EEA Technical report | No 11/2014

# Effects of air pollution on European ecosystems

## Past and future exposure of European freshwater and terrestrial habitats to acidifying and eutrophying air pollutants

ISSN 1725-2237

European Environment Agency

# Effects of air pollution on European ecosystems

## Past and future exposure of European freshwater and terrestrial habitats to acidifying and eutrophying air pollutants

European Environment Agency

Cover design: EEA
Cover photo © Anke Lükewille
Layout: EEA/Pia Schmidt



Information about the European Union is available on the Internet. It can be accessed through the Europa server (www.europa.eu).

Luxembourg: Publications Office of the European Union, 2014

ISBN 978-92-9213-463-1
ISSN 1725-2237
doi:10.2800/18365

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

# Contents

# Acknowledgements

This report was prepared by the European Environment Agency (EEA) on the basis of a technical study carried out by its European Topic Centre for Air Pollution and Climate Change Mitigation (ETC/ACM) located at the National Institute for Public Health and the Environment of the Netherlands (RIVM), and the Coordination Centre for Effects (CCE) also located at RIVM. The CCE is the programme centre of the 'International Cooperative Programme for Modelling and Mapping of critical levels and loads and air pollution effects, risks and trends' (ICP M&M) of the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP Convention).

The authors of the study were Jean-Paul Hettelingh and Maximilian Posch, with contributions by Paul Ruyssenaars, Jaap Slootweg and Anke Lükewille. We wish to thank Dominique Richard and Sophie Condé, European Topic Centre on Biological Diversity, for constructive comments on the draft version of this report.

The EEA project manager of this report was Anke Lükewille.

The underpinning work was also partly funded by the Directorate for Climate and Air Quality of the Dutch Ministry of Infrastructure and the Environment, under the European Commission's Seventh Framework Programme, Theme ENV.2011.1.1.2-1, Grant agreement no. 282910 'Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems' and by the Working Group on Effects through the trust fund for the effect-oriented activities under the LRTAP Convention. The national information on critical loads was provided by National Focal Centres within the LRTAP Convention's International Cooperative Programme on Modelling and Mapping.

The EEA acknowledges comments received on the draft report from the Eionet national reference centres of EEA member countries and the European Commission (DG Environment).

# Executive summary

Poor air quality not only harms human health; it also impacts the structure and function of ecosystems, often far away from the emission sources. This report focuses on the deposition of airborne sulphur (S) and nitrogen (N) compounds and their negative effects on ecosystems. N- and S-containing air pollutants are released to the atmosphere by combustion processes such as the burning of coal or petrol, and by non-combustion processes such as agricultural fertiliser application (EEA, 2013a; EEA, 2014a).

The report evaluates how European ecosystems were affected by acidifying and eutrophying air pollutants in the past decades, and also how they are predicted to be affected in the future if the 2012 amended Gothenburg Protocol under the Convention on Long-range Transboundary Air Pollution (LRTAP) will be fully implemented by 2020. The presented results will be used to inform forthcoming updates of the EEA Core Set Indicator 'Exposure of ecosystems to acidification, eutrophication and ozone' (CSI 005) (EEA, 2012a) and the biodiversity indicator 'Critical load exceedance for nitrogen' (Streamlining European Biodiversity Indicators; SEBI 009) (EEA, 2010a).

## Background

Over the last century, rising anthropogenic air pollutant emissions accompanied increasing industrialisation in Europe. Polluted air masses containing sulphur (S) and nitrogen (N) compounds can travel long distances over national borders and damage other countries' resources: their freshwaters, forests, grasslands or cultural heritage (i.e. buildings, monuments, etc.).

Atmospheric deposition of such pollutants caused the past acidification of thousands of European lakes, rivers and streams. Fish species such as brown trout and Atlantic salmon, the latter a fish that spends most of its life in the sea before returning to fresh water to spawn, are particularly sensitive to acidification. 'Acid rain' led to the loss of fisheries in large regions of Sweden and Norway, with the issue being recognised as a major environmental problem by scientists and the public from the 1960s (e.g. Odén, 1968).

In the early 1970s symptoms of widespread forest decline appeared in central Europe, with the acidification of many forest soils first being regarded as a major cause in Germany (e.g. Ulrich et al., 1979). Scientific consensus subsequently emerged that acid deposition of S and N compounds was playing a significant role as predisposing or contributing factors leading to the observed impacts on trees.

To allow the quantification of environmental harm associated with air pollution, the so-called 'critical loads' concept was introduced as an effects-based tool for assessing the sensitivity of freshwater and terrestrial habitats to the harmful effects of S and N deposition (e.g. Nilsson and Grennfelt, 1988). A critical load is the upper limit of one or more pollutants, deposited to the Earth's surface, that an ecosystem such as a lake or a forest can tolerate without being damaged in its function (as for example the nutrient nitrogen cycle) or its structure (as for example with respect to plant species richness). A positive difference between the deposition loads of acidifying and/or eutrophying airborne pollutants and the critical loads is termed an 'exceedance' (see Boxes 1.1 and 1.3 in Chapter 1).

With respect to eutrophication, in different regions of Europe the atmospheric supply of nutrient N is in the range of around 2 to more than 40 kilograms per hectare per year (see Box 1.1 in Chapter 1). This has the potential to enrich the short- and long-term N content of soils, resulting in increased plant growth and hence species competition. The N supply via the air can therefore directly lead to eutrophication effects in terrestrial habitats, such as nutrient-poor grasslands. While excessive N stimulates the presence of nitrophilous (nitrogen-loving) plant species, it reduces the occurrence of species adapted to low N availability. This in turn can lead to changes in species richness i.e. changes in biodiversity over time (e.g. Steven et al., 2004; Emmett et al., 2007).

## Policy context

### *Air pollution*

Internationally, a first step to address air pollution related impacts on health and the environment was the 1979 United Nations Economic Commission for Europe (UNECE) Geneva Convention on Long-range Transboundary Air Pollution (LRTAP Convention) (UNECE, 1979). A centrepiece of the convention is the Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (UNECE, 1999), subsequently amended in 2012 (UNECE, 2012). The protocol sets national ceilings (limits) for the main air pollutants and established the critical loads concept as a tool able to inform political discussions concerning damage to sensitive ecosystems.

The Gothenburg Protocol was followed in 2001 by the European Union's (EU's) National Emission Ceilings (NEC) Directive which set specific environmental objectives addressing acidification and eutrophication impacts on ecosystems, to be met by 2010 (EC, 2001). The directive introduced legally binding national emission limits for four main air pollutants, including three important pollutants that contribute to acidification and eutrophication: sulphur dioxide ($SO_2$), nitrogen oxides ($NO_X$) and ammonia ($NH_3$). The directive requires EU Member States to have met emission ceilings by 2010 and in years thereafter, although in actuality around half of all Member States missed at least one of their ceilings by 2010 (EEA, 2014a). The NEC Directive is currently under revision (Box ES.1).

The long-term strategic objective and core of a new European Clean Air Package, proposed by the European Commission (EC) in December 2013, is to attain air quality levels that do not give rise to significant negative impacts on, or risks for, human health and the environment. Concerning ecosystem impacts the proposed text of the Strategy names as the long-term EU objective *'no exceedance of the critical loads and levels which mark*

**Box ES.1 Review of the EU's air policy and the new European Clean Air Package**

In December 2013, the European Commission (EC) published its proposed European Clean Air Package following a detailed two year review of the EU's air policy. The proposed strategic goals for 2020 and 2030 are laid down in the Communication *A Clean Air Programme for Europe* (EC, 2013). The Communication contains as its overall long-term strategic objective the ambition of attaining air quality levels that do not give rise to significant negative impacts on, or risks for, human health and the environment. Addressing ecosystem impacts, the proposed text contains the long-term objective of *no exceedance of the critical loads and levels which mark the limits of ecosystem tolerance*. More concretely, the proposed goal is to achieve a situation whereby the EU ecosystem area exceeding critical loads for eutrophication is reduced by 35 % by 2030 (EC, 2013).

A first general objective of the proposed Package is to ensure full compliance with existing air quality policies and coherence with the EU's international commitments by 2020, here particularly the amended Gothenburg Protocol. A full implementation of existing measures will be targeted, including compliance with air quality limit values and measures on transport, small and medium-scale combustion and background pollution (within the EU MS, intra-EU and globally). The Communication also highlights the importance of the agriculture sector in terms of the EU being able to achieve its desired levels of air quality in the future: '*For ammonia…, EU source legislation will deliver only around 25% of the required reduction. Thus the case for source measures for agriculture is pressing…*' The proposal suggests further measures to abate ammonia emissions from agriculture and recognises the co-benefits associated with this *'will also help reduce emissions of nitrous oxide, a greenhouse gas regulated under the Kyoto Protocol'*.

A second priority of the European Clean Air Package is to reduce the impact of air pollution beyond 2020, with 2030 as the target year. A revision of the NEC Directive is included in the proposed package, consistent with the implementation of the 2005 Thematic Strategy on Air Pollution. The new NEC Directive proposes new national emission reduction commitments applicable from 2020 and 2030 for $NO_X$, NMVOC, $SO_2$, $NH_3$, with additional ceilings for fine particulate matter ($PM_{2.5}$) and methane ($CH_4$) now included. To ensure timely compliance, interim targets are proposed for 2025. The foreseen staged tightening of commitments aims at compliance with the amended Gothenburg Protocol by 2020, followed by more ambitious reductions from 2030 onward. Detailed information on the Clean Air Package can be found on the EC's website (EC, 2014a).

*the limits of ecosystem tolerance*'. More concrete the suggested goal is to achieve a situation where the EU ecosystem area exceeding critical loads for eutrophication is reduced by 35 % by 2030 (EC, 2013; Box ES.1).

***Biodiversity***

In April 2012, a new EU biodiversity strategy was adopted which is '*aimed at reversing biodiversity loss and speeding up the EU's transition towards a resource efficient and green economy*' by 2020 (EC, 2012). In the EU, the conservation status of habitat types of European interest in grassland ecosystems has been identified to be 'unfavourable – bad' for 54 % of the habitats. Agricultural intensification and land abandonment provide two of the main pressures on biodiversity linked to grassland ecosystems. Habitat fragmentation and conversion to biofuel or forest cultivation also represent growing threats (EEA, 2010b). Contributing to biodiversity harm, deposition of airborne nitrogen has also been identified as a threat because '*such deposition encourages the growth of competitive plant species, favouring species-poor mesotrophic and eutrophic communities and reducing the structural density of grasslands*' (e.g. EC, 2008b; see also Box ES. 2).

## Main findings

Applying latest scientific knowledge and a modelling approach consistent with the one used under the Gothenburg Protocol amendment and the NECD revision, this report has investigated the past and future (1880 to 2030) effects of the atmospheric deposition of S and N compounds on sensitive elements of the environment in Europe. Impacts on the following are discussed:

- ecosystem-types defined according to the European Nature Information System (EUNIS) Habitats classification ([1]);
- areas designated as Natura 2000 sites, a EU conservation network which aims at ensuring the long-term survival of Europe's most valuable and threatened species and habitats, and
- species richness in selected grassland ecosystems, identified within the LRTAP Convention as a possible biodiversity indicator sensitive to the impacts of air pollution (see Box ES.2).

A scenario is used that calculates probable conditions in past decades (a so-called hindcast scenario). It is based on emission trends since 1880 (Schöpp et al., 2003), with deposition patterns following different versions of the EMEP model (e.g. Hettelingh et al., 2013; Box 2.1). Further, different forecast scenarios are applied in this report (based on Amann et al., 2011):

- a (baseline) scenario assuming the implementation of current legislation (CLE) by 2020, as defined in the amended Gothenburg Protocol;
- two scenarios assuming that between 2020 and 2030 current legislation (GP CLE) or maximum technically feasible reduction (MTFR) measures are implemented.

The report applies the concept of critical loads exceedances, using the most recent critical load database (Posch et al., 2012). Biodiversity-related results are based on a first application of a nitrogen dose–response relationship (Stevens et al., 2010a; Stevens et al., 2010b) for specific European grasslands defined according to EUNIS Habitats classification (EEA, 2014b).

**Box ES. 2 Species richness in grasslands as possible biodiversity indicator**

In 2007, when efforts began to amend the Gothenburg Protocol, the Executive Body of the LRTAP Convention invited its Working Group on Effects (WGE) '*to consider further quantification of policy-relevant effect indicators such as biodiversity change, and to link them to integrated modelling work*' (UNECE, 2007). This invitation prompted work by the International Cooperative Programmes under the LRTAP Convention to review biodiversity indicators (Hettelingh et al., 2009; WGE, 2013a and 2013b), for possible application in air pollution scenario analyses. Species richness in grassland ecosystems was identified by the WGE as one such possible indicator.

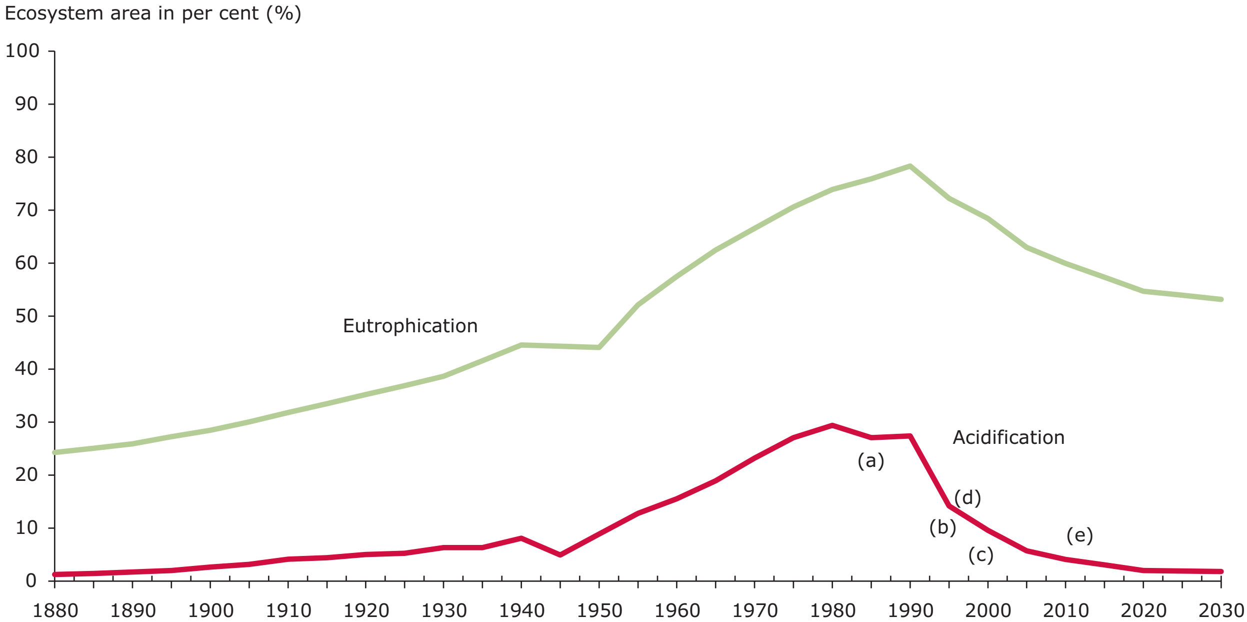
([1]) Database hosted by the EEA.

According to the hindcast scenario, peaks in exceedances of the critical loads for acidification in habitats such as freshwaters and forests (forest soils) occurred in 1980: in the EU-28, 43 % of the ecosystem area was exceeded (30 % of the whole of Europe see Figure ES.1). In subsequent years, international cooperation to combat the environmental effects of particularly airborne $SO_2$ pollution under the LRTAP Convention and within the EU became effective. The findings suggest that by 2020, the ecosystem area where critical loads are exceeded, as well as the absolute magnitude of exceedances, will be as low as they were in 1880, i.e. only 4 % of the EU-28 ecosystem area will still have exceedances of the acidification critical loads. The results do not change significantly if the focus is only on Natura 2000 areas, with approximately 2 % of these areas being projected to have exceedances of the acidification critical loads in 2020. It must be noted however that it may still take decades before ecosystems recover from acidification, even when they receive deposition not exceeding the critical loads (see e.g. ICP Waters, 2011).

According to the scenarios assessed in the report, critical loads for eutrophication peaked with 79 % of the EU-28 ecosystem area having exceedances in 1990. This percentage is projected to decrease to 54 % in 2020 under the amended Gothenburg Protocol. As the amount of nutrient N that is deposited per hectare per year will decrease, the absolute magnitude of exceedances will also be reduced considerably in most areas. The exceptions to this are a few 'hot spot' areas in western France and the border areas between the Netherlands, Belgium and Germany, as well as in northern Italy. When computed for Natura 2000 areas alone, the extent of eutrophication critical load exceedances is projected to be 65 % in 2020. The report concludes that even if all technically feasible reduction measures are implemented, the area at risk of eutrophication will still be 51 % in the EU-28 in 2030.

Finally, the report presents the first assessment of possible impacts of nutrient nitrogen deposition on species richness in nutrient-poor grasslands.

**Figure ES.1 Area (in per cent) where critical loads for eutrophication and acidification are exceeded in sensitive ecosystems in Europe, 1880–2030**




**Note:** (a) First Sulphur Protocol (1985); (b) Second Sulphur Protocol (1994); (c) Gothenburg Protocol (1999); (d) NEC Directive (2001); (e) Amended Gothenburg Protocol (2012).

The (a) to (e) show the point in time when protocols under the LRTAP Convention or the EU's NEC Directive were signed or adopted. The area covered is the so-called EMEP domain, here the geographic area between 30°N-82°N latitude and 30°W–90°E longitude. This includes all EU-28 countries as well as the EEA member and cooperating countries, other non-EU eastern European countries, parts of the Russian Federation and parts of Turkey (EMEP, 2014a and 2014b).

The percentage (%) results are based on emission trends since 1880 (Schöpp et al., 2003), with deposition patterns following different versions of the EMEP model (e.g. Hettelingh et al., 2013), and the most recent critical load database (Posch et al., 2012) in combination with the current legislation (CLE) scenario developed for the Gothenburg Protocol amendment for the period 2010 to 2030 (Amann et al., 2011).

These results show that the computed species richness in European areas is projected to improve from below 70 % in 1980 to 82 % by 2020. This outcome does not significantly change when the analysis is restricted to the chosen grasslands within Natura 2000 areas only. The use of species richness as a biodiversity indicator can be criticised because it may be influenced by, for example, invasive species. However, in this report the chosen indicator is used only in a relative sense, i.e. for comparing effects between scenarios or between countries.

## Conclusions

As $SO_2$ emissions have fallen, the relative contribution made by ammonia ($NH_3$) emitted from agricultural activities and nitrogen oxides ($NO_X$) emitted from combustion processes to surface water and soil acidification has increased or even become predominant in some regions in Europe. $NH_3$ and $NO_X$ are also eutrophying air pollutants. The assessment findings shown in this report indicate that measures to abate $SO_2$ and $NO_X$ emissions over the last decades have generally been successful in improving the situation related to acidification phenomena. In addition, structural changes in national economies, such as the decline in heavy industry and the closure of older inefficient power plants in certain countries, have also contributed to this development. Emissions of these two pollutants are projected to further decrease in future years but $NH_3$ emissions will broadly stay constant to 2020, with agriculture as the main source.

When implementing current legislation, more than 50 % of the ecosystem areas classified according to the EUNIS habitats classification are expected to be still at risk of excessive nutrient N deposition in 2020. However, the magnitude of exceedances will decrease considerably. The relative (%) increase in grasslands' species richness from 1990 to 2020 also indicates that emission reductions have a positive effect on biodiversity. This is similarly true for sensitive areas within the Natura 2000 network. Notwithstanding that the first approach presented in this report to address the effects of nutrient nitrogen deposition on species richness in grasslands has its limitations and uncertainties, the results suggest that further reductions in $NO_X$ and $NH_3$ emissions will have positive effects on biodiversity in habitat types of European interest.

When assuming the implementation of maximum technically feasible reduction (MTFR) measures to reduce $NH_3$ and $NO_X$ emissions between 2020 and 2030, decreases in critical load exceedances and increases in species richness in grasslands will be only slightly higher compared to the current legislation scenario. For example the increase in species richness is calculated to be 86 % in 2030, compared to 82 % when assuming the Gothenburg Protocol's current legislation scenario.

The new strategy proposed by the European Commission in late 2013 (A Clean Air Programme for Europe) aims at achieving a situation where the EU ecosystem area exceeding critical loads for eutrophication is reduced by 35 % by 2030 relative to 2005 (EC, 2013; Box ES.1).

# 1 Introduction

Over the last century, rising anthropogenic air pollutant emissions accompanied increasing industrialisation in Europe, until targeted abatement measures started taking effect (see Box 1.1). Air pollution was first recognised as an issue on the local scale. Particularly in densely populated, industrialised areas people started complaining about poor air quality, and an air pollutant emission 'control' tactic became the so-called 'high stack policy' for power plants in the 1960's and 1970's. Air pollutants were dispersed in higher atmospheric layers and the local situation improved. However, polluted air masses can travel long distances over national borders and damage resources of other countries: their rivers and lakes, forests, grasslands or cultural heritage. Emissions from elevated chimneys contributed significantly to the transboundary air pollution problem.

Poor air quality not only harms human health; it also impacts the structure and function of ecosystems, often far away from the emission sources. This report focuses on the deposition of airborne sulphur (S) and nitrogen (N) compounds (Box 1.1) and their negative effects on ecosystems. N- and S-containing air pollutants are released to the atmosphere by combustion processes such as the burning of coal or petrol, and by non-combustion processes such as agricultural fertiliser application (EEA 2013a, EEA 2014a). Atmospheric deposition of those pollutants caused in the past acidification of thousands of lakes, rivers and streams. Fish species such as brown trout and Atlantic salmon, the latter a fish that spends most of its life in the sea and returns to fresh water to spawn, are sensitive to acidification. 'Acid rain' led to loss of fisheries in large regions of northern Europe in particular, which was recognised as a major environmental problem by scientists and the public in the 1960s (Odén, 1968). Broad international cooperation to address air pollution and acidification began with the 1972 United Nations Conference on the Human Environment in Stockholm, Sweden. The conference recommendations included that governments communicate about environmental issues that have international implications, such as air pollution.

In the early 1970s, symptoms of widespread forest decline first appeared in central Europe. Serious acidification of many forest soils in Europe was seen as a major cause (e.g. Ulrich et al., 1979). Scientific consensus subsequently emerged that acid deposition of S and N compounds played a significant role as predisposing or contributing factors leading to the observed decline of trees.

A first step to enforce emission reduction measures internationally was the 1979 United Nations Economic Commission for Europe (UNECE) Geneva Convention on Long-range Transboundary Air

**Box 1.1 The deposition of air pollutants to the Earth's surface**

Air pollutants emitted to the atmosphere undergo dispersion and many of them subsequently are involved in a number of (photo-) chemical reactions. Important in relation to ecosystem effects is that pollutants are, after a certain lifetime, deposited on Earth by one of two processes: wet deposition or dry deposition. Wet deposition occurs when pollutants are emitted into the atmosphere and oxidised to form an acid. Sulphur dioxide ($SO_2$), for example, is emitted and oxidised to sulphuric acid ($H_2SO_4$). The pollutants then fall to earth as acidic precipitation (as rain, snow, hail or dew). Dry deposition occurs when the acids are transformed chemically into gases and salts, and then deposit for example on vegetation surfaces. They can subsequently be washed off into soils by rain. $SO_2$ has normally a lifetime of a few days in the air. The lifetime of $NO_x$ depends on whether it is dispersed close to the Earth's surface, where it can react with other pollutants (lifetime usually a few hours) or in higher layers of the atmosphere, the troposphere (lifetime ca. 1–2 weeks in the upper troposphere). Airborne $NH_3$ is usually relatively short-lived (1–5 days or less).

Pollution (LRTAP Convention), put into effect in 1983 (Box 1.2). The protocols under the LRTAP Convention were followed by the EU's National Emission Ceilings (NEC) Directive (EC, 2001). Article 5 of the directive defines an interim environmental objective concerning the acidification of ecosystems: '*areas where critical loads of acid deposition are exceeded shall be reduced by at least 50 % (in each grid cell) compared with the 1990 situation*'. Footnote 1 of Annex I to the NEC Directive addresses eutrophication: '*Meeting those [interim environmental] objectives is expected to result in a reduction of soil eutrophication to such an extent that the Community area with depositions of nutrient nitrogen in excess of the critical loads will be reduced by about 30 % compared with the situation in 1990'*. A definition of 'critical load' will be provided in Section 1.1. The NEC Directive is currently under revision (see Box 1.2).

**Box 1.2 The policy context**

**The 1979 LRTAP Convention and its protocols**

Since 1979 the LRTAP Convention has addressed some of the major environmental problems of the UNECE region through scientific collaboration and policy negotiation (UNECE, 1979). The Convention has now 51 Parties (47 in Europe), and the major aim is that Parties shall endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution. Parties develop policies and strategies to combat the discharge of air pollutants through exchanges of information, consultation, research and monitoring.

The first Protocol under the LRTAP Convention, the 1985 Sulphur Protocol, adopted a flat rate approach (reduction of national annual sulphur (S) emissions by at least 30 % between 1980 and 1993). The two succeeding Protocols, the 1994 Sulphur Protocol and the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone were effect based. This means that they aimed at efficiently reducing particularly S emissions where environmental effects were most severe. The 1999 Gothenburg Protocol set emission ceilings for 2010 for four pollutants: sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$), volatile organic compounds (VOC) and ammonia ($NH_3$). This so-called multi-pollutant/multi-effect protocol was amended in 2012. The amendment relates to further reduction of pollutants affecting human health, leading to acidification and eutrophication of ecosystems, and climate change. For details on the LRTAP Convention and the protocols, please see the respective website (UNECE, 2014).

**European Union strategies and legislation addressing air pollution**

Within the European Union (EU), the Sixth Environment Action Programme (6EAP; 2002 to 2012) contained the long-term objective of achieving levels of air quality that do not give rise to significant negative impacts on, and pose risks to, human health and the environment, i.e. also addressing ecosystems.

In order to improve air quality, the EU has acted at a number of levels to reduce exposure to air pollution: through legislation, through cooperation with organisations responsible for air pollution in different sectors, through national and regional authorities and non-government organisations, and through research. Strategies have been developed that call for both reduction of emissions at source and reduction of exposures. Main policy instruments include the National Emission Ceilings (NEC) Directive (EC, 2001) containing emission ceilings for 2010 and years thereafter, the Ambient Air Quality Directives (AQD) establishing ambient air quality standards (EC 2004; EC, 2008a) and source-specific legislation addressing industrial emissions, road and off-road vehicle emissions, fuel quality standards etc.

A main strategic element of the EU policy is so far the 2005 Thematic Strategy on Air Pollution (TSAP). The strategy is a response to the EU's 6 EAP and includes with respect to terrestrial and aquatic ecosystems the objective '*no exceedence of critical loads and levels for acidification or eutrophication*'. To move toward achieving the TSAP objectives, the EU's air legislation follows a twin-track approach of implementing local air quality standards together with source-based mitigation controls including binding national limits for emissions of the most important pollutants. The long-term strategic objective and core of the *new European Clean Air Package*, proposed by the European Commission (EC) in December 2013, is to attain *'air quality levels that do not give rise to significant negative impacts on, or risks for, human health and the environment'*. Concerning ecosystem impacts the new policy objective laid down in the strategy is to achieve a situation where the EU ecosystem area exceeding critical loads for eutrophication is reduced by 35 % by 2030 (EC, 2013; EC, 2014; see also Box ES.1).

**Box 1.2 The policy context (cont.)**

In January 2014, the Seventh Environment Action Programme entered into force, guided by the overall long-term vision *'Living well, within the limits of our planet'* (7EAP; EC, 2014b). Key action areas cover challenges to human health and wellbeing as well as natural capital.

**European Union strategies and legislation addressing biodiversity**
Natura 2000 is the centrepiece of EU nature and biodiversity policy. It is an EU-wide network of nature protection areas established under the 1992 Habitats Directive (EC, 1992). The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. It is comprised of Special Areas of Conservation (SAC) designated by Member States under the Habitats Directive, and also incorporates Special Protection Areas (SPAs) which they designate under the 1979 Birds Directive (EC, 2009).

In the EU, a new biodiversity strategy was adopted in April 2012, which '*is aimed at reversing biodiversity loss and speeding up the EU's transition towards a resource efficient and green economy*' by 2020 (EC, 2012).

The attainment year for the Article 5 interim objective was 2010. A recent EEA report showed that when considering the EU area as a whole, as stipulated in the directive, an assessment performed on the basis of 2001 scientific knowledge indicates that the area at risk of eutrophication was reduced by 34 % in the EU-27 as a whole (and by 30 % in the EU-15) (EEA, 2012b). Thus, the directive's objective was met at EU level. However, when an assessment was performed using present scientific knowledge, the NEC Directive eutrophication objective was not met. In this case, the computed reduction of the area at risk turns out to be smaller than 30 % (22.5 % for the EU-27, and 22.8 % in the EU-15). The critical loads concept and latest scientific knowledge is also the main approach used in this report to evaluate past and future effects of air pollution on ecosystems.

## 1.1 The critical loads concept

The concept of critical loads is a method to estimate sensitivity towards stress factors and risks to ecosystems. The critical load definition used in this report represents an environmental quality standard which covers the effects of all relevant air pollutant emission sources on one or more receptors to be protected in the environment. It is defined as '*a quantitative estimate of an 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; see also UNECE, 2013). This definition can apply to several different receptors: terrestrial, groundwater and freshwater habitats. Critical loads are used as a tool for assessing the sensitivity of these habitats to the harmful effects of airborne pollutants (see for example Hettelingh et al., 2007).

To calculate a critical load, the target ecosystem is first defined, for example a forest, and sensitive elements such as forest growth rate must be identified. The next step is to link the status of the elements to a chemical criterion, for example, the base cation (Bc) to aluminium ($Al^{3+}$) ratio in soil, and a critical limit, such as $Bc/Al^{3+} = 1$, that should not be exceeded. Finally, a mathematical model is applied to calculate the deposition loads that result in the critical limit being reached. The resulting deposition amount is called the critical load, and a positive difference between the current deposition load and the critical load is termed the 'exceedance'. This information is used to help guide and formulate policies that define the emissions (here S and N compounds) abatement required to protect sensitive habitats across Europe (for details see for example Hettelingh et al., 2013).

The critical loads approach is applied under the LRTAP Convention and the EU's NEC Directive to quantify impacts of acidifying and eutrophying air pollutant deposition on ecosystems. It was first developed based on research addressing water and soil acidification.

## 1.2 Ecosystem areas addressed in this report

***Ecosystem-types according to the European Nature Information System (EUNIS) Habitats classification***

Based on the critical loads concept, possible negative effects of atmospheric S and N pollution

**Box 1.3 Critical load database**

The European database of critical loads for acidification and eutrophication, also used in this study, is compiled by the Coordination Centre for Effects (CCE) by applying methods that are described in CCE Status Reports (see for example CCE, 2013) and as adopted by the Task Force of the International Cooperative Programme on 'Modelling and Mapping critical levels and loads and air pollution effects, risks and trends' (ICP M&M) under the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) (UNECE, 2014). The European background information used around 2001, when the NEC Directive was adopted, covered only forest ecosystems (EUNIS class G) and freshwaters. Now semi-natural vegetation (EUNIS classes D, E and F) is also included. This leads to a broader range of critical loads for nitrogen in particular, based on a range of critical acceptable nitrogen concentration in the soil solution that varies between 0.2 g N $m^{-3}$ and 0.3 g N $m^{-3}$, on the precautionary side. The European critical load database contains about 1.5 million critical load data points.

The methods to assess critical loads are documented in the so-called Mapping Manual (UNECE, 2013), for use by National Focal Centres (NFCs) under the ICP M&M. NFCs compute critical loads and submit data to the CCE at regular intervals following consensus of Parties to the LRTAP Convention (including the 28 EU Member States). It was agreed that the CCE uses a European background database (Reinds et al., 2008; Posch and Reinds, 2005) to compute critical loads for ecosystems in countries that do not submit data.

can be analysed by focussing on European ecosystem-types defined according to the EUNIS Habitats classification (EEA, 2014b). A critical load is the upper limit of the amount of a pollutant a habitat such as a lake or a forest can tolerate without being damaged in its structure (as for example the plant species richness) or its function (as for example the nutrient nitrogen cycle) (for details see Box 1.3).

***Natura 2000 network***

The Natura 2000 network's aim is to ensure the long-term survival of Europe's most valuable and threatened species and habitats (Box 1.2). Because the network is targeted to selected species and habitats, it does not cover all ecosystem-types as defined in the EUNIS Habitats classification. In this report, Natura 2000 areas have been chosen as a specific receptor that can be sensitive to impacts of atmospheric S and N deposition.

***European grasslands***

The question arises if an excess S and/or N deposition can also be linked directly to changes in species richness. In 2007, when efforts began to revise the Gothenburg Protocol, the Executive Body of the LRTAP Convention invited its Working Group on Effects (WGE) *to consider further quantification of policy-relevant effect indicators such as biodiversity change, and to link them to integrated modelling work* (UNECE, 2007). This invitation promoted work by the International Cooperative Programmes under the LRTAP Convention to review biodiversity indicators (Hettelingh et al., 2009; WGE, 2013a and 2013b), and possibly apply them in scenario analyses. Excessive nitrogen in ecosystems is known to affect plant species richness (Bobbink et al., 1998; Stevens et al., 2004; Emmett et al., 2007). Species richness in grassland ecosystems was identified by the WGE as a possible biodiversity indicator.

Most European non-planted grasslands can be defined as 'semi-natural' because they have developed through natural processes over long periods of grazing by domestic stock, cutting and even deliberate light burning regimes (EEA, 2010b). As requested by Article 17 of the Habitats Directive, the Member States prepared a first assessment, covering the period 2001–2006. According to this assessment, the conservation status of habitat types of European interest in grassland ecosystems in different biogeographic areas has been identified to be 'unfavourable-bad' for 54 % of the habitats (EEA, 2010b).

Agricultural intensification and land abandonment together provide two main pressures on biodiversity linked to grassland ecosystems and habitat fragmentation. Conversion to biofuel or forest cultivation represent growing threats (EEA, 2010b). However, deposition of airborne nitrogen has also been identified as a threat because *such deposition encourages the growth of* *competitive plant species, favouring species-poor mesotrophic and eutrophic communities and reducing the structural density of grasslands* (e.g. EC, 2008b).

The atmospheric supply of nutrient N has the potential to enrich the N content of soils, resulting in increased plant growth and hence competition for light. It can lead to eutrophication effects in sensitive terrestrial habitats, as for example nutrient-poor grasslands. Excessive N stimulates the presence of nitrophilous (nitrogen-loving) plant species, but reduces the occurrence of species adapted to low N availability. This can lead to changes in species richness, i.e. to changes in biodiversity.

Research has shown that low N deposition enhances plant species diversity and relative species richness in grasslands located in the Atlantic biogeographic zone (e.g. Stevens et al., 2010a and 2010b). This scientific knowledge allows making first assessments of effects of different atmospheric N loads on grasslands. According to the first Article 17 reporting under the Habitats Directive (see above), the conservation status of targeted grasslands in this European biogeographic region is assessed, in 70 % of the cases, as 'unfavourable-bad', i.e. the lowest category. This is worse than the average 54 % for all European grasslands targeted by the Habitats Directive EEA, 2010c).

## 1.3 Scope of this report

The overall goal of the report is to evaluate — for the whole of Europe — how aquatic and terrestrial ecosystems were affected by acidifying and eutrophying air pollutants, particularly in the past decades, and are predicted to be affected if the in 2012 amended Gothenburg Protocol under the LRTAP Convention will be implemented by 2020. Possible further improvements by 2030 are also addressed by assuming the implementation of maximum technically feasible reduction measures.

***Firstly***, this assessment reports on the computation and mapping of exceedances of the critical loads for acidification (caused by atmospheric S and N deposition) and eutrophication (caused by N deposition alone) for past, recent and future years. Receptors are ecosystem-types defined according to the EUNIS Habitats classification (EEA, 2014c).

***Secondly***, the study reports on the computation and mapping of exceedances of the critical loads for acidification (caused by S and N compounds) and eutrophication (caused by N compounds) in areas classified by the EU Member States as Natura 2000.

***Thirdly***, changes in species richness in selected grasslands of the Atlantic biogeographic region were chosen as a possible indicator for impacts on biodiversity, caused by excess atmospheric N deposition alone. The assessment is based on a first application of a N dose–response relationship, as described in detail in Chapter 2.

The findings of the report will provide the basis for an update of EEA's current Core Set Indicator 005 'Exposure of ecosystems to acidification, eutrophication and ozone' (CSI 005) (EEA, 2012a) and EEA's current biodiversity indicator 'Critical load exceedance for nitrogen' (Streamlining European Biodiversity Indicators; SEBI 009) (EEA, 2010a). The exceedance of ozone thresholds as set in the EU legislation, also part of CSI 005, is not addressed in this report.

It is beyond the scope of this report to analyse the costs and ecosystem benefits of mitigating the emissions of acidifying and eutrophying air pollutants.

# 2 Tools and assumptions used for assessing ecosystem impacts

In 2012 the Gothenburg Protocol was amended (Box 1.2). To inform discussion on the scope for further cost-effective measures, the European Monitoring and Evaluation Programme (EMEP) ([2]) Centre for Integrated Assessment Modelling (CIAM) provided a series of future emission control scenarios that illustrate options for cost-effective improvements of air quality in Europe (e.g. Hettelingh et al., 2010 and 2012; Amann et al., 2011 and ). The maps and tables presented in this report are an update of model and data versions that informed the Gothenburg Protocol revision; they are based on our knowledge of the status quo in 2013, including the following:

- different scenarios are applied in this report (based on Amann et al., 2011):
  - A (baseline) scenario assuming the implementation of current legislation (CLE) by 2020, as defined in the amended Gothenburg Protocol;
  - Two scenarios assuming that between 2020 and 2030 current legislation (GP CLE) or maximum technically feasible reduction (MTFR) measures are implemented.
- emission trends since 1880 ([3]) (Schöpp et al., 2003), deposition patterns following different versions of the EMEP model (e.g. Hettelingh et al., 2013) and the most recent critical load database (Posch et al., 2012);
- modelled deposition data provided by the EMEP Meteorological Synthesising Centre West (MSC-W) ([4]) with a spatial coverage of 0.50º × 0.25º longitude–latitude grid (provided by the LRTAP Convention, MSC-W in April 2013);
- critical loads data from the LRTAP Convention's Coordination Centre for Effects (CCE) ([5]) under the Working Group on Effects (CCE, 2013);
- recent research results on the effects of N deposition on plant species diversity and relative species richness in grasslands (e.g. Stevens et al., 2010a and 2010b).

The European Monitoring and Evaluation Programme (EMEP) is a scientifically based and policy driven programme under the LRTAP Convention for international cooperation to solve transboundary air pollution problems (EMEP, 2014a). EMEP provides an integrated system of models and observations in support of European air policies, for example the NEC Directive. The EMEP model with a spatial resolution of 50 × 50 $km^2$ was recently revised to cover a 0.50º × 0.25º (about 28 × 28 $km^2$) longitude-latitude grid (Simpson et al., 2012) (Box 3.1). In anticipation of the increased resolution of the EMEP model, National Focal Centres (NFCs) under the International Cooperative Programme on Modelling and Mapping (ICP M&M) of the LRTAP Convention responded to a CCE call for data in 2010 to update the scale (and protection requirements as appropriate) of their contribution to the European critical load database (for details, see Posch et al., 2012). Data from this most recent critical load database were used in this report. These new methods and data have enabled the recalculation of exceedances and areas at risk as a result of

([2]) Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe under the LRTAP Convention.

([3]) 1880 was chosen because this was the earliest year for which deposition data had been reconstructed as part of the EMEP work. In this kind of modelling studies, ca. 1880 is often considered as the pre-industrial area in most European countries. Schöpp et al. (2003) state that the quality of the background data (e.g. energy and industry statistics) to calculate deposition for the period 1880 to 1960 is not as reliable as the historic data for the period after 1960, which is particularly true for N deposition results.

([4]) Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP), Meteorological Synthesizing Centre West (MSC-W, 2013) at the Norwegian Meteorological Institute.

([5]) The Coordination Centre for Effects is the Programme Centre of the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends (ICP M&M, 2013) under the Working Group on Effects (WGE) of the Convention on Long-range Transboundary Air Pollution (LRTAP Convention).

**Box 2.1 Regional air quality models**

Regional air quality models or chemical transport models (CTMs) describe the functional relation between emissions and air pollutant concentration or deposition. The change over time of a concentration of species in a certain grid cell volume is described by the (changes in) mean wind speed, turbulent dispersion, chemical and physical transformation, dry and wet deposition, and emissions.

The required input for these models are the meteorological conditions, land use and land cover to determine the dry deposition of pollutants to the Earth's surface (i.e. the amount not deposited 'wet' via rain, snow, etc.). The anthropogenic, biogenic (e.g. isoprene) and — as far as possible — natural emissions (e.g. $SO_2$ emissions from volcanos) also constitute important inputs. Furthermore, regional scale models, centred over Europe for example, need boundary conditions at the lateral and upper boundaries of the model domain. Thus, these models contain in principle the most relevant processes needed to calculate the concentration and deposition fields of pollutants regulated in the EU's legislation, as for example the NEC Directive (EC, 2001).

Most regional models are so-called 3D Eulerian grid models. The model applied in the current study to provide results based upon present knowledge is the Eulerian version of the EMEP model (Tarrasón et al., 2003). Eulerian grid models calculate concentrations and deposition based on a solution of advection diffusion equations and chemical equations. These models may have complex chemical schemes.

Today, the resolutions of regional air quality models are generally 50 x 50 $km^2$ or less. Currently around 10 x 10 $km^2$ is the highest feasible grid resolution for calculating concentrations and deposition across all of Europe for the time scale of (usually) a year.

deposition patterns, provided by the LRTAP Convention's Meteorological Synthesizing Centre West (MSC-W) in April 2013.

To provide a first assessment, species richness in grasslands was chosen in this report as an indicator for changes in biodiversity caused by excess airborne nitrogen deposition. Biodiversity-related results are based on the first application of a nitrogen dose–response relationship (Stevens et al., 2010a; Stevens et al., 2010b) for specific European grasslands that are defined according to the EUNIS Habitats classification (EEA, 2014b), i.e. classes E1 (dry grasslands), E2 (mesic grasslands) and E3 (seasonally wet and wet grasslands). The hypothesis is that 100 % species richness occurred at the lowest N-deposition covered by the study of Stevens et al. (2010). This use of the dose-response relationship makes it possible to illustrate species richness — for any nitrogen emission scenario — as a percentage compared with the lowest (assumed) N deposition ([6]).

For all of the investigated sites, well documented dispersion models were used for estimating the deposition of N and S. National models were used for Germany (Gauger et al., 2002), the Netherlands (Van Jaarsveld, 2004; Asman and Van Jaarsveld, 2002) and the United Kingdom (NEGTAP, 2001). For all other countries, the EMEP-based (Pieterse et al., 2007) models were applied. Finally, the relationship between N deposition and species richness was fitted with a negative exponential curve (dose–response or D–R function).

The harmonised European land cover map (Cinderby et al., 2007) was used for the regionalised application of the above-mentioned D–R function. The analysis was carried out for EUNIS classes E1 (dry grasslands), E2 (mesic grasslands) and E3 (seasonally wet and wet grasslands) restricted to locations with precipitation between 490 mm $a^{-1}$ and 1 970 mm $a^{-1}$, altitude below 800 m and soil pH < 5.5. The limitation of available precipitation data excluded areas located east of 32ºE. The total coverage of the study was about 446 000 $km^2$.

([6]) The lowest N-deposition load, for which results for the relationship specifies and %-value for richness are available in the Stevens et al. (2010) is slightly higher than 0, about 2–3 kg N $ha^{-1}a^{-1}$. However, for the mathematical formulation the assumption is that the function is also valid for lower depositions, i.e. between 0 and the 2–3 kg N $ha^{-1}a^{-1}$. The function value at 0 is then assumed to be 100 %. The approach used in this report is based upon the following: Hettelingh, J-P., Stevens, C. J., Posch, M., Bobbink, R. and De Vries, W., 'Assessing the impacts of nitrogen deposition on indicator values of plant species in Europe', in: De Vries, Hettelingh and Posch (eds.), 'Critical loads and dynamic risk assessments of nitrogen, acidity and metals for terrestrial and aquatic ecosystems' (in prep.). A summary has also been published in the LRTAP Convention Working Group on Effects (WGE, 2013b).

**Box 2.2 Nitrogen deposition and dose-response relationship to species richness for selected grasslands**

Stevens et al. (2010a and 2010b) surveyed 153 semi-natural acid grasslands on a transect across Europe with total atmospheric N deposition ranging from 2 kg N $ha^{-1}$ $a^{-1}$ to 44 kg N $ha^{-1}$ $a^{-1}$, covering much of the range of deposition found in the industrialised world. The surveyed grasslands were dominated by species such as Common Bent *(Agrostis capillaris)*, Sheep Fescue *(Festuca ovina)* and Red Fescue *(Festuca rubra)*, Common Tormentil *(Potentilla erecta)* and Heath Bedstraw *(Galium saxatile)*. The survey covered acid grasslands all located in countries of the Atlantic biogeographic zone: 9 grasslands in Belgium, 3 in Denmark, 25 in France, 12 in Germany, 11 in Ireland, 7 in the Netherlands, 9 in Norway, 4 in Sweden and 88 in the United Kingdom (including 11 sites in Northern Ireland and on the Isle of Man). The United Kingdom has many sites; this is due partly to the intensive national survey within the framework of earlier studies, and partly to the fact that the investigated so-called *Violion caninae* grasslands cover a much larger area there than in other countries addressed by the study mentioned above (Stevens et al., 2004). None of the investigated grasslands were either fertilised or in the vicinity of a point source of nitrogen, and many were in areas where nature conservation policies applied. Within each site, five randomly located 4 $m^2$ vegetation quadrants were surveyed (for methodological details see Stevens et al., 2010a and 2010b).

The above mentioned gradient study also indicates that the presently defined critical loads of 10–15 kg N $ha^{-1}$ $a^{-1}$ are too high to prevent species changes in the grassland communities assessed, i.e. part of those changes can already peak at an N load of 6-7 kg $ha^{-1}$ $a^{-1}$ (Payne et al., 2013).

# 3 Exposure of ecosystems to eutrophication and acidification — results

## 3.1 Development of the exposure indicators over time (1850–2030)

The methodologies described in Chapter 2 were used to calculate critical load exceedances and areas at risk. Assuming that the Gothenburg Protocol current legislation (GP-CLE) scenario was implemented as of 2010, Figure 3.1 shows that in 2030, both the percentage of the area exceeded (in %), i.e. the area at risk of acidification, as well as the magnitude of the average accumulated exceedance (AAE in eq $ha^{-1}a^{-1}$), are similar to those in 1880. The results are 2 % and 5 eq $ha^{-1}a^{-1}$, respectively (for units and definitions, please see Box 3.1).

When the transboundary character of air pollution was first robustly established and documented in the 1970s, initially much attention was given to the abatement of acidifying sulphur dioxide ($SO_2$) emissions (e.g. OECD, 1977) (Box 1.1). This is reflected in Figure 3.1 where peaks in the area at risk of acidification and the exceedance magnitude are shown to have occurred in 1980. In the decades after, international cooperation to combat the environmental effects of air pollutants became effective. In 1983, the LRTAP Convention entered into force, in 1999 the Gothenburg Protocol was signed and in 2001 the EU's NEC Directive was adopted by the Member States (Box 1.1). It also has to be noted that structural changes in countries' economies, such as the decline in heavy industry and the closure of older inefficient power plants, also contributed to the downwards trends in emissions over the last decades.

According to the GP-CLE emissions scenario, eutrophication continues remaining an issue in 2020: about 55 % (54 % in the EU-28) of the European *ecosystem area* [7] will be affected in 2020, with an AAE of about 144 eq $ha^{-1}a^{-1}$ (159 eq $ha^{-1}a^{-1}$ in the EU-28). In 1990 the AAE peaked with 361 eq $ha^{-1}a^{-1}$ (505 eq $ha^{-1}a^{-1}$ in the EU-28). According to the GP-CLE scenario the situation will only slightly improve between 2020 and 2030.

As $SO_2$ emissions have fallen, the relative contribution made by ammonia ($NH_3$) emitted from

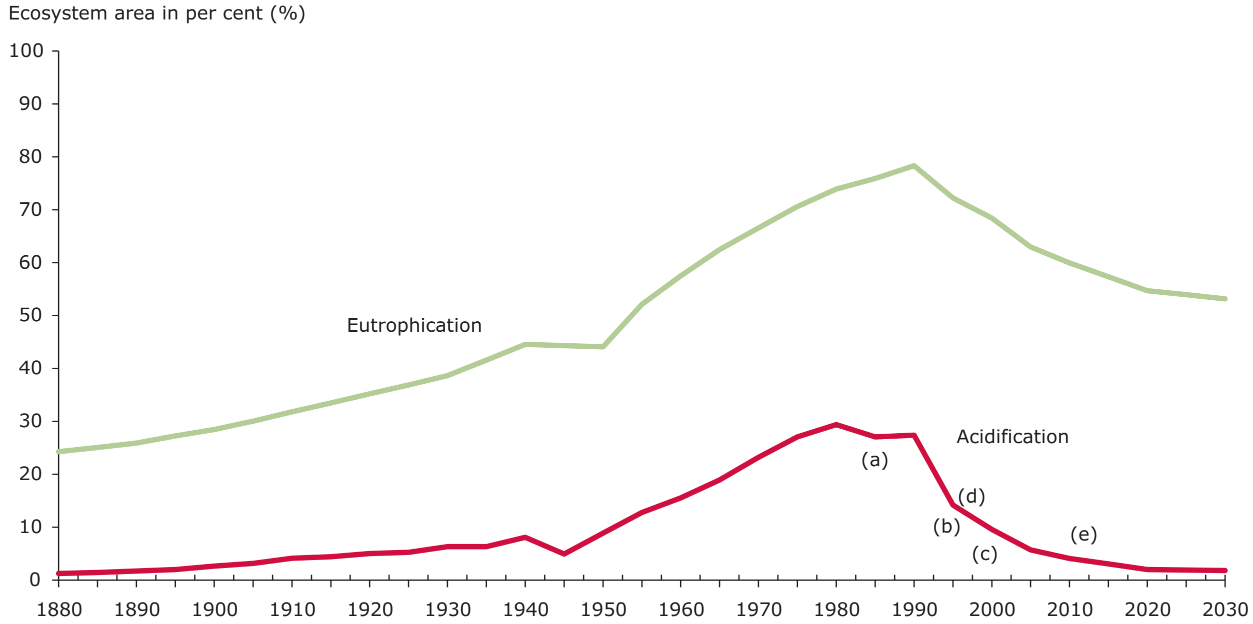
**Box 3.1 Units and definitions**

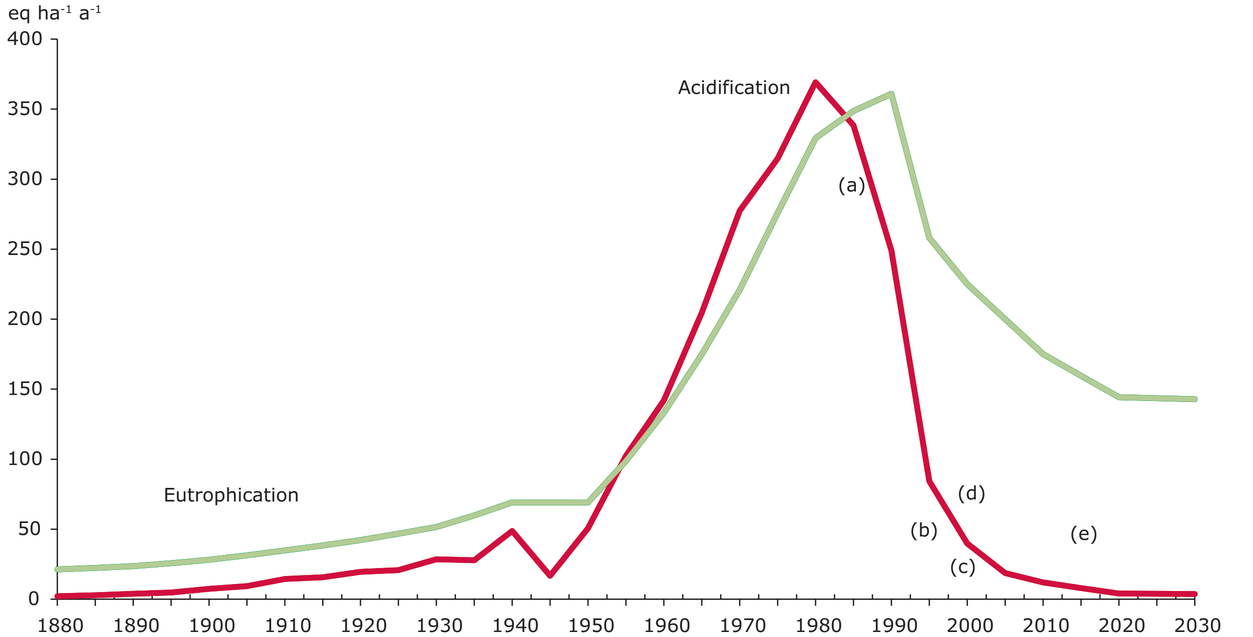
For calculating the extend of critical load exceedances it is important to assess how much acidifying or eutrophying potential the deposited air pollutants have in an ecosystem such as a lake or a forest. This depends on several factors, such as the capacity of buffering systems, the rate of buffering processes or the cycling of nutrients in the ecosystem. Therefore the *magnitude* of the critical load exceedance is commonly expressed in (acid or N) equivalents per hectare and year, i.e. as eq ($H^+$ or N) $ha^{-1}$ $a^{-1}$.

For the area where critical loads for acidification or eutrophication are exceeded, a *percentage of the total ecosystem area* in each grid cell can be calculated (see Figure 3.1). 'Total ecosystem area' is defined as area of ecosystem-types classified according to the EUNIS Habitats classification (EEA, 2014b). An *average accumulated exceedance (AAE)* can be computed for an ecosystem, a grid cell and any region or country for which multiple critical loads and deposition values are available (Posch et al., 2001). In this report, the AAE is defined as the area-weighted average of exceedances, accumulated over all sensitive habitats (or ecosystem points) defined in a grid cell.

(7) The area covered is the so-called EMEP domain, here the geographic area between 30°N–82°N latitude and 30°W–90°E longitude (EMEP, 2014b). This includes all EU-28 Member States as well as the EEA member and cooperating countries.

**Figure 3.1 The temporal development since 1880 of the area at risk in Europe (in %, above) and magnitude (in eq ha⁻¹a⁻¹, below) of exceedance (AAE) of acidification (red) and eutrophication (green), using GP-CLE scenario depositions for 2010 onwards**




**Note:** (a) First Sulphur Protocol (1985); (b) Second Sulphur Protocol (1994); (c) Gothenburg Protocol (1999); (d) NEC Directive (2001); (e) Amended Gothenburg Protocol (2012).

For the explanation of the unit eq $ha^{-1}$ $a^{-1}$ please see Box 3.1. The (a) to (e) show the point in time when protocols under the LRTAP Convention or the EU's NEC Directive were signed or adopted. The area covered is the so-called EMEP domain, here the geographic area between 30°N-82°N latitude and 30°W–90°E longitude. This includes all EU-28 countries as well as the EEA member and cooperating countries, other non-EU eastern European countries, parts of the Russian Federation and parts of Turkey (EMEP, 2014a and 2014b).

The percentage (%) results are based on emission trends since 1880 (Schöpp et al., 2003), with deposition patterns following different versions of the EMEP model (e.g. Hettelingh et al., 2013), and the most recent critical load database (Posch et al., 2012) in combination with the current legislation (CLE) scenario developed for the Gothenburg Protocol amendment for the period 2010 to 2030 (Amann et al., 2011).

agricultural activities and nitrogen oxides ($NO_X$) emitted from combustion processes to surface water and soil acidification has increased or even become predominant in some regions in Europe. Figure 3.1 indicates that eutrophication was already present in 1880; the ecosystem area where critical loads were exceeded was 26 % in 1880. It is likely that this was in particular caused by $NH_3$ emissions (Kopáček and Posch, 2011). However, it has to be considered that historic S and N emission estimates are uncertain, particularly for N compounds. The calculated peaks for eutrophication become evident a decade later than those for acidification.

## 3.2 Mapped magnitude and area of critical load exceedances (1880–2030)

The EEA CSI 005 (and SEBI 009) exposure indicator is characterised by magnitude as well as by area of critical load exceedances. In this section (Section 3.2), maps for the CSI 005 indicator are provided, for acidification and eutrophication respectively. Detailed tables with results for the EU Member States and EEA member countries as well as cooperating countries are presented in Annex 1 and Annex 3.

As mentioned above, exposure in an ecosystem area for which information on critical loads is available, is calculated as the average accumulated exceedance (AAE) (see Box 3.1). The AAE can be computed for any region, i.e. also for a subset of natural areas like the Natura 2000 areas, for instance. In this chapter, the AAE is given for areas of all ecosystem-types in Europe defined according to the EUNIS Habitats classification, and discussed for Natura 2000 areas in the EU-28. The area at risk is expressed as the percentage of the ecosystem areas in a country where deposition exceeds the given critical loads for those areas. The detailed country tables are presented in Annex 2 and Annex 4.

***Acidification — exceedance of the critical loads for all EUNIS ecosystem-types and Natura 2000 areas***

*Development of the magnitude of the critical loads exceedances in Europe*
Map 3.1 shows the exposure and area at risk for European countries in the EMEP domain, as of 1980. The successful reduction of anthropogenic acidifying emissions since 1980 is clearly demonstrated: the maps show a clear reduction of the area with exceedances of more than 1 200 eq $ha^{-1}a^{-1}$ (red shading), for example, between 1980 and 2010. The scenario calculations suggest that the area in exceedance will decrease even further between 2010 and 2020 — assuming that current legislation reduction measures are implemented.

*Development of the European area at risk of acidification*
The reduction of both the area at risk as well as the decrease in the magnitude of the exceedance of critical loads for acidification is shown in detail for the single countries in Annex 1. The European area at risk of acidification is reduced from 30 % (43 % in the EU-28) in 1980, to 2 % in 2020 (4 % in the EU-28).

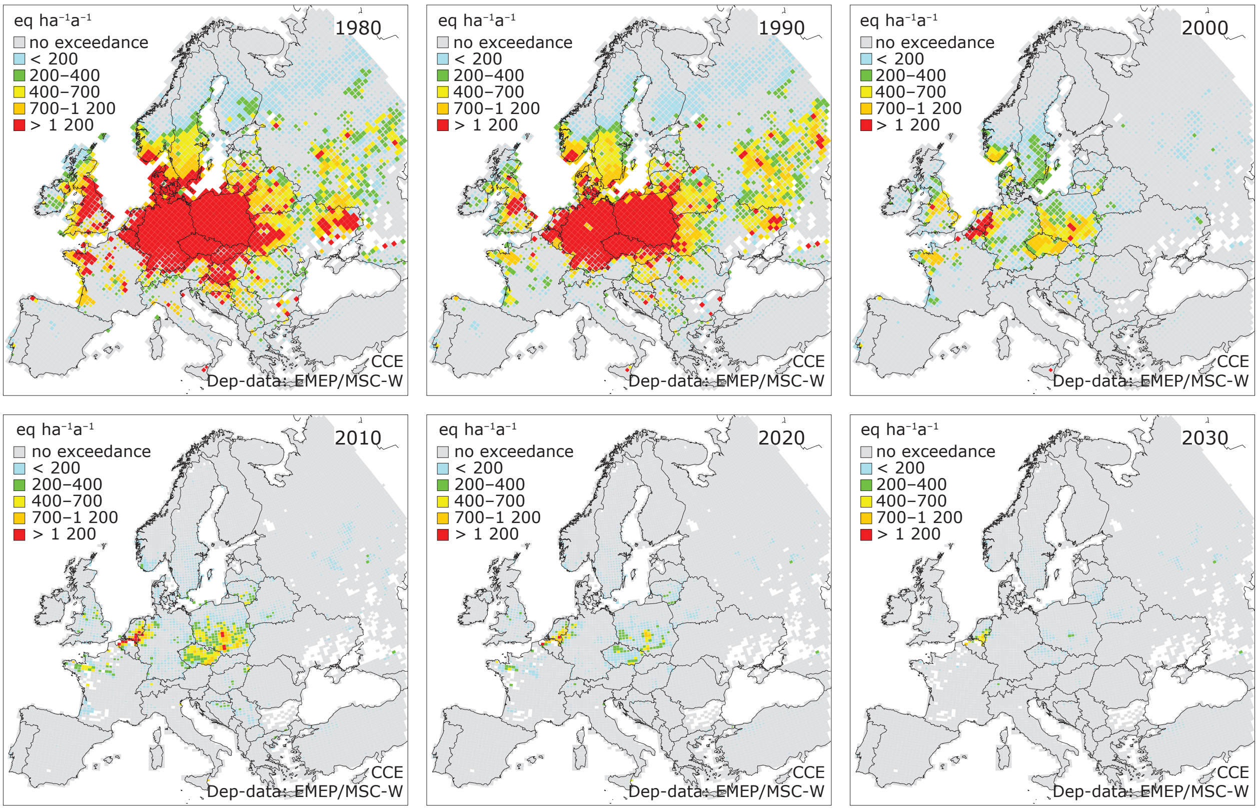
As shown in Annex 2, the percentages do not considerably increase if the focus is on Natura 2000 areas. For some countries, there was obviously no information on Natura 2000 areas available when the analysis was performed. Annex 2 shows results for the amended Gothenburg Protocol base year 2005, the year 2010, the Protocol target year 2020 and the year 2030 (GP-CLE scenario). In the base year 2005, the area at risk of all ecosystems in the EU-28 is 6 %, while the percentage of Natura 2000 areas at risk in that year is 8 %. In 2020, these percentages are 4 % and 2 %, respectively. Considering uncertainties in the calculations, those differences are only minor.

***Eutrophication — exceedance of the critical loads for all EUNIS ecosystem-types and Natura 2000 areas***

*Development of the magnitude of the critical loads exceedances in Europe*
Map 3.2 shows the development of eutrophication critical load exceedances in Europe starting in 1980. It also shows the projection of the exceedances in 2020 ([8]) based on the amended Gothenburg Protocol, and the projection of exceedances in 2030 according to the MTFR scenario. Most central European areas of very high exceedances in 1980 (red shading: larger than 1200 eq $ha^{-1}$ $a^{-1}$) are on track to be markedly reduced in 2020. However, the modelling results predict that there will still be a few hot spots with very high exceedances in western France and the

([8]) The European database of critical loads of nutrient nitrogen is compiled by the CCE using computed results from National Focal Centres, or the background database (see Box 1.3) when national data is lacking. A few National Focal Centres have also included empirical critical loads as part of the submitted computed results.

**Map 3.1 Areas where critical loads for acidification are exceeded (CSI 005) by depositions of acidifying compounds caused by emissions between 1980 (top left) and 2030 (bottom right)**




**Note:** The maps show the average accumulated exceedance (AAE) of critical loads for acidification in 1980 (top left), 1990 (top centre), 2000 (top right), 2010 (bottom left), 2020 under the revised Gothenburg Protocol (GP-CLE scenario) emission reduction agreements (bottom centre), and in 2030 assuming maximum technically feasible reduction (MTFR scenario) (bottom right).

border areas between the Netherlands, Belgium and Germany, as well as in northern Italy.

*Development of the European area at risk of eutrophication*

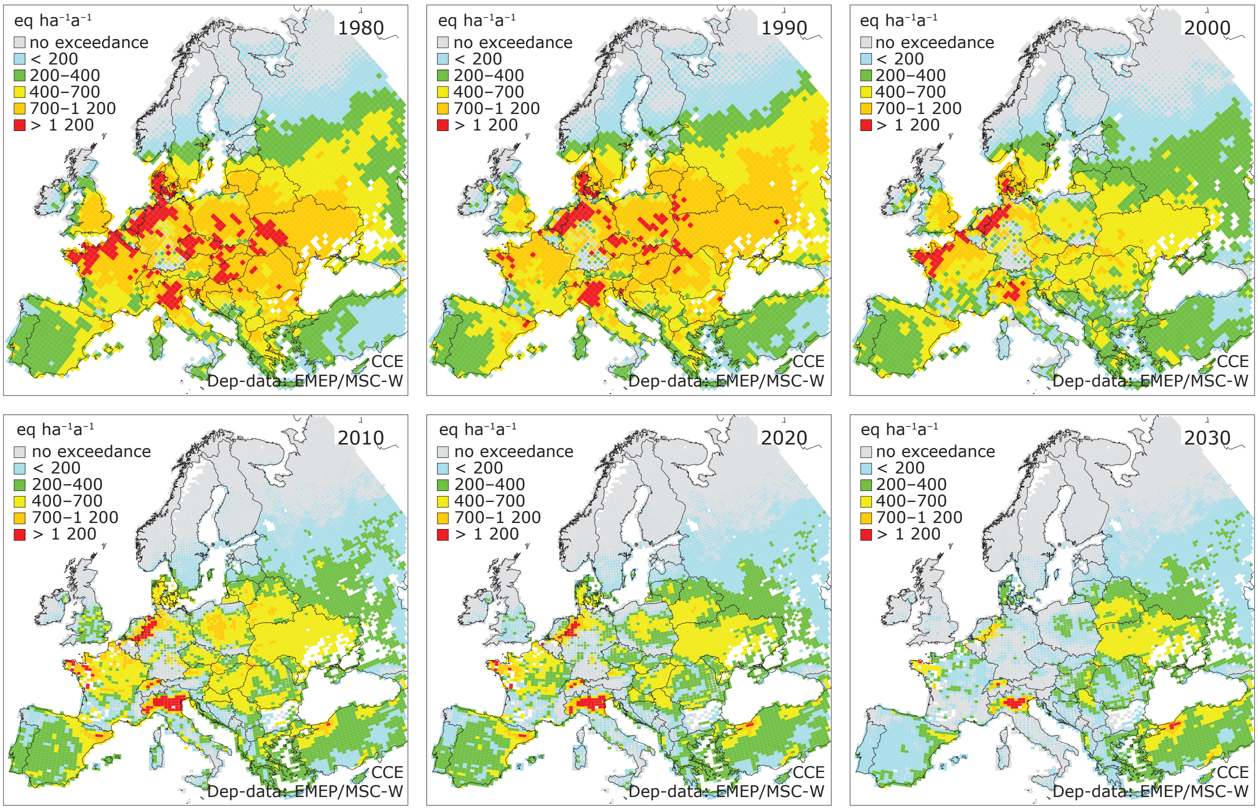
The development of the area at risk of eutrophication since 1980 is given in Annex 3 for individual countries. According to the scenario analyses, the European area at risk due to nutrient N deposition decreased from 75 % (in 1980) to 55 % (in 2020) under the amended Gothenburg Protocol.

Thus, in 2020 more than 50 % of the ecosystem areas classified according to EUNIS are still expected to be at risk of excessive nutrient nitrogen deposition. However, the *magnitude* of exceedance will be reduced considerably in those areas (see the eq $ha^{-1}$ $a^{-1}$ ranges in Map. 3.2). The area at risk of eutrophication in the EU-28 is on track to decrease, from 80 % in 1980 to 55 % in 2020 (53 % in 2030 under the GP-CLE scenario).

Using the methodology applied in this report, the risk of eutrophication increases slightly when computed for Natura 2000 areas alone (Annex 4). In 2005 and 2020, the area at risk for Natura 2000 regions is computed to be 78 % and 65 % respectively. The risk of eutrophication in Natura 2000 areas in 2030 is further reduced to 61 %, slightly higher than the calculated result (51 %) when the risk to all ecosystem areas classified according to EUNIS in the EU-28 is taken into account (see Annex 3, GP-CLE scenario).

The new strategy proposed by the European Commission in late 2013 (*A Clean Air Programme for Europe*) aims at achieving a situation where the EU ecosystem area exceeding critical loads for eutrophication is reduced by 35 % by 2030 relative to 2005 (EC, 2013; Box ES.1).

**Map 3.2 Areas where critical loads for eutrophication are exceeded (CSI 005) by nitrogen depositions caused by emissions between 1980 (top left) and 2030 (bottom right)**




**Note:** The maps show the average accumulated exceedance (AAE) of critical loads for eutrophication in 1980 (top left), 1990 (top centre), 2000 (top right), 2010 (bottom left), 2020 under the revised Gothenburg Protocol (GP-CLE scenario) emission reduction agreements (bottom centre), and in 2030 assuming maximum technically feasible reduction (MTFR scenario) (bottom right).

## 3.3 The impact of nitrogen deposition on plant species richness in selected European grasslands — a first assessment

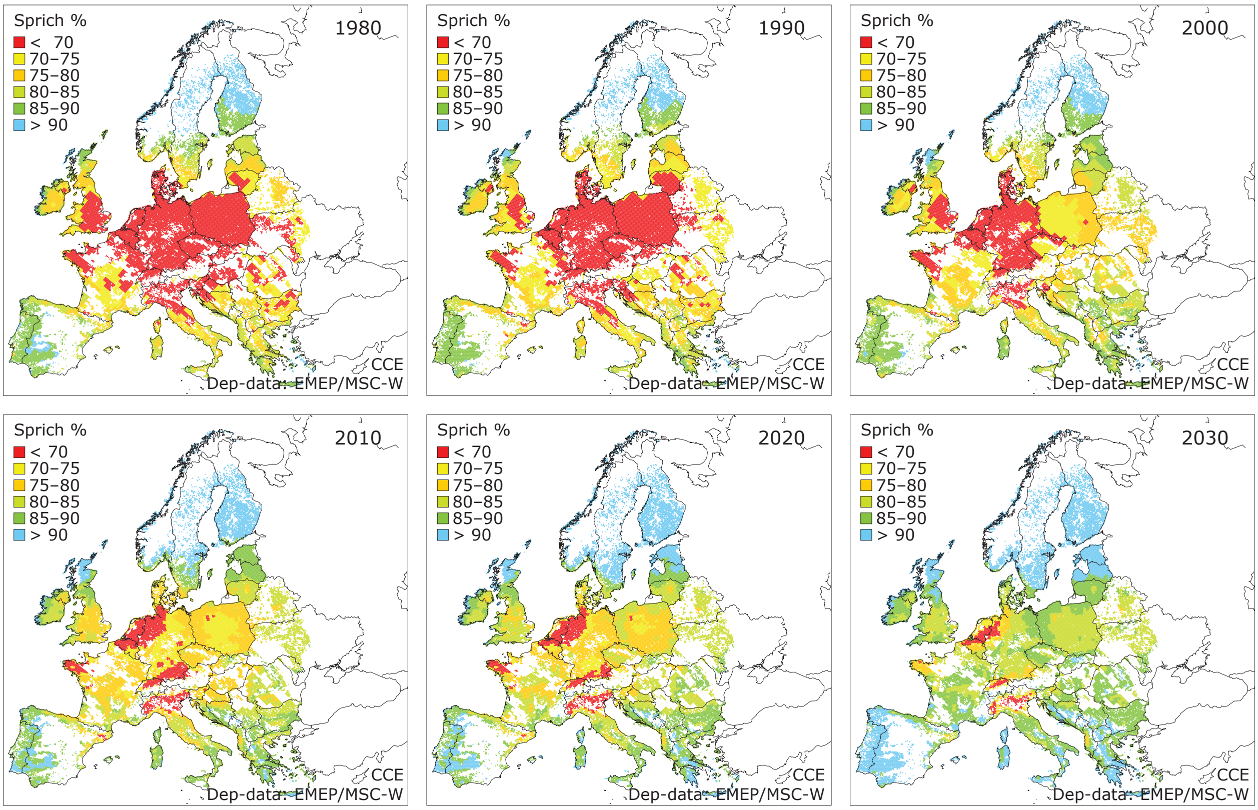
The ranges of critical load exceedances presented in Section 3.2, i.e. the magnitude of exeedance, inform only indirectly about the consequences of excess N deposition on 'sensitive elements of the environment' (see critical loads definition in Box 1.2). Indirectly means that the calculations for assessing the critical loads for N address biogeochemical responses within the nitrogen cycle of an ecosystem leading for example to higher N availability for plant and microbial uptake or increased N leaching.

The analysis in this chapter presents a first approach to link the amount of N deposition to changes in species richness in selected grasslands in Europe. It is based on Stevens et al. (2010a and 2010b) who surveyed 153 semi-natural grasslands on a transect across Europe with total atmospheric N deposition ranging from low (2 kg N $ha^{-1}$ $a^{-1}$) to high (44 kg N $ha^{-1}$ $a^{-1}$) fluxes covering much of the range of deposition found in the industrialised world (Box 2.2).

Map 3.3 shows how the area with computed species richness in grasslands below 70 % (red shading) in 1980 clearly diminishes in subsequent decades. It should be noted that the outcome of regional assessments of species richness in grasslands within the entire EMEP domain does not significantly change when the analysis is restricted to E1 (dry grasslands), E2 (mesic grasslands) and E3 (seasonally wet and wet grasslands) within Natura 2000 areas.

Table 3.1 shows the area-weighted average species richness in grasslands per country, by overlaying Natura 2000 grassland areas on the Coordination Centre for Effect's European background database (as far as data were available when the analysis was done; Reinds et al., 2008). The overall area-

**Map 3.3 Species richness in grasslands related to nitrogen depositions caused by emissions between 1980 (top left) and 2030 (bottom right)**




**Note:** The maps show the tentative development of species richness in grasslands (EUNIS classes E1, E2 and E3) in 1980 (top left), 1990 (top middle), 2000 (top right), 2010 (bottom left), 2020 under the revised Gothenburg Protocol (bottom middle) and maximum technically feasible reductions (MTFR) scenario in 2030 (bottom right).

90 % species richness corresponds to approximately 6–7 kg N ha$^{-1}$ a$^{-1}$.

weighted average species richness in E1, E2 and E3 grasslands in 1980 (high N deposition) is lower than predicted for 2020 under the revised Gothenburg Protocol, i.e. 71 % and 82 %, respectively. The application of maximum technically feasible reductions on nitrogen emissions (MTFR scenario) would lead to further minor improvement of the overall average species richness in grasslands to 86 %.

Species richness as indicator can be critisised because it may be influenced by for example invasive species (for uncertainties, see also Box 3.1). The indicator may also be misleading as in certain grassland ecosystems species richness can be due to the presence of many 'generalist' species. Those plants can be found in other ecosystem types, under a large variety of ecological conditions. They grow at the expenses of more 'specialist' species which are strictly limited to certain ecological conditions (and are therefore threatened by changes in these conditions). The N dose-response relationship applied in this report does not consider that a certain amount of N can be accumulated in an ecosystem, i.e. that changes in composition and diversity might not be readily reversible in all grasslands (e.g. Isbell et al., 2013). The ability to 'reverse back down' the species richness versus N deposition curve may therefore be a simplification.

However, in this report the chosen indicator is used in a *relative* sense, i.e. for comparing effects between scenarios or between countries.

The Coordination Centre for Effects (CCE) under the LRTAP Convention is currently collaborating with National Focal Centres (NFCs) of the ICP M&M to improve the choice of indicators for the assessment of 'no net loss of biodiversity'. A call for data in this respect, to be conducted by the CCE, has been issued by the Working Group on Effects of the LRTAP Convention in 2012, with a deadline to review first results in 2014.

**Table 3.1 Area-weighted average species richness in grasslands per country in Natura 2000 areas with EUNIS classes E1, E2 and E3 grasslands west of 32 ºE, 1980–2020 (GP-CLE scenario), and MTFR scenario for 2030**

| | Species richness (%) in specific Natura 2000 grasslands (EUNIS codes E1, E2, E3) compared to a species richness of 100 % (*) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1980** | **1990** | **2000** | **2005** | **2010** | **2020 (GP-CLE)** | **2030 (MTFR)** |
| Austria | 63 | 66 | 72 | 72 | 75 | 78 | 83 |
| Belgium | 54 | 58 | 60 | 65 | 67 | 70 | 75 |
| Bulgaria | 74 | 75 | 84 | 84 | 85 | 87 | 88 |
| Croatia | 62 | 64 | 70 | 73 | 76 | 79 | 84 |
| Czech Republic | 56 | 59 | 68 | 75 | 77 | 80 | 86 |
| Denmark | 64 | 67 | 68 | 75 | 78 | 82 | 86 |
| Estonia | 83 | 81 | 85 | 88 | 89 | 91 | 93 |
| Finland | 91 | 90 | 91 | 93 | 94 | 95 | 96 |
| France | 71 | 73 | 75 | 76 | 78 | 80 | 85 |
| Germany | 56 | 59 | 64 | 70 | 71 | 74 | 83 |
| Greece | 85 | 86 | 87 | 86 | 88 | 89 | 90 |
| Hungary | 66 | 73 | 79 | 75 | 78 | 81 | 85 |
| Ireland | 83 | 84 | 82 | 86 | 87 | 87 | 89 |
| Italy | 77 | 77 | 82 | 80 | 82 | 84 | 87 |
| Latvia | 78 | 74 | 85 | 87 | 87 | 89 | 91 |
| Lithuania | 71 | 69 | 80 | 81 | 81 | 84 | 87 |
| Luxembourg | 59 | 62 | 64 | 73 | 73 | 76 | 82 |
| Netherlands | 50 | 52 | 57 | 61 | 64 | 68 | 71 |
| Norway | 92 | 89 | 92 | 95 | 95 | 96 | 97 |
| Poland | 65 | 65 | 74 | 77 | 76 | 79 | 84 |
| Portugal | 88 | 88 | 88 | 90 | 90 | 90 | 93 |
| Romania | 70 | 71 | 78 | 79 | 82 | 84 | 87 |
| Slovakia | 64 | 63 | 74 | 79 | 81 | 84 | 88 |
| Slovenia | 66 | 68 | 73 | 71 | 74 | 77 | 82 |
| Spain | 88 | 87 | 87 | 88 | 89 | 90 | 93 |
| Sweden | 79 | 79 | 81 | 85 | 86 | 89 | 91 |
| Switzerland | 54 | 61 | 64 | 67 | 68 | 71 | 76 |
| United Kingdom | 74 | 77 | 77 | 83 | 85 | 86 | 88 |
| **Overall** | **71** | **72** | **76** | **79** | **80** | **82** | **86** |

**Note:** (*) The lowest N-deposition load, for which results for the relationship specifies and %-value for richness are available in the Stevens et al. (2010) is slightly higher than 0, about 2–3 kg N $ha^{-1}a^{-1}$. However, for the mathematical formulation the assumption is that the function is also valid for lower depositions, i.e. between 0 and the 2–3 kg N $ha^{-1}a^{-1}$. The function value at 0 is then assumed to be 100 %.

**Box 3.1 Uncertainty inherent in biodiversity analysis**

There are several sources of uncertainty in relation to the presented first assessment linking N deposition to biodiversity, as described in Hettelingh et al. (2010). Firstly, it does not account for nitrogen induced changes that may occur to other EUNIS classes for which no dose-response curves are yet available. Secondly, it assumes that available relationships between dose and response do not vary geographically, i.e. they are valid irrespective of where an area is located in Europe. These uncertainties make it challenging to interpret *absolute magnitudes* of scenario results. However, the direction of the change in biodiversity, obtained by *comparison* of one scenario *relative* to another in specific target years, is more robust. This is not least because most of the causes of model and data uncertainties do not vary between scenarios.

It should also be considered that there are uncertainties in this first assessment of the impact of atmospheric nitrogen deposition on species richness in acidic grasslands on a regional scale. This includes in particular the appropriateness of:

1. assuming species richness to be a suitable indicator for assessing scenario-specific 'no net loss of biodiversity', i.e. enabling the comparison between the effects of nitrogen emission reduction scenarios on the species richness for grasslands;
2. assuming 100 % species richness at 'zero' nitrogen deposition;
3. applying a dose–response relationship obtained from a gradient study on a regional scale;
4. using grasslands as the targeted receptor in all countries;
5. allowing an extrapolation from E1.7 (closed non-Mediterranean dry acid and neutral grassland) and E.1.9 (open non-Mediterranean dry acid and neutral grassland, including inland dune grassland) to E1 (dry grasslands), E2 (mesic grasslands) and E3 (seasonally wet and wet grasslands).

# 4 Conclusions

Based on latest scientific knowledge and an air quality modelling approach, this report documents the past and projected future (1880 to 2030) effects of atmospheric deposition of sulphur and nitrogen compounds on sensitive elements of the environment, investigating the impacts on:

- ecosystem-types defined according to the EUNIS Habitats classification;
- areas designated as Natura 2000 sites, a EU conservation network which aims at assuring the long-term survival of Europe's most valuable and threatened species and habitats, and
- species richness in selected grassland habitats, identified by the LRTAP Convention as a possible biodiversity indicator sensitive to impacts of air pollution.

### Acidification

According to the hindcast (backwards-looking) scenario, peaks in exceedances of the critical loads for acidification in habitats such as freshwaters and forests (forest soils) occurred in 1980 with 43 % of the EU-28 ecosystem area being in exceedance. In subsequent years, international co-operation under the LRTAP Convention and within the EU to combat the environmental effects of particularly airborne $SO_2$ pollution became effective. Findings suggest that by 2020 the ecosystem area where acidification critical loads are exceeded, as well as the magnitude of exceedances, will be as low as they were in 1880, i.e. only 4 % of the EU-28 area will still be in exceedance. The percentage is approximately the same for Natura 2000 areas alone (2 % in 2020). The report does not address the fact that even though ecosystems will in the future receive deposition of acidifying substances not exceeding critical loads, it may still take decades before a full recovery from past acidification occurs.

### Eutrophication

According to the scenario analyses presented in this report, the EU-28 area where the critical loads for eutrophication are exceeded peaked with 84 % exceedances in 1990. This percentage is projected to decrease to 54 % in 2020 assuming the amended Gothenburg Protocol is fully implemented. The magnitude of exceedances is also projected to reduce considerably in most areas, except for a few 'hot spot' areas in western France and the border areas between the Netherlands, Belgium and Germany, as well as in northern Italy. When exceedances are computed for Natura 2000 areas alone, the projected extent of eutrophication critical load exceedances is 65 % for 2020.

### Species richness

The presented first assessment of possible impacts of nutrient nitrogen deposition in nutrient-poor grasslands shows that in European areas (entire EMEP domain) the computed species richness is projected to improve from below 70 % in 1980 to 82 % by 2020. This outcome does not significantly change when the analysis is restricted to the chosen grasslands within Natura 2000 areas only. Species richness as biodiversity indicator can be criticised because it may be influenced by for example invasive species. However, in this report the chosen indicator is used only in a relative sense, i.e. for comparing effects between scenarios or between countries.

### Environmental objectives

As $SO_2$ emissions have fallen, the relative contribution made by ammonia ($NH_3$) emitted from agricultural activities and nitrogen oxides ($NO_X$) emitted from combustion processes to surface water and soil acidification has increased or even become predominant in some regions in Europe. $NH_3$

and $NO_X$ are also eutrophying air pollutants. The evidence from the analyses presented in this report suggests that measures to abate particularly $SO_2$ and also $NO_X$ emissions over the last decades have largely been successful ([9]) in improving the situation related to acidification phenomena. The situation will further improve if the Gothenburg Protocol will be fully implemented by 2020.

While $NO_X$ and $SO_2$ emissions to the air are expected to further decrease during the implementation of the Gothenburg Protocol, $NH_3$ emissions will broadly stay constant, with agriculture as the main source. In 2020, more than 50 % of the area of ecosystems defined according to the EUNIS Habitats classification is expected to be still at risk of excessive nutrient nitrogen deposition. The updated air pollution strategy proposed by the European Commission in late 2013 aims to achieve a situation where the EU ecosystem area exceeding critical loads for eutrophication is reduced by 35 % by 2030 relative to 2005 (EC, 2013). Further improvements in reducing eutrophication critical load exeedances within the EU are therefore foreseen.

According to this report, the reduction of the area at risk in 2030 relative to 2005 is 24 % when applying the Gothenburg current legislation (CLE) scenario and about 40 % when assuming a maximum technically feasible reduction (MTFR) scenario, available at the time when this report was prepared. This means that the EC target of 35 % reduction would be met in 2030 under a MTFR scenario, but would not be met under the GP CLE scenario.

The magnitude of exceedances will decrease considerably. The relative (%) projected increase in species richness from 1990 onwards indicates that emission reductions have a positive effect on biodiversity in the grasslands chosen as an indicator in this report. This is also true for sensitive areas within the Natura 2000 network. Further reductions in $NO_X$ and $NH_3$ emissions are therefore projected to have positive effects on biodiversity in habitat types of European interest, although attainment of currently proposed policy objectives may require a long timescale to be reached.

([9]) However, structural changes in countries' economies, such as the decline in heavy industry and the closure of older inefficient power plants, have also contributed to this development.

# References


Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Hoeglund-Isaksson, L., Klimont, Z., Rafaj, P., Schöpp, W. and Wagner, F., 2011, *An Updated Set of Scenarios of Cost-effective Emission Reductions for the Revision of the Gothenburg Protocol*, CIAM Report 4/2011 (http://www.iiasa.ac.at/publication/more_XO-11-072.php) accessed 17 June 2014.

Asman, W.A.H. and Van Jaarsveld, J. A., 2002, 'A variable-resolution transport model applied for $NH_x$ in Europe', *Atmospheric Environment*, (26A) 445–464.

Bobbink, R., Hornung, M. and Roelofs, J. G. M., 1998, 'The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation', *Journal of Ecology* (86) 717–738.

CCE, 2013, 'Coordination Centre for Effects (CCE)' (http://www.wge-cce.org/) accessed 17 June 2014.

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

EC, 1992, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7–50) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31992L0043:EN:NOT) accessed 17 June 2014.

EC, 2001, Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants (OJ L 309/22, 27.11.2001) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:309:0022:0030:EN:PDF) accessed accessed 17 June 2014.

EC, 2004, Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (http://eur-lex.europa.eu/legal-content/en/ALL/;jsessionid=LDpPTBPKs6kqGpl3vHBmTh88XcYBNQsC8p0GjrnpzryhsJhhrZ6j!-1679440255?uri=CELEX:32004L0107) accessed 17 June 2014.

EC, 2008a, Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1396805702633&uri=CELEX:32008L0050) accessed 17 June 2014.

EC, 2008b, LIFE and Europe's grasslands, Restoring a forgotten habitat, European Commission, Environment Directorate-General, LIFE Focus, 54 pp. (http://ec.europa.eu/environment/life/publications/lifepublications/lifefocus/documents/grassland.pdf), accessed 17 June 2014.

EC, 2009, Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (codified version of Directive 79/409/EEC as amended) (OJ L 20, 26.1.2010, p. 7–25) (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0147) accessed 17 June 2014.

EC, 2012, EU Biodiversity Strategy to 2020 — towards implementation, (http://ec.europa.eu/environment/nature/biodiversity/comm2006/2020.htm) accessed 17 June 2014.

EC, 2013, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, *A Clean Air Programme for Europe*, COM(2013) 918 final, (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52013DC0918) accessed 17 June 2014.

EC, 2014a, The Clean Air Policy Package (http://ec.europa.eu/environment/air/clean_air_policy.htm) accessed 17 June 2014.

EC, 2014b, Environment Action Programme to 2020, (http://ec.europa.eu/environment/newprg/) accessed 17 June 2014.

EEA, 2010a, Critical load exceedance for nitrogen (SEBI 009) (http://www.eea.europa.eu/data-and-maps/indicators/critical-load-exceedance-for-nitrogen/critical-load-exceedance-for-nitrogen) accessed 17 June 2014.

EEA, 2010b, *EU 2010 biodiversity baseline*, EEA Report No 12/2010, European Environment Agency (http://www.eea.europa.eu/publications/eu-2010-biodiversity-baseline) accessed 17 June 2014.

EEA, 2010c, *Assessing biodiversity in Europe — the 2010 report*, EEA Report No 5/2010, European Environment Agency (http://www.eea.europa.eu/publications/assessing-biodiversity-in-europe-84) accessed 17 June 2014.

EEA, 2012a, 'European Environment Agency, Exposure of ecosystems to acidification, eutrophication and ozone (CSI 005) — Assessment published Nov 2012' (http://www.eea.europa.eu/data-and-maps/indicators/exposure-of-ecosystems-to-acidification-2/exposure-of-ecosystems-to-acidification-4) accessed 17 June 2014.

EEA, 2012b, *Evaluation of progress under the EU National Emission Ceilings Directive Progress towards EU air quality objectives*, EEA Technical report No 14/2012, European Environment Agency (http://www.eea.europa.eu/publications/evaluation-progress-nec-2012) accessed 17 June 2014.

EEA, 2013, *EU emission inventory report 1990–2011 under the UNECE Convention on LRTAP*, EEA Technical report No 10/2013, European Environment Agency (http://www.eea.europa.eu/publications/eu-emission-inventory-report-lrtap) accessed 17 June 2014.

EEA, 2014a, *NEC Directive status report 2013, Reporting by the Member States under Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants*, EEA Technical report No 10/2014, European Environment Agency (http://www.eea.europa.eu/publications/nec-directive-status-report-2013) accessed 17 June 2014.

EEA, 2014b, 'About the European Nature Information System, EUNIS', European Environment Agency (http://eunis.eea.europa.eu/about.jsp) accessed 17 June 2014.

EMEP, 2014a, Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) (http://www.emep.int/) accessed 17 June 2014.

EMEP, 2014b, Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP), '*The new EMEP grid*' (http://www.ceip.at/ms/ceip_home1/ceip_home/new_emep-grid) accessed 17 June 2014.

Emmett, B., Ashmore, M., Britton, A., Broadmeadow, M., Bullock, J., Cape, N., Caporn, S.J.M., Carroll, J.A., Cooper, J.R., Cresser, M.S., Crossley, A., D'Hooghe, P., De Lange, I., Edmondson, J., Evans, C.D., Field, C., Fowler, D., Grant, H., Green, E., Griffiths, B., Haworth, B. et al., 2007. *Terrestrial Umbrella: effects of eutrophication and acidification on terrestrial ecosystems*. Final report. NERC/Centre for Ecology & Hydrology, 288 pp. (CEH Project Number: C02613, DEFRA Contract No. CPEA 18).

Gauger, T., Anshelm, F., Schuster, H., Erisman, J.W., Vermeulen, A.T., Draaijers, G.P.J., Bleeker, A. And Nagel, H-D., 2002, *Mapping of ecosystems specific long-term trends in deposition loads and concentrations of air pollutants in Germany and their comparison with critical loads and critical levels*, Institut für Navigation, University of Stuttgart, Germany.

Hettelingh, J-P., Posch, M., Slootweg, J., Reinds, G.J., Spranger, T., Tarrason, L., 2007, Critical loads and dynamic modelling to assess European areas at risk of acidification and eutrophication. *Water, Air and Soil Pollution: Focus* 7:379–384.

Hettelingh J-P., Posch, M. and Slootweg, J. (eds), 2009, *Progress in the modelling of critical thresholds, impacts to plant species diversity and ecosystem services in Europe*, CCE Status Report 2009, ISBN 978-90-78645-32-0 (http://www.wge-cce.org/Publications/CCE_Status_Reports/Status_Report_2009) accessed 17 June 2014.

Hettelingh J.-P, Posch M., Slootweg, J., Le Gall, A.-C., 2010, 'Analysis of Environmental impacts caused by the baseline and maximum feasible reduction scenarios' in: Slootweg,J., Posch,M. 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, ISBN 978-90-6960-249-3 (http://www.wge-cce.org/Publications/CCE_Status_Reports/Status_Report_2010) accessed 17 June 2014.

Hettelingh, J.-P., Posch, M. and Slootweg, J., 2012, 'Assessing the effects of the Gothenburg Protocol', in: Posch, M., Slootweg, J., and Hettelingh, J-P. (eds.), *Modelling and mapping of atmospherically-induced ecosystem impacts in Europe*, CCE Status Report 2012. ISBN: 978-90-6960-262-2, Bilthoven, pp. 13–20 (http://www.wge-cce.org/Publications/CCE_Status_Reports/Status_Report_2012) accessed 17 June 2014.

Hettelingh, J.-P., Posch, M., Velders, G.J.M., Ruyssenaars, P., Adams, M., De Leeuw, F., Lükewille, A., Maas, R., Sliggers, J. and Slootweg, J., 2013, 'Assessing interim objectives for acidification, eutrophication and ground-level ozone of the EU National Emission Ceilings Directive with 2001 and 2012 knowledge', *Atmospheric Environment*, (75) 129–140.

ICP M&M, 2013, 'ICP M&M — The International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends' (http://www.icpmapping.org) accessed 17 June 2014.

ICP Waters, 2011, *Trends in precipitation chemistry, surface water chemistry and aquatic biota in acidified areas in Europe and North America from 1990 to 2008*, ICP Waters Report 106/2011, Report SNO. 6218-2011 (http://repository.supsi.ch/3453/1/ICPW%20Report%20106_2011%20Trends%20from%201990%20to%202008%20pp19-46.pdf) accessed 17 June 2014.

Isbell, F., Tilman, D., Polasky, S., Binder, S. and Hawthorne, P., 2013, 'Low biodiversity state persists two decades after cessation of nutrient enrichment', *Ecology Letters*, Vol. 16, Issue 4, 454–460 (http://onlinelibrary.wiley.com/doi/10.1111/ele.12066/abstract) accessed 17 June 2014.

Kopáček, J., and Posch, M., 2011, Anthropogenic nitrogen emissions during the Holocene and their possible effects on remote ecosystems, *Global Biogeochemical Cycles* 25: GB2017 (16 pp).

MSC-W, 2013, 'Meteorological Synthesizing Centre — West (MSC-W)' (http://www.emep.int/mscw/) accessed accessed 17 June 2014.

NEGTAP, 2001, Transboundary Air Pollution: Acidification, Eutrophication and Ground-level Ozone in the UK. Centre for Ecology & Hydrology (CEH), Edinburgh.

Nilsson, J. and Grennfelt, P., 1988, *Critical loads for sulphur and nitrogen*. Report from a Workshop held at Skokloster Sweden, 19–24 March 1988, Miljø rapport 1988: 15. Copenhagen Denmark Nordic Council of Ministers.

Odén, S., 1968, 'The Acidification of Air and Precipitation and its Consequences in the Natural Environment', *Ecology Committee Bulletin Number 1*, Swedish National Science Research Council (Stockholm).

OECD, 1977, Organisation for Economic Co-operation and Development, The OECE programme on Long Range Transport of Air Pollutants. Measurements and Findings, Report 35.192.

Payne, R.J., Dise, N. B., Stevens, C.J., Gowing, D.J. and BEGIN Partners, 2013, 'Impact of nitrogen deposition at the species level', *PNAS*, Vol. 110, 984-987 (http://www.pnas.org/content/early/2012/12/26/1214299109) accessed 17 June 2014.

Pieterse, G., Bleeker, A., Vermeulen, A. T., Wu, Y. and Erisman, J.W., 2007, 'High resolution modelling of atmosphere-canopy exchange of acidifying and eutrophying components and carbon dioxide for European forests', *Tellus* (59B) 412–424.

Posch, M., Hettelingh, J-P. and De Smet, P.A.M., 2001, 'Characterization of critical load exceedances in Europe', *Water, Air and Soil Pollution*, (130) 1 139–1 144.

Posch, M. and Reinds, G.J., 2005, 'The European Background database', in: Posch, M., Slootweg,J. and Hettelingh,J.-P. (eds.), *European critical loads and dynamic modelling*, ISBN 9069601281, pp. 63–70 (http://www.wge-cce.org/Publications/CCE_Status_Reports/Status_Report_2005) accessed 17 June 2014.

Posch, M., Slootweg, J. and Hettelingh, J-P. (eds), 2012, *Modelling and Mapping of atmospherically-induced ecosystem impacts in Europe*, CCE Status Report 2012, RIVM Report 680359004, Coordination Centre for Effects, Bilthoven, Netherlands (https://docs.google.com/viewer?docex=1&url=http://www.rivm.nl/media/documenten/cce/Publications/SR2012/CCE_SR2012_introfull.pdf) accessed 17 June 2014.

Reinds, G.J., Posch, M., De Vries, W., Slootweg, J. and Hettelingh, J-P., 2008, 'Critical loads of sulphur and nitrogen for terrestrial ecosystems in Europe and Northern Asia using different soil chemical criteria', *Water, Air and Soil Pollution*, (193) 269–287.

Reis, S., Grennfelt, P., Klimont, Z., Amann, M., ApSimon, H., Hettelingh, J-P., Holland, M., LeGall, A-C., Maas, R., Posch, M., Spranger, T., Sutton, M.A.

and Williams, M., 2012, 'From acid rain to climate change', *Science*, (338) 1 153–1 154. doi:10.1126/science.1226514.

Schöpp, W., Posch, M., Mylona, S. and Johansson, M., 2003, 'Long-term development of acid deposition (1880–2030) in sensitive freshwater regions in Europe', *Hydrology and Earth System Sciences*, 7(4) 436–446.

Simpson, D., Benedictow, A., Berge, H., Bergström, R., Emberson, L.D., Fagerli, H., Flechard, C.R., Hayman, G.D., Gauss, M., Jonson, J.E., Jenkin, M.E., Nyiri, A., Richter, C., Semeena, V. S., Tsyro, S., Tuovinen, J-P., Valdebenito, A. and Wind, P., 2012, 'The EMEP MSC-W chemical transport model — technical description', *Atmospheric Chemistry and Physics*, (12) 7 825–7 865.

Slootweg, J., Posch, M. and Hettelingh, J-P. (eds), 2007, *Critical Loads of Nitrogen and Dynamic Modelling*, CCE Progress Report 2007, MNP Report 5000900001, Coordination Centre for Effects, Bilthoven, Netherlands (https://docs.google.com/viewer?docex=1&url=http://www.pbl.nl/sites/default/files/cms/publicaties/500090001.pdf) accessed 17 June 2014.

Stevens, C.J., Dise, N.B., Mountford, J.O. and Gowing, D.J., 2004, 'Impact of nitrogen deposition on the species richness of grasslands', *Science*, (303) 1 876–1 879.

Stevens, C.J., Thompson, K., Grime, P., Long, C.J. and Gowing, D.J.G., 2010a, 'Contribution of acidification and eutrophication to declines in species richness of calcifuge grasslands along a gradient of atmospheric nitrogen deposition', *Functional Ecology*, (24) 478–484.

Stevens, C.J., Duprè, C., Dorland, E., Gaudnik, C., Gowing, D.J.G., Bleeker, A., Diekmann, M., Alard, D., Bobbink, R., Fowler, D., Corcket, E., Mountford, J.O., Vandvik, V, Aarrestad, P. A., Muller, S.and Dise, N.B., 2010b, 'Nitrogen deposition threatens species richness of grasslands across Europe', *Environmental Pollution*, (158) 2 940–2 945.

Tarrasón, L., Jonson, J.E., Fagerli, H., Benedictow, A., Wind, P., Simpson, D., Klein, H., 2003, *Transboundary acidification eutrophication and ground level ozone in Europe, Part III: Source-receptor relationships*, EMEP Report 1/2003, Norwegian Meteorological Institute, Oslo, Norway (http://emep.int/publ/reports/2003/emep_report_1_part3_2003.pdf) accessed 17 June 2014.

Ulrich, B.; Mayer, R.; Khanna, P. K. 1979: *Deposition von Luftverunreinigungen und ihre Auswirkungen in Waldökosystemen im Solling*. Sauerländer´s, Frankfurt a.M., Schriften aus d. Forstlichen Fakultät d. Univ. Göttingen u. d. Niedersächsischen Forstl. Versuchsanst.; 58.

UNECE, 1979, United Nations Economic Commission for Europe, *The 1979 Geneva Convention on Long-range Transboundary Air Pollution*, United Nations Economic Commission for Europe, Geneva (https://docs.google.com/viewer?docex=1&url=http://www.unece.org/fileadmin/DAM/env/lrtap/full%20text/1979.CLRTAP.e.pdf) accessed 17 June 2014.

UNECE, 1999, Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to abate acidification, eutrophication and ground-level ozone (http://www.unece.org/fileadmin/DAM/env/lrtap/full%20text/1999%20Multi.E.Amended.2005.pdf) accessed 17 June 2014.

UNECE, 2007, United Nations Economic Commission for Europe, Convention on Long-range Transboundary Air Pollution, Report of the Executive Body on its 25th session held in Geneva from 10 to 13 December 2007, ECE/EB.AIR/91, Art. 32.

UNECE, 2012, United Nations Economic Commission for Europe, Decision 2012/2 of the Executive Body (see ECE/EB.AIR/113/Add.1), Geneva (http://www.unece.org/fileadmin/DAM/env/documents/2013/air/eb/2013_1.pdf) accessed 17 June 2014.

UNECE, 2013, United Nations Economic Commission for Europe, Convention on Long-range Transboundary Air Pollution, The International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends, *Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. UNECE Convention on Long-range Transboundary Air Pollution* (http://www.icpmapping.org/Mapping_Manual) accessed 17 June 2014.

UNECE, 2014, United Nations Economic Commission for Europe, Convention on Long-range Transboudary Air Pollution (http://www.unece.org/env/lrtap) accessed 17 June 2014.

Van Jaarsveld, J. A., 2004, 'The Operation Priority Substances Model', Report No. 500045001/2004. National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

WGE, 2013a, 'Benefits of Air pollution control for biodiversity and ecosystem services', Report prepared for the 32nd session of the Working Group on Effects, Convention on Long-range Transboundary Air Pollution, Geneva 12–13 September 2012, ECE/EB.AIR/WG.1/2013/14.

WGE, 2013b, 'Guidance document on health and environmental improvements using new knowledge, methods and data', Report prepared for the 32nd session of the Working Group on Effects, Convention on Long-range Transboundary Air Pollution, Geneva 12–13 September 2012, Informal document 4.

# Annex 1 EUNIS — results for acidification

The ecosystem area at risk (% of total ecosystems) of acidification and the exceedance (AAE) in each country from 1980 to 2030 (eq ha$^{-1}$a$^{-1}$) for all EUNIS classes; exceedances in 2020 were computed with nitrogen depositions according to Gothenburg Protocol current legislation (GP-CLE) scenario for 2020 and 2030.

| Acidity | 1980 | | 1990 | | 2000 | | 2005 | | 2010 | | GP-CLE 2020 | | GP-CLE 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area | AAE | Area | AAE | Area | AAE | Area | AAE | Area | AAE | Area | AAE | Area | AAE |
| Albania | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Armenia | 7 | 27 | 7 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Austria | 43 | 590 | 18 | 100 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Azerbaijan | 2 | 7 | 10 | 53 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 |
| Belarus | 76 | 736 | 73 | 671 | 18 | 52 | 15 | 38 | 12 | 28 | 6 | 10 | 6 | 9 |
| Belgium | 99 | 3 411 | 95 | 1 271 | 49 | 227 | 13 | 62 | 7 | 20 | 1 | 3 | 1 | 2 |
| Bosnia and Herzegovina | 31 | 528 | 25 | 386 | 16 | 90 | 12 | 61 | 10 | 41 | 2 | 1 | 1 | 2 |
| Bulgaria | 18 | 212 | 10 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Croatia | 35 | 442 | 11 | 98 | 4 | 26 | 5 | 32 | 4 | 17 | 2 | 3 | 1 | 2 |
| Cyprus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Czech Republic | 100 | 5 123 | 100 | 3 681 | 95 | 763 | 85 | 546 | 75 | 343 | 50 | 123 | 35 | 71 |
| Denmark | 96 | 1 942 | 86 | 1 066 | 49 | 317 | 36 | 112 | 20 | 26 | 1 | 2 | 1 | 1 |
| Estonia | 26 | 134 | 22 | 93 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland | 34 | 69 | 24 | 32 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Former Yugoslav Republic of Macedonia | 19 | 120 | 18 | 96 | 3 | 6 | 11 | 39 | 6 | 12 | 0 | 0 | 0 | 0 |
| France | 24 | 322 | 20 | 122 | 12 | 43 | 10 | 39 | 7 | 13 | 3 | 3 | 2 | 3 |
| Georgia | 13 | 47 | 11 | 28 | 0 | 0 | 3 | 4 | 3 | 4 | 4 | 7 | 5 | 10 |
| Germany | 95 | 4 238 | 93 | 2 299 | 47 | 230 | 28 | 89 | 18 | 47 | 5 | 13 | 3 | 8 |
| Greece | 10 | 65 | 7 | 43 | 2 | 7 | 3 | 19 | 2 | 9 | 1 | 1 | 1 | 1 |
| Hungary | 73 | 1 898 | 55 | 780 | 24 | 105 | 22 | 90 | 8 | 38 | 5 | 11 | 5 | 8 |
| Iceland | 18 | 12 | 22 | 19 | 7 | 3 | 8 | 5 | 4 | 1 | 3 | 1 | 3 | 0 |
| Ireland | 33 | 153 | 19 | 63 | 14 | 38 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Italy | 18 | 219 | 12 | 77 | 3 | 12 | 1 | 4 | 0 | 1 | 0 | 1 | 0 | 0 |
| Latvia | 46 | 458 | 44 | 431 | 21 | 38 | 14 | 23 | 9 | 13 | 3 | 3 | 2 | 2 |
| Lithuania | 77 | 1 123 | 71 | 1 024 | 37 | 211 | 34 | 170 | 34 | 154 | 30 | 86 | 29 | 73 |
| Luxembourg | 86 | 1.995 | 59 | 725 | 18 | 187 | 14 | 102 | 13 | 80 | 12 | 32 | 10 | 19 |
| Moldova | 33 | 404 | 30 | 160 | 1 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Netherlands | 87 | 6 171 | 86 | 3 687 | 82 | 1 739 | 77 | 1 192 | 74 | 864 | 63 | 518 | 60 | 455 |
| Norway | 35 | 215 | 37 | 219 | 21 | 76 | 8 | 13 | 5 | 6 | 2 | 1 | 2 | 1 |
| Poland | 100 | 3 175 | 100 | 2 451 | 65 | 419 | 46 | 243 | 43 | 217 | 24 | 74 | 17 | 44 |
| Portugal | 4 | 19 | 4 | 14 | 4 | 15 | 2 | 3 | 1 | 2 | 0 | 1 | 0 | 1 |
| Romania | 45 | 346 | 37 | 275 | 4 | 16 | 3 | 11 | 1 | 3 | 0 | 0 | 0 | 0 |

| Acidity | 1980 | | 1990 | | 2000 | | 2005 | | 2010 | | GP-CLE 2020 | | GP-CLE 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** |
| Russia | 22 | 81 | 23 | 92 | 2 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 |
| Serbia and Montenegro | 39 | 388 | 32 | 253 | 12 | 28 | 17 | 52 | 13 | 30 | 0 | 0 | 0 | 0 |
| Slovakia | 86 | 2 471 | 83 | 1 573 | 21 | 134 | 10 | 45 | 6 | 24 | 3 | 6 | 3 | 3 |
| Slovenia | 35 | 609 | 23 | 190 | 3 | 9 | 2 | 5 | 0 | 1 | 0 | 0 | 0 | 0 |
| Spain | 3 | 28 | 3 | 16 | 1 | 6 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sweden | 59 | 366 | 59 | 311 | 36 | 107 | 12 | 18 | 9 | 11 | 6 | 4 | 5 | 3 |
| Switzerland | 49 | 700 | 26 | 191 | 7 | 29 | 12 | 52 | 9 | 32 | 5 | 18 | 4 | 14 |
| Turkey | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 3 | 1 | 5 |
| Ukraine | 73 | 859 | 62 | 579 | 4 | 10 | 2 | 4 | 1 | 2 | 0 | 0 | 0 | 0 |
| United Kingdom | 76 | 774 | 53 | 323 | 26 | 115 | 14 | 37 | 7 | 17 | 3 | 6 | 3 | 4 |
| EU-27 | 43 | 763 | 38 | 470 | 18 | 83 | 10 | 39 | 7 | 26 | 4 | 10 | 3 | 7 |
| **EU-28** | **43** | **758** | **37** | **464** | **18** | **82** | **10** | **39** | **7** | **26** | **4** | **9** | **3** | **7** |
| EEA member countries | n.c. | n.c. | n.c. | n.c. | n.c. | n.c. | 10 | 35 | 7 | 22 | 3 | 8 | 3 | 6 |
| Europe, EMEP domain as of 1980 | 30 | 370 | 28 | 251 | 10 | 40 | 6 | 19 | 4 | 12 | 2 | 5 | 2 | 4 |

**Note:** Statistics for EEA member countries apply to current members, if listed in the table.
n.c. = not computed.

# Annex 2 Natura 2000 areas — results for acidification

The Natura 2000 area (%) at risk of acidification and the exceedance (AAE) in each EU member state, 2005–2020; exceedances in 2020 were computed with nitrogen depositions according to Gothenburg Protocol current legislation (GP-CLE) scenario for 2020 and 2030..

| Acidification | 2005 | | 2010 | | 2020 | | 2030 | |
|---|---|---|---|---|---|---|---|---|
| | Area | AAE | Area | AAE | Area | AAE | Area | AAE |
| Austria ([a]) | – | – | – | – | – | – | – | – |
| Belgium ([a]) | – | – | – | – | – | – | – | – |
| Bulgaria ([a]) | – | – | – | – | – | – | – | – |
| Croatia ([b]) | – | – | – | – | – | – | – | – |
| Cyprus ([c]) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Czech Republic | 78 | 479 | 65 | 300 | 41 | 107 | 29 | 66 |
| Denmark ([c]) | 23 | 67 | 12 | 19 | 1 | 1 | 1 | 1 |
| Estonia ([c]) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland ([c]) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 10 | 40 | 7 | 13 | 3 | 3 | 2 | 2 |
| Germany | 27 | 79 | 16 | 40 | 4 | 11 | 3 | 7 |
| Greece ([c]) | 5 | 23 | 3 | 10 | 1 | 2 | 1 | 1 |
| Hungary ([c]) | 15 | 43 | 3 | 11 | 1 | 3 | 1 | 2 |
| Ireland | 2 | 5 | 2 | 3 | 2 | 1 | 0 | 1 |
| Italy | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latvia ([c]) | 14 | 24 | 9 | 14 | 4 | 5 | 3 | 4 |
| Lithuania ([c]) | 41 | 192 | 40 | 170 | 35 | 90 | 34 | 76 |
| Luxembourg ([c]) | 28 | 206 | 27 | 164 | 25 | 65 | 20 | 38 |
| Malta ([b]) | – | – | – | – | – | – | – | – |
| Netherlands | 76 | 1 046 | 73 | 732 | 62 | 401 | 59 | 339 |
| Poland ([a]) | – | – | – | – | – | – | – | – |
| Portugal ([c]) | 2 | 5 | 1 | 3 | 1 | 2 | 1 | 2 |
| Romania ([c]) | 3 | 13 | 1 | 4 | 0 | 0 | 0 | 0 |
| Slovakia ([c]) | 13 | 56 | 8 | 30 | 3 | 6 | 3 | 4 |
| Slovenia | 2 | 5 | 1 | 1 | 0 | 0 | 0 | 0 |
| Spain ([c]) | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sweden | 12 | 16 | 9 | 10 | 5 | 3 | 5 | 2 |
| United Kingdom ([a]) | – | – | – | – | – | – | – | – |
| **EU-28** | **8** | **32** | **5** | **16** | **2** | **6** | **2** | **5** |

**Note:** ([a]) NFC submitted critical load, but did not distinguish Natura 2000 areas.

([b]) No information on Natura 2000 areas (yet).

([c]) NFC did not submit critical loads (CCE background database used).

# Annex 3 EUNIS — results for eutrophication

Areas at risk (%) of nutrient nitrogen and the AAE from 1980 to 2030 (eq $ha^{-1}a^{-1}$) for all EUNIS classes; exceedances in 2020 were computed with nitrogen depositions according to Gothenburg Protocol current legislation (GP-CLE) scenario for 2020 and 2030.

| Eutrophication | 1980 | | 1990 | | 2000 | | 2005 | | 2010 | | GP-CLE 2020 | | GP-CLE2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area | AAE | Area | AAE | Area | AAE | Area | AAE | Area | AAE | Area | AAE | Area | AAE |
| Albania | 100 | 474 | 100 | 465 | 100 | 374 | 92 | 289 | 87 | 241 | 81 | 218 | 76 | 195 |
| Armenia | 99 | 456 | 99 | 571 | 97 | 315 | 100 | 383 | 100 | 414 | 100 | 455 | 100 | 517 |
| Austria | 100 | 749 | 100 | 675 | 99 | 411 | 81 | 316 | 70 | 230 | 51 | 134 | 43 | 104 |
| Azerbaijan | 97 | 332 | 100 | 515 | 95 | 256 | 100 | 321 | 100 | 350 | 100 | 397 | 100 | 455 |
| Belarus | 100 | 730 | 100 | 932 | 100 | 423 | 100 | 460 | 100 | 466 | 100 | 397 | 100 | 393 |
| Belgium | 74 | 289 | 50 | 95 | 37 | 61 | 4 | 7 | 2 | 3 | 1 | 1 | 0 | 1 |
| Bosnia and Herzegovina | 87 | 500 | 88 | 529 | 78 | 285 | 72 | 233 | 70 | 177 | 67 | 131 | 66 | 122 |
| Bulgaria | 100 | 728 | 100 | 667 | 91 | 181 | 77 | 165 | 63 | 123 | 38 | 52 | 33 | 47 |
| Croatia | 100 | 859 | 100 | 733 | 99 | 479 | 96 | 502 | 89 | 362 | 82 | 262 | 79 | 230 |
| Cyprus | 100 | 236 | 100 | 297 | 100 | 323 | 100 | 281 | 100 | 259 | 100 | 243 | 100 | 265 |
| Czech Republic | 99 | 1 275 | 99 | 1 161 | 97 | 646 | 94 | 516 | 91 | 388 | 80 | 229 | 74 | 169 |
| Denmark | 100 | 1 243 | 100 | 1 147 | 100 | 1 028 | 100 | 718 | 100 | 533 | 99 | 365 | 99 | 324 |
| Estonia | 61 | 130 | 76 | 200 | 48 | 75 | 37 | 38 | 35 | 33 | 18 | 16 | 16 | 13 |
| Finland | 24 | 20 | 33 | 33 | 26 | 23 | 11 | 7 | 8 | 4 | 3 | 1 | 2 | 1 |
| Former Yugoslav Republic of Macedonia | 100 | 537 | 100 | 472 | 100 | 345 | 91 | 280 | 83 | 216 | 73 | 151 | 64 | 119 |
| France | 100 | 726 | 99 | 623 | 97 | 485 | 89 | 437 | 84 | 333 | 74 | 230 | 67 | 201 |
| Georgia | 93 | 377 | 88 | 286 | 67 | 100 | 83 | 276 | 84 | 308 | 86 | 351 | 88 | 409 |
| Germany | 82 | 940 | 73 | 743 | 66 | 527 | 57 | 373 | 54 | 316 | 46 | 218 | 43 | 184 |
| Greece | 100 | 501 | 100 | 453 | 100 | 361 | 100 | 377 | 98 | 285 | 95 | 219 | 93 | 205 |
| Hungary | 100 | 1 133 | 100 | 862 | 100 | 509 | 100 | 667 | 100 | 501 | 90 | 370 | 82 | 324 |
| Iceland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ireland | 40 | 79 | 35 | 64 | 45 | 114 | 24 | 39 | 17 | 23 | 11 | 14 | 10 | 12 |
| Italy | 94 | 704 | 93 | 685 | 84 | 431 | 74 | 367 | 63 | 271 | 48 | 195 | 43 | 171 |
| Latvia | 99 | 500 | 100 | 642 | 93 | 251 | 93 | 201 | 92 | 179 | 75 | 112 | 70 | 99 |
| Lithuania | 100 | 825 | 100 | 977 | 99 | 412 | 98 | 390 | 99 | 416 | 97 | 318 | 95 | 299 |
| Luxembourg | 100 | 1 499 | 100 | 1 258 | 100 | 1 154 | 100 | 727 | 100 | 699 | 97 | 504 | 97 | 442 |
| Moldova | 100 | 1 004 | 100 | 768 | 100 | 492 | 100 | 407 | 100 | 347 | 100 | 309 | 100 | 315 |
| Netherlands | 96 | 1 996 | 95 | 1 793 | 93 | 1 233 | 90 | 957 | 88 | 792 | 85 | 559 | 84 | 514 |
| Norway | 23 | 35 | 33 | 69 | 28 | 56 | 5 | 5 | 3 | 2 | 1 | 1 | 1 | 0 |
| Poland | 95 | 852 | 95 | 869 | 79 | 384 | 74 | 328 | 74 | 350 | 64 | 223 | 60 | 182 |
| Portugal | 100 | 302 | 100 | 305 | 100 | 304 | 100 | 264 | 100 | 234 | 99 | 194 | 99 | 184 |
| Romania | 100 | 931 | 100 | 858 | 98 | 552 | 99 | 493 | 96 | 356 | 92 | 269 | 91 | 243 |
| Russia | 64 | 159 | 71 | 221 | 51 | 88 | 48 | 78 | 45 | 67 | 40 | 52 | 39 | 51 |
| Serbia and Montenegro | 100 | 585 | 100 | 516 | 97 | 274 | 83 | 345 | 80 | 275 | 74 | 196 | 69 | 158 |

| Eutrophication | 1980 | | 1990 | | 2000 | | 2005 | | 2010 | | GP-CLE 2020 | | GP-CLE2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** | **Area** | **AAE** |
| Slovakia | 100 | 1 212 | 100 | 1 223 | 100 | 677 | 98 | 524 | 95 | 415 | 89 | 287 | 87 | 244 |
| Slovenia | 99 | 807 | 99 | 722 | 96 | 384 | 91 | 265 | 75 | 157 | 34 | 42 | 21 | 26 |
| Spain | 99 | 370 | 100 | 464 | 100 | 396 | 99 | 400 | 96 | 308 | 95 | 273 | 94 | 254 |
| Sweden | 61 | 163 | 83 | 232 | 70 | 193 | 36 | 62 | 30 | 42 | 19 | 19 | 16 | 14 |
| Switzerland | 100 | 914 | 100 | 730 | 98 | 538 | 75 | 579 | 74 | 510 | 66 | 403 | 66 | 356 |
| Turkey | 99 | 198 | 99 | 255 | 99 | 258 | 99 | 269 | 100 | 288 | 100 | 292 | 100 | 332 |
| Ukraine | 100 | 1 070 | 100 | 1 055 | 100 | 619 | 100 | 520 | 100 | 489 | 100 | 424 | 100 | 421 |
| United Kingdom | 80 | 421 | 76 | 324 | 72 | 310 | 53 | 170 | 43 | 96 | 27 | 38 | 24 | 33 |
| EU-27 | 80 | 512 | 84 | 501 | 78 | 333 | 67 | 276 | 62 | 218 | 54 | 157 | 51 | 139 |
| **EU-28** | **80** | **518** | **84** | **505** | **78** | **336** | **67** | **280** | **63** | **221** | **54** | **159** | **51** | **141** |
| EEA | | | | | | | 59 | 244 | 55 | 192 | 48 | 139 | 45 | 122 |
| Europe, EMEP domain as of 1980 | 75 | 333 | 79 | 361 | 69 | 225 | 63 | 200 | 60 | 175 | 55 | 144 | 53 | 143 |

**Note:** Statistics for EEA member countries apply to current members, if listed in the table.

# Annex 4 Natura 2000 areas — results for eutrophication

The Natura 2000 area (%) at risk of eutrophication and the AAE in each EU member country (2005–2020); exceedances in 2020 were computed with nitrogen depositions according to Gothenburg Protocol current legislation (GP-CLE) scenario for 2020 and 2030

| Eutrophication | 2005 | | 2010 | | 2020 | | 2030 | |
|---|---|---|---|---|---|---|---|---|
| | Area | AAE | Area | AAE | Area | AAE | Area | AAE |
| Austria ([a]) | – | – | – | – | – | – | – | – |
| Belgium ([a]) | – | – | – | – | – | – | – | – |
| Bulgaria ([a]) | – | – | – | – | – | – | – | – |
| Croatia ([b]) | – | – | – | – | – | – | – | – |
| Cyprus ([c]) | 100 | 325 | 100 | 301 | 100 | 282 | 100 | 310 |
| Czech Republic | 91 | 446 | 87 | 329 | 69 | 186 | 61 | 137 |
| Denmark ([c]) | 100 | 687 | 100 | 527 | 99 | 377 | 99 | 340 |
| Estonia ([c]) | 48 | 52 | 46 | 45 | 28 | 20 | 26 | 17 |
| Finland ([c]) | 5 | 3 | 4 | 2 | 2 | 1 | 1 | 1 |
| France | 86 | 389 | 81 | 290 | 70 | 195 | 63 | 168 |
| Germany | 55 | 323 | 51 | 269 | 42 | 179 | 39 | 149 |
| Greece ([c]) | 100 | 369 | 98 | 278 | 96 | 211 | 95 | 196 |
| Hungary ([c]) | 100 | 672 | 100 | 508 | 92 | 381 | 83 | 335 |
| Ireland | 18 | 30 | 13 | 18 | 8 | 11 | 8 | 10 |
| Italy | 76 | 331 | 63 | 237 | 47 | 163 | 42 | 139 |
| Latvia ([c]) | 94 | 194 | 93 | 174 | 78 | 107 | 74 | 94 |
| Lithuania ([c]) | 97 | 387 | 98 | 405 | 95 | 306 | 94 | 287 |
| Luxembourg ([c]) | 100 | 709 | 100 | 687 | 95 | 474 | 93 | 406 |
| Malta ([b]) | – | – | – | – | – | – | – | – |
| Netherlands | 88 | 826 | 87 | 681 | 84 | 465 | 83 | 421 |
| Poland ([a]) | – | – | – | – | – | – | – | – |
| Portugal ([c]) | 100 | 257 | 99 | 229 | 99 | 195 | 99 | 186 |
| Romania ([c]) | 99 | 434 | 93 | 304 | 89 | 222 | 87 | 197 |
| Slovakia ([c]) | 97 | 494 | 93 | 390 | 86 | 267 | 84 | 227 |
| Slovenia | 88 | 240 | 67 | 136 | 28 | 36 | 19 | 21 |
| Spain ([c]) | 99 | 381 | 97 | 291 | 96 | 256 | 95 | 236 |
| Sweden | 41 | 82 | 32 | 58 | 18 | 30 | 17 | 24 |
| United Kingdom ([a]) | – | – | – | – | – | – | – | – |
| **EU-28** | **78** | **337** | **73** | **257** | **65** | **189** | **61** | **167** |

**Note:** ([a]) NFC submitted critical load, but did not distinguish Natura 2000 areas.

([b]) No information on Natura 2000 areas (yet).

([c]) NFC did not submit critical loads (CCE background database used).

European Environment Agency

**Effects of air pollution on European ecosystems**
Past and future exposure of European freshwater and
terrestrial habitats to acidifying and eutrophying air pollutants

2014 — 38 pp. — 21 x 29.7 cm

ISBN 978-92-9213-463-1
doi:10.2800/18365

TH-AK-14-011-EN-N
doi:10.2800/18365

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Publications Office

European Environment Agency