniferous forest	312	Coniferous forest (managed)	G3.1
Managed forest	313	Mixed forest (managed)	G4.6
Water bodies	512	Permanent oligotrophic lakes, ponds and pools	C1.1

2004). Similarly, a mass balance approach for nutrient nitrogen ($CL_{nut}N$) was applied to managed forest habitats (EUNIS G1, G3.1 and G4.6).

Critical leaching of alkalinity was calculated as described in the Mapping Manual (CLRTAP, 2004) where $ANC_{crit} = -Al_{le(crit)} - [H]_{le(crit)}$; $Al_{le(crit)} = Q \times [Al]_{crit}$ and $H_{le(crit)} = Q \times [H]_{crit}$, where Q is precipitation surplus ($m^3 ha^{-1} a^{-1}$) and $[H]_{crit}$ and $[Al]_{crit}$ are critical hydrogen and aluminium concentration ($eq\,m^{-3}$). A pH of 4.2 was selected as defining the H^+ concentration limit and used to estimate the Al concentration critical limit via the gibbsite relationship (see CLRTAP, 2004). The H^+ critical limit was selected based on work by Ulrich (1987), which states that at pH lower than 4.2 there is a greater tendency for Al^{3+} to dissolve into soil solution. Aluminium, specifically free aluminium such as Al^{3+}, is the main chemical species that causes damage to plant roots and aquatic organisms.

A2.4 Data Table 3: Inputs

The "inputs" table contains 28 variables describing the inputs used to determine critical loads for terrestrial ecosystems; 185,680 records were submitted to the CCE. The 28 variables are described below.

1. Site ID: Unique site identifier (see Data Table 1).

2. Acceptable nitrogen concentration ($meq\,m^{-3}$), cN_{acc}: The acceptable nitrogen concentration for managed forests (EUNIS code G1, G3.1 and G4.6) was set to 0.0214 $eq\,m^{-3}$ (0.3 $mg\,N\,L^{-1}$) to avoid nutrient imbalances based on the recommend range 0.2–0.4 $mg\,N\,L^{-1}$ (CLRTAP, 2004). All other ecosystem records were set to NULL; empirical critical loads for nutrient nitrogen were set for these systems (see A2.5 Data Table 4: EmpNload).

3–4. Chemical criterion (crittype) and critical value (critvalue): Soil solution pH was selected as the chemical criterion, with a critical value of 4.2 for all terrestrial ecosystems (EUNIS habitats E, F and G).

5–6. Soil thickness (m; thick) and bulk density ($g\,cm^{-3}$; bulkdens): Set to NULL.

7–10. Base cation deposition ($eq\,ha^{-1} a^{-1}$), Ca_{dep}, Mg_{dep}, K_{dep}, Na_{dep}: Non-marine base cation deposition was

calculated from interpolated (kriging) point source bulk concentration measurements (approximately 20 point observations) and interpolated (kriged) rainfall volumes (approximately 600 point observations). All deposition was assigned to Ca_{dep}, which is the dominant component of non-marine base cation deposition; magnesium and sodium are predominantly of marine origin (for further details, see Aherne and Farrell, 2000a; Aherne and Farrell, 2002b).

11. Total chloride deposition ($eq\,ha^{-1}\,a^{-1}$), Cl_{dep}: This was set to NULL as only non-marine deposition was submitted; it is generally assumed that all chloride is of marine origin.

12–15. Weathering of base cations ($eq\,ha^{-1}\,a^{-1}$), Ca_{we}, Mg_{we}, K_{we}, Na_{we}: Base cation weathering was calculated using the Skokloster classification ranges for mineral soils, the mid-value of each of the five classes was used to define soil weathering, except for the final (non-sensitive) class, which was set at $4000\,eq\,ha^{-1}\,a^{-1}$. (see Aherne and Farrell, 2000a,b, 2002b). A default of 20% of the total weathering was allocated to sodium weathering (Na_{we}) and the remainder was assigned to calcium weathering (Ca_{we}).

16–18. Base cation uptake ($eq\,ha^{-1}\,a^{-1}$), Ca_{upt}, Mg_{upt}, K_{upt}: Base cation (Bc) uptake for managed forests (coniferous, deciduous, mixed) was estimated from the following: $\min(BC_{avail}, Bc_{upt})$ where BC_{avail} is the available base cation flux estimate according to $BC_{avail} = (BC_{we} + BC_{dep} - BC_{leaching})$, where $BC_{leaching}$ was set equal to $0.002\,eq\,m^{-1}$ (see CLRTAP, 2004) and where Bc_{upt} is the uptake removal for managed forests (coniferous, deciduous, and mixed) under stem only harvesting according to $Bc_{upt} = \text{yield class} \times \text{wood density} \times \text{stem nutrient content}$ [see equation 5.8, p. V–13, in the Mapping Manual (CLRTAP, 2004)].

For coniferous forests, yield class ranged between 14.25 and $27.5\,m^3 ha^{-1}\,a^{-1}$ based on Sitka spruce (*Picea sitchensis*) for different soil types following Farrelly *et al*. (2010). For deciduous forests, a yield class of $6\,m^3\,ha^{-1}\,a^{-1}$ was used, which represented an average of yield values derived for two dominant deciduous species (ash and beech) from spatially distributed sites across Ireland within Climadapt. Wood density was set to $390\,kg\,m^{-3}$ and $550\,kg\,m^{-3}$ for coniferous and deciduous species, respectively. Stem nutrient concentrations (Table A2.2) for calcium, magnesium and potassium for coniferous forests were derived from Johnson *et al*. (2015) and for deciduous forests from the Mapping Manual (CLRTAP, 2004; Table 5.8, p. V-14). For mixed forests (where no specific proportion of coniferous or deciduous forest was available) a ratio of 75% coniferous and 25% deciduous was assumed based on the average distribution of the two forest types. All base cation uptake was assigned to Ca_{upt}. For native woodlands, grasslands, intact bogs (lowland, mountain, upland) and heathlands an uptake of $45\,eq\,ha^{-1}\,a^{-1}$ was set to account for uptake from grazing.

Table A2.2. Stem nutrient concentrations for coniferous (based on Sitka spruce) and deciduous trees (ash and beech)

Nutrient	Coniferous ($eq\,kg^{-1}$)	Deciduous ($eq\,kg^{-1}$)
Calcium	0.027	0.062
Magnesium	0.007	0.017
Potassium	0.009	0.018

19. Runoff ($mm\,a^{-1}$), Q_{le}: Runoff or soil percolation was estimated as the difference between rainfall and evapotranspiration plus overland surface runoff (see Aherne and Farrell, 2000a). Rainfall and evapotranspiration were interpolated from long-term (1950–1980) meteorological station measurements. Surface runoff was estimated from soil type (see Collins and Cummins, 1996).

20–21. Equilibrium constant for Al–H relationship (where $lgKA_{lox}$ is the log gibbsite equilibrium constant) and exponent (expAl): Both parameters were based on the “classic” gibbsite equilibrium relationship (where K_{gibb} is the gibbsite equilibrium constant); therefore, the exponent was set to 3. The spatial distribution of K_{gibb} was defined by reclassifying the indicative soil map of Ireland into several classes (Table A2.3) based on organic matter content following CLRTAP (2004).

22. Partial CO_2 pressure, pCO_{2fac}: For consistency with previous critical load methodologies, pCO_{2fac} was set to NULL. This is a simplification; however, in soils with pH lower than 5.0 (the soils of interest in relation to critical loads), the production of carbonate from pCO_{2fac} is negligible. Therefore, this simplification has very minor implications for critical load estimates.

23. Total concentration of organic acids ($eq\,m^{-3}$), cOrgacids: Organic acids have previously not been included in Irish critical load calculations, owing to limited data on the concentration of organic acids in soil

solution for terrestrial habitats. Organic acids were set to NULL.

24. Acceptable nitrogen immobilisation ($eq\,ha^{-1}\,a^{-1}$), N_{imacc}: The spatial distribution of N_{immacc} ($eq\,ha^{-1}\,a^{-1}$) was based on soil type, with histosols and podzols set to 214.18 $eq\,ha^{-1}\,a^{-1}$, and all other soil types set to 71.39 $eq\,ha^{-1}\,a^{-1}$ (Table A2.3).

25. Nitrogen uptake ($eq\,ha^{-1}\,a^{-1}$), N_{upt}: For managed forests (coniferous, deciduous and mixed), N_{upt} followed the same method as Bc_{upt} (see variables 16–18), and used the same values for wood density and yield class. Nitrogen stem content was set to 0.077 $eq\,kg^{-1}$ for coniferous forest (Johnson *et al.*, 2015) and to 0.130 $eq\,kg^{-1}$ for deciduous forest (average of oak and beech, see Table 5.8, p. V-14; CLRTAP, 2004). Further, Bc_{upt} was used to scale the N_{upt} where $Bc_{avail} < Bc_{upt}$. For native forests, grasslands, intact bogs (lowland, mountain, upland) and healthlands, an uptake of 71 $eq\,ha^{-1}\,a^{-1}$ was set to account for uptake from grazing.

26. Denitrification fraction, f_{de}: The spatial distribution of f_{de} was based on the drainage status of each soil type (Table A2.3) following Reinds *et al.* (2001).

27. Nitrogen denitrified ($eq\,ha^{-1}\,a^{-1}$), N_{de}: Set to NULL. Not required as f_{de} was submitted.

28. Measured: On-site measurements included in the data for critical load calculations, set to 0 (no measurements).

A2.5 Data Table 4: EmpNload

The "EmpNload" table contains two variables that describe empirical critical loads for N; 192,407 records were submitted. Empirical critical loads were set for all ecosystems based on Bobbink and Hettelingh (2011), except for wet basic grassland. The EUNIS code for this category was set to E (see Table 2.2).

1. Site ID: Unique site identifier (see Data Table 1).

2. $CL_{emp}N$ ($eq\,ha^{-1}\,a^{-1}$).

A2.6 Data Table 5: h2oinputs

The "h2oinputs" table contains 16 variables describing the inputs used to determine critical loads for aquatic ecosystems; 221 records (each representing one lake catchment) were submitted to the CCE. The variables are described below, for further details see Figure 2.5 and Curtis *et al.* (2015).

1. Site ID: Unique site identifier (see Data Table 1).

2. Criterion used, crittype: Set to 5, which corresponds to an ANC_{limit}.

3. Value of the criterion used, critvalue: Estimated using a variable limit where $ANC_{limit} = ANC_{OAA} + (10.2/3) \times TOC$, with ANC_{OAA} (organic adjusted ANC) = 8 $meq\,m^{-3}$ for brown trout, *Salmo trutta*, after Lydersen *et al.* (2004).

Table A2.3. Soil type categories (from the Teagasc Indicative Soils Map), gibbsite equilibrium constant, log gibbsite equilibrium constant, acceptable nitrogen immobilisation and denitrification fraction

Soil type	K_{gibb}	$lgKAl_{ox}$	N_{imacc}	f_{de}
Acid brown earths/brown podzolics	300	8	71.39	0.1
Grey brown podzolics/brown earths	300	8	71.39	0.1
Renzinas/lithosols	300	8	71.39	0.1
Lithosols/regosols	100	7.5	71.39	0.1
Lithosols/peats	100	7.5	214.18	0.1
Basin peats	9.5	6.5	214.18	0.8
Basin peats/blanket peats	9.5	6.5	214.18	0.8
Blanket peats	9.5	6.5	214.18	0.8
Peaty gleys	9.5	6.5	214.18	0.7
Peaty gleys (shallow)	9.5	6.5	214.18	0.7
Podzols (peaty)/lithosols/peats	9.5	6.5	214.18	0.2
Surface water gleys (shallow)/ground water gleys (shallow)	300	8	71.39	0.4
Surface water gleys/ground water gleys	300	8	71.39	0.4
Alluvial mineral	300	8	71.39	0.4

f_{de}, denitrification fraction; K_{gibb}, gibbsite equilibrium constant; $lgKAl_{ox}$, log gibbsite equilibrium constant; N_{imacc}, acceptable nitrogen concentration.

4–5. Lake area (ha), areaL, and catchment area (ha), areaC: Lake area was taken from the EPA digital database, and catchment area was estimated for each lake using a digital elevation model.

6. Mean lake depth (m), depth: Set to NULL. Data were not available for all lakes.

7. Annual runoff ($m\,a^{-1}$), Q_s: Long-term normals for discharge (runoff) at a 1 km × 1 km grid resolution were estimated using MetHyd (a meteo-hydrological model; Slootweg *et al*., 2010), and monthly climate normals for rainfall volume, average temperature and sunshine hours (Met Éireann; www.met.ie).

8. Non-marine pre-acidification base cation flux ($eq\,ha^{-1}\,a^{-1}$), $nmBC_0$: Determined using the Steady-State Water Chemistry model (CLRTAP, 2004).

9. Acceptable amount of nitrogen immobilised in the soil ($eq\,ha^{-1}\,a^{-1}$), N_{imacc}: Set to 0.5 $kg\,N\,ha^{-1}\,a^{-1}$ following CLRTAP (2004).

10. Average net growth uptake of nitrogen ($eq\,ha^{-1}\,a^{-1}$), N_{upt}: Nitrogen removal in harvested biomass assumed that managed Irish forests were dominated by Sitka spruce (*Picea sitchensis*), with an average yield class of 16 $m^3\,ha^{-1}\,a^{-1}$ (COFORD, 1994), stem concentrations of N were 0.05% (Emmett and Reynolds, 1996; Johnson *et al*., 2015), and a wood density of 390 $kg\,m^{-3}$. The potential net uptake of 310 $eq\,ha^{-1}\,a^{-1}$ was multiplied by the percent cover of forest in each catchment.

11. Denitrification fraction, f_{de} ($0 \leq f_{de} < 1$): Estimated as $0.1 + 0.7_{fpeat}$ following CLRTAP (2004), where f_{peat} is the fraction of peat in the lake catchment.

12. Average amount of nitrogen denitrified ($eq\,ha^{-1}\,a^{-1}$), N_{de}: Set to NULL. Not required, as f_{de} was submitted.

13. Net mass transfer coefficient for N in the lake ($m\,a^{-1}$), sN: Set to 6.5 $m\,a^{-1}$ following Kaste and Dillon (2003).

14. Net mass transfer coefficient for S in the lake ($m\,a^{-1}$), sS: Set to 0.5 $m\,a^{-1}$ following Baker and Brezonik (1988).

15. Total concentration of organic acids, ($eq\,m^{-3}$), cOrgacids: Based on lake observations.

16. On-site measurements included in the data for critical load calculations, measured: Set to 4 for ICP Waters and 1 for other measurement programme.

Appendix 3 A Receptor Ecosystem Map

A3.1 National Distribution of Receptor Ecosystems

This appendix describes the development of a "receptor ecosystem" distribution map for Ireland based on available land cover data in combination with other national data layers, e.g. CORINE Land Cover (CLC), elevation, soils and subsoils (see Figure 2.1). It is important to note that the resultant map is not a national habitat map, but rather a spatial data layer reclassified to European Nature Information System (EUNIS[25]) habitat categories to support effects-based air pollutant approaches, i.e. critical load assessments (acidity and nitrogen). The map is constrained by the quality and resolution of the underlying data sources; therefore, habitat distribution and areal coverage may differ from national habitat assessments.

There are two land cover maps available for Ireland, CORINE (CLC1990, CLC2000 and CLC2006[26]) and the National Teagasc Landcover Map 1995 (TLC95); the latter was also used to produce the National Teagasc Habitat Indicator Map (THIM95) by combining land cover classes with other thematic maps, e.g. subsoils and Digital Elevation Model (DEM) derivatives. While CORINE is the most comprehensive inventory of land cover for Ireland, the land cover categories under CLC2006, and the older THIM95, are not directly aligned to receptor ecosystem classes (based on the EUNIS habitat classification). The objective of this study was to develop a receptor ecosystem map (REM) describing the spatial distribution of semi-natural ecosystems for use in transboundary air pollution activities, and specifically to support the 2011–2012 Coordination Centre for Effects (CCE) call for national critical load data (see Appendix 2). Broad ecosystem classes (and sub-classes) were defined by overlaying and combining information from several digital maps and databases including CLC2000 (level 6) and CLC2006, THIM95, EPA-Teagasc Soils and Subsoils [Indicative Forest Soil/Indicative Soil Map (IFS/ISM[27])], a DEM, the Forest07 dataset (national forest coverage and attribute data[28]) and the Vascular Plants Database[29].

A3.2 Mapping Methodology

The REM includes six broad habitat classes (see Figure 2.1 and Table 2.2): intact bogs [raised and blanket (upland, lowland and mountain)], grasslands [wet (acid and basic) and dry (acid and basic)], moss and lichen-dominated mountain areas, heathlands (wet and dry), saltmarshes and forests [coniferous, mixed and deciduous (native and oak)]. These habitats were defined by overlaying and combining existing digital maps and databases using a decision tree process (see Figure A3.1). In general, initial land cover was defined using CLC2000, CLC2006 (at a resolution of 25 ha) and the Forest07 databases for intact bogs, natural grasslands, unimproved pastures, sparsely vegetated areas, heathlands, saltmarshes and forests. These classes were subsequently combined with the national subsoils map (1:50,000) describing 16 themes and the indicative soils map (25 classes, 1:100,000–150,000) to derive wet–dry and acid–basic ecosystems. The habitats were further refined using elevation, the National Survey of Native Woodlands (NSNW)[30] database and plant species richness (Preston *et al*. 2002, 2003) or presence–absence of selected species (Vascular Plants Database). The final REM (Figure 2.1) describes the spatial distribution of semi-natural ecosystems covering approximately 28% of the terrestrial area of Ireland (Table 2.2).

25 The EUNIS habitat classification is a pan-European system, developed by the European Environment Agency (EEA) that covers all types of natural and artificial habitats, both aquatic and terrestrial (eunis.eea.europa.eu).

26 Note: the latest update of the CORINE land cover inventory is CORINE 2012, for further details see EPA website (epa.ie/soilandbiodiversity/soils/land/corine).

27 Indicative Forest Soil/Indicative Soil Map. Teagasc–EPA Soils and Subsoils Mapping Project, and CORINE 2000 and 2006 (gis.epa.ie).

28 Forest07 Data Set, Forest Service, Department of Agriculture, Food and the Marine.

29 Vascular Plants Database, National Biodiversity Network's (NBN) Gateway (data.nbn.org.uk).

30 www.npws.ie/research-projects/woodlands

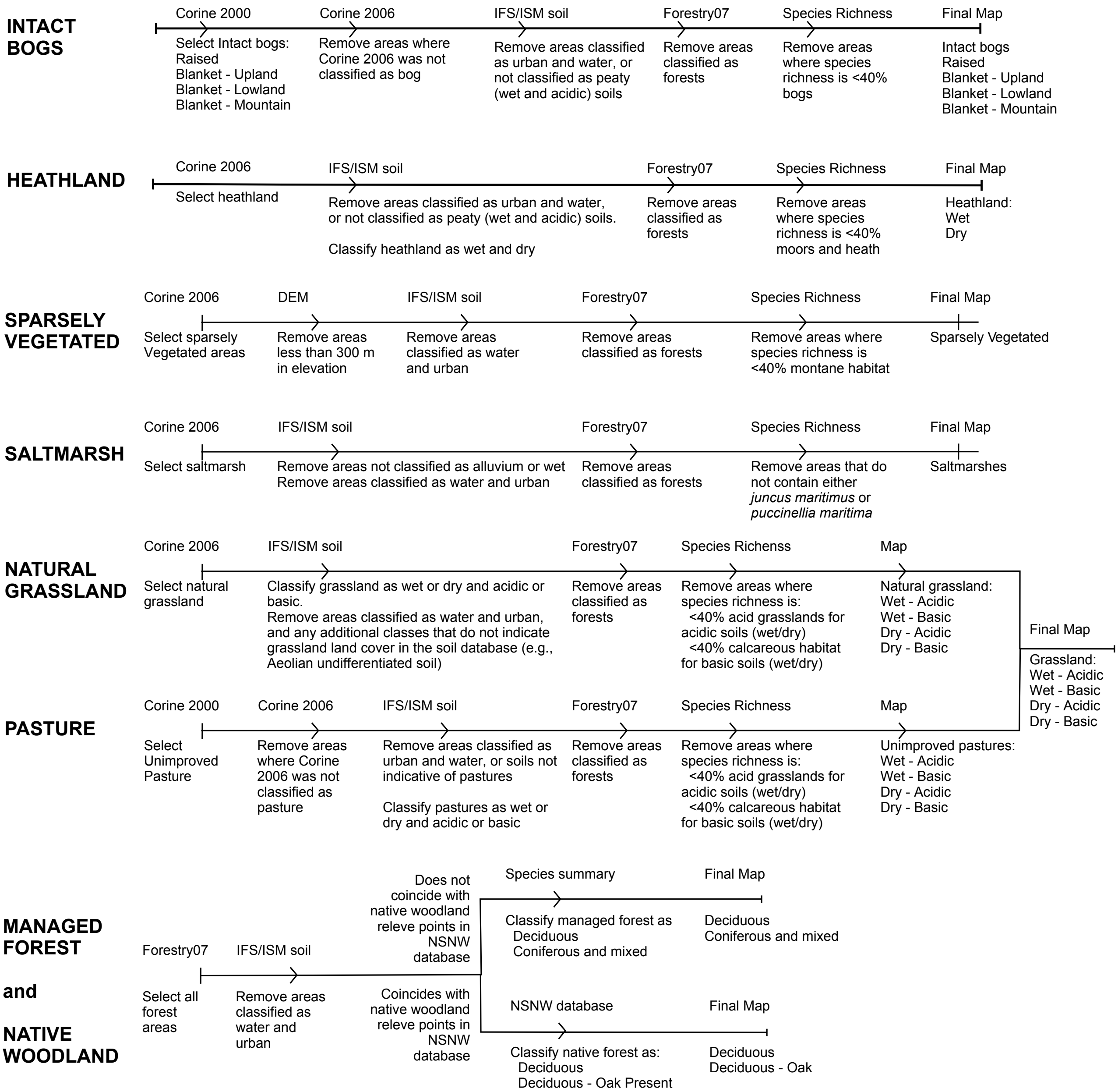

Figure A3.1. Decision tree used to define receptor ecosystem classes: intact bog, heathland, sparsely vegetated areas (moss and lichen-dominated mountain summits), saltmarshes, natural grassland (combination of natural grassland and unimproved pasture under CORINE 2006), native woodland and (managed) forest habitats.

A3.2.1 Intact bogs and heathlands

Intact bog (raised, blanket-upland, blanket-mountain, blanket-lowland) and heathland data were derived from CLC2000 (level 6) and CLC2006, respectively. Intact bog was further refined by removing all areas under CLC2006 that were not categorised as bogs. Subsequently, the IFS/IFM was used to remove areas not representative of either intact bog or heathland (e.g. urban, water, etc.). In addition, IFS/IFM was used to classify heathland as wet or dry. Forest07 was used to remove all areas from the heathland and intact bog coverages that overlapped with forests, based on the assumption that the Forest07 database was the most recent high-resolution inventory available for Ireland. Finally, plant species richness (on a 10 km × 10 km grid) was used to remove areas with <40% richness for species characteristic of bogs and heathlands.

A3.2.2 Moss and lichen-dominated mountains (sparsely vegetated areas) and saltmarshes

Saltmarshes and sparsely vegetated areas were derived from CLC2006. Sparsely vegetated areas were re-classed as moss and lichen-dominated mountains by removing areas below 300 m in elevation, areas classified as urban, water (using IFS/ISM), forest (using Forest07) and with plant species richness < 40% of montane habitat species (10 km × 10 km). Saltmarshes were refined by removing areas not characterised as alluvium or wet soils, areas classified as urban and water (using IFS/ISM), and forest (using Forest07). In addition, all areas that did not contain either *juncus maritimus* or *puccinellia maritima* under the vascular plants database (10 km × 10 km) were eliminated.

A3.2.3 Semi-natural grasslands

Unimproved pasture was derived from CLC2000 and refined by eliminating areas not classified as pasture in CLC2006; natural grassland was directly derived from CLC2006. Subsequently, both maps were categorised into wet or dry and acid or basic using IFS/ISM. The grassland and unimproved pasture maps were further refined by eliminating areas that overlapped with forests or had plant species richness < 40% for acid and basic grasslands.

A3.2.4 Forests (coniferous, deciduous, native wood and native oak)

Native woodland and managed forest were extracted from Forest07. Native woodland was extracted only if relevé classes from the NSNW database spatially coincided with Forest07 polygons; all other polygons were assumed to represent managed forest. Native woodlands were further categorised as native oak or non-oak using relevé data. Managed forests were classified based on their dominant forest type (deciduous, coniferous and mixed).

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Development of Critical Loads for Ireland: Simulating Impacts on Systems (SIOS)

EPA Research
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Author: Julian Aherne, Jason Henry and Marta Wolniewicz

Under the United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution, each party is obliged to submit national critical loads for natural habitat areas on a regular basis. In addition, critical loads are widely used by European Union Member States to assess the impacts of national policies on the exceedance of critical loads, evaluate the emissions permitting and licensing of industrial and agricultural facilities, and support Appropriate Assessments under Article 6.3 of the Habitats Directive (92/43/EEC).

Identifying Pressures

Air pollution can have unacceptable impacts on the natural environment; pollutants, such as sulphur and nitrogen oxides, can travel several hundred or even thousands of kilometers before damage, for example acidification and eutrophication, occurs. Initial efforts to reduce the extent of environmental damage led to national and international legislation aimed at controlling emissions of long-range transboundary air pollution. Emphasis on a cost-effective abatement strategy, based on scientific criteria, led to the development of the critical loads concept. In simple terms, this concept indicates how much pollutant deposition an ecosystem can tolerate without unacceptable long-term damage.

Informing Policy

Critical loads are widely used as a tool for assessing the sensitivity of terrestrial and aquatic habitats; exceedance, whereby atmospheric pollutant deposition is greater than the habitat critical load, is used as an indicator of unacceptable effects. The critical loads approach is used under the United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution and the European Union National Emission Ceilings Directive (2001/81/EC) to quantify the impacts of acidifying and eutrophying air pollutant deposition on natural ecosystems, and to guide policy on reducing the environmental impacts of transboundary air pollutants.

Developing Solutions

The report describes the determination of critical loads of acidity and eutrophication for terrestrial and aquatic ecosystems in Ireland. In addition, the project evaluated the potential impacts of nitrogen deposition on plant species diversity. National critical load data have made an important contribution to the abatement of long-range transboundary air pollution; however, critical loads have been virtually ignored under national policy assessments. As such, it is recommended that there should be a wider adoption of critical loads in national and international policy assessments (e.g. Article 6.3 of the Habitats Directive), and development of national synergies between the Habitats and Clean Air Directives, given that nitrogen deposition is a threat to biodiversity.

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