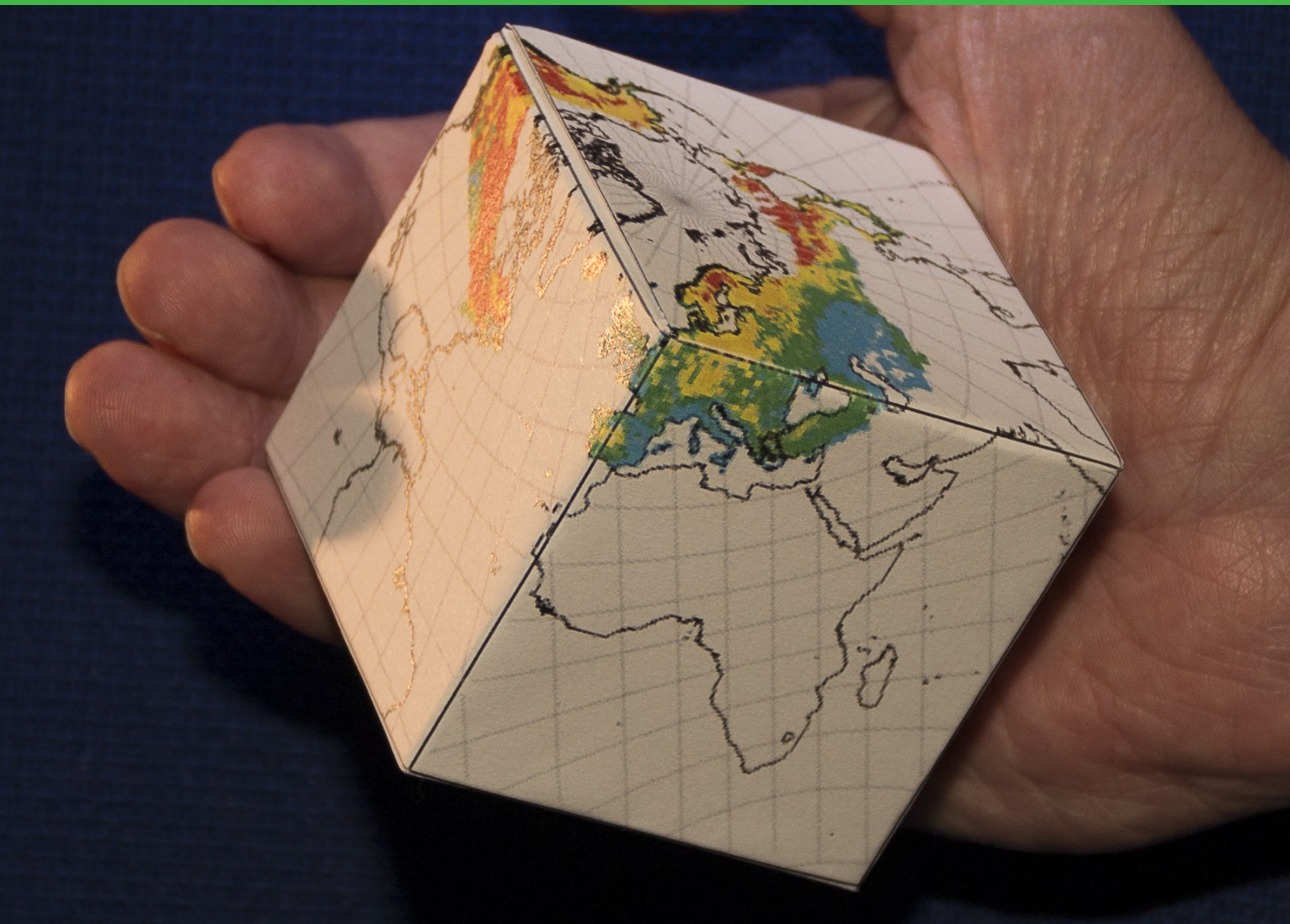
European critical loads: database, biodiversity and ecosystems at risk

CCE Final Report 2017



European critical loads: database, biodiversity and ecosystems at risk

CCE Final Report 2017

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Publiekssamenvatting

**Europese kritische waarden: database, biodiversiteit en gevoelige ecosystemen.
Slotrapport van het CCE 2017**

Met dit rapport sluit Nederland zijn rol als trekker van de taken van het Coordination Centre for Effects (CCE) af. Het CCE heeft tot eind 2017 de taak om het Europese luchtbeleid te ondersteunen met informatie over risico's van effecten van te veel zwavel en stikstof op Europese natuurgebieden. Het CCE helpt deze vraag te beantwoorden door modellen te ontwikkelen en een Europese database te beheren waarmee risicogrenzen ('kritische belastingsgrenzen') van deze stoffen per type natuurgebied worden bepaald.

Twaalf EU-landen, plus Zwitserland en Noorwegen, rapporteren over het gebruik van deze methoden en leverden hiervoor informatie. Voor de overige Europese landen heeft het CCE met Alterra een database ontwikkeld zodat de limieten voor het gehele continent berekend kunnen worden. De database is ook gebruikt om wetenschappelijke instellingen uit het CCE-netwerk van de landen die deze taak hebben, te trainen (National Focal Centre). Over de CCE-resultaten bestaat consensus binnen de VN-conventie over luchtkwaliteit (die jaarlijks de CCE-resultaten evalueert) en de EU, zodat over de wetenschappelijke basis voor het Europese luchtbeleid, tot eind 2017, geen misverstand bestaat.

CCE-data worden onder andere gebruikt om alternatieven voor luchtbeleid door rekenen. Recentelijk zijn ze ingezet om de Europese Richtlijn voor nationale emissieplafonds te herzien. Met de berekeningen worden de oorzaken, kosten en gevolgen van luchtverontreiniging voor de biodiversiteit en de bodem doorgerekend. Hieruit blijkt dat circa 79 procent van de natuurgebieden (Natura 2000-gebieden) in de 28 Europese landen in 2020 aan te veel stikstof blootstaat.

Dit jaar is voor het eerst voor heel Europa in kaart gebracht of specifieke plantensoorten het risico lopen om door te veel stikstof of verzuring te verdwijnen. De methoden en data die hiervoor zijn gebruikt, worden vooralsnog voor wetenschappelijke doelstellingen ingezet; voor beleidsondersteuning moeten ze nog worden aangevuld en verbeterd.

Dit op biodiversiteitsverlies gerichte werk kan voor meer doelen worden gebruikt. Bijvoorbeeld om beleidsmaatregelen te helpen vinden om natuurlijke eigenschappen die belangrijk zijn voor de veerkracht van de natuur, te beschermen tegen luchtverontreiniging en andere milieurisico's, waaronder klimaatverandering.

Het RIVM heeft namens Nederland de CCE-rol sinds 1990 uitgevoerd voor de Conventie voor Grootschalige Grensoverschrijdende Luchtverontreiniging van de Verenigde Naties (LRTAP-Conventie). Een ander Europees land zal de rol vanaf 2019 overnemen.

Kernwoorden: biodiversiteit, CCE, ecosystemen, kritische depositieniveaus, luchtverontreiniging, natuurbescherming, overschrijding

Summary

European critical loads: database, biodiversity and ecosystems at risk

With this Final Report 2017 the Coordination Centre for Effects (CCE) located at the National Institute for Public Health and the Environment (RIVM, Bilthoven, the Netherlands) is concluding its work. In 1990, tasks of the CCE were offered by the Netherlands to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) of the United Nations Economic Commission for Europe (UNECE). The LRTAP Convention then adopted the CCE as programme centre of the "International Cooperative Programme for the Modelling and Mapping of Critical Loads and Levels and Air Pollution Effects, Risks and Trends" (ICP M&M) under its Working Group on Effects.

The main task of the CCE includes the development of methodologies and databases enabling the assessment of thresholds ("critical loads") for the protection of ecosystems against adverse effects of atmospheric pollutants, with an emphasis on acid and nitrogen depositions. For this task, the CCE collaborates with a European network of National Focal Centres of the ICP M&M. In this context, the CCE is regularly requested by the Convention to issue calls for data to these centres. The CCE is finally responsible for the compilation of national information on critical loads into a European database. The European critical loads database is then used in the Greenhouse Gas Interactions and Synergy Model (GAINS) held by the Centre for Integrated Assessment Modelling of the LRTAP Convention (located at IIASA, Austria) in support of European air pollution abatement policies.

In this report, latest results of the CCE are described (Part 1) with special attention for the consolidation of information in a manner that is tailored for use by the - at the time of writing this report not yet identified - successor of the CCE. Part 2 contains detailed accounts of the work conducted by National Focal Centres over the past two years.

Chapter 2 focuses on the call for critical loads data 2015-2017. A novel element consisted of requesting National Focal Centres to include methods to compile critical loads for biodiversity, i.e. thresholds of acid and nitrogen deposition below which the loss of specific plant species does not occur according to present knowledge. Consensus on these methods had been achieved under the ICP M&M during a number of preparatory meetings and workshops prior to the 2015-2017 call for data. In addition to these novel critical loads, also data were requested to enable an update of the European critical loads database that had been used in support of LRTAP Convention protocols and the National Emission Ceilings Directive of the European Union.

Fourteen Parties to the Convention, i.e. twelve EU Member States plus Switzerland and Norway, submitted critical loads of nitrogen and of sulphur, including seven Parties that also submitted critical loads for biodiversity. It is noted that that the data required for the assessment of

critical loads for biodiversity need to be further completed to include more NFC submissions and more nature types. In view of this, a possible improvement of the modelling of relationships between the probability of occurrence of plant species and abiotic conditions is described in Chapter 4.

For countries that do not submit data, the CCE developed over the years a so-called European background database, described in Chapter 3, in collaboration with Alterra (the Netherlands). The use of this database enables computed critical loads for acidity, nitrogen and biodiversity to cover ecosystems in the whole of Europe. Thus, critical loads are available for European ecosystems categorized according to the European Nature Information System of the EEA, covering an area between two and three million km2.

The updated European database on critical loads, has then been used for the analysis of effects of air pollution abatement alternatives (Chapter 1) to illustrate results of the application of the database in the GAINS model. It turns out that a simulation of abatement policies embedded in the so-called Current Legislation pathway leads to a reduction of the ecosystem areas being at risk of excessive nitrogen deposition from 67 % in 2005 to about 58 % of in 2020. For the EU28 these percentages are 81 % and 71 % respectively. When acidification is used as endpoint a reduction from 11 to 4 percent of areas at risk can be noted between these years.
In addition, the impact of climate change on critical loads and exceedances is included in Chapter 1 to illustrate the potential capability of methodologies to assess interactions with effects of air pollution as expressed in the long-term strategy of the Convention.

Finally, it is recommended that knowledge of effects of interactions between air pollution and climate change be further strengthened by improving critical loads of biodiversity. This could include various interactions that affect the health of ecosystems, such as between temperature, drought, ozone, nitrogen and aerosol exposure. These assessments could help support multi-effect oriented policies that are jointly framed under UN-Conventions and EU strategies for air pollution, climate and biodiversity.

The successor of the Coordination Centre for Effects is encouraged to continue the coordination and programming of this scientific challenge in collaboration with other effect-based programmes under the LRTAP Convention.

Keywords: air pollution, biodiversity, CCE, critical loads, ecosystem, exceedance, impacts.

Contents

Part 1 Progress CCE

1 Use of 2017 critical loads: exceedances, biodiversity and climate change

Jean-Paul Hettelingh, Maximilian Posch and Jaap Slootweg

1.1 Introduction

In this chapter, the focus is on applications with the new European critical loads database. This database is established on the basis of the 2015-2017 Call for Data, to which the response by National Focal Centres is described in Chapter 2. The critical loads compiled for the other countries are based on the European Background database that is described in Chapter 3. Applications using this 2017 critical load database consist of the computation and mapping of European ecosystem areas at risk of acidification, eutrophication and loss of biodiversity and of the robustness of the geographical pattern of exceedances.

The Call for Data[1], issued in 2015, requested National Focal Centres (NFCs) to update, in the European critical loads database, their data on classical critical loads, i.e. for acidification and eutrophication, and provide for the first time, official data on critical loads of biodiversity. However, it was decided at the 33rd meeting of the Task Force on Modelling and Mapping (TF M&M) held in Wallingford (UK, 4-6 April 2017) to further develop data on critical loads for biodiversity and use them for research purposes only. The reason includes that a number of NFCs have indicated that they need more time to verify their work and data on these biodiversity thresholds. Therefore, the use of the database on critical loads of biodiversity for the assessment of exceedances, included in this chapter, should be considered for illustrative purposes only.

First, the European critical loads database is summarized, consisting of NFC submissions and the European background database for Parties that fell short of submitting data. Results of computations of exceedances of critical loads are mapped for 2005 and 2020, using an emission reduction scenario developed under the EU Thematic Strategy on Air Pollution. Then, the robustness of the location of the areas where exceedances of critical loads may occur is presented. The chapter is concluded with a glimpse towards the possible impact of climate change on exceedances. Modelled effects are described of a climate change induced temperature increase of + 3 ^{o}C and related altered hydrology on the magnitudes of critical loads and exceedances of Natura 2000 areas in the EU28.

[1] At the 1st joint session of the Steering Body to the EMEP and the Working Group on Effects (Geneva, 14-18 September 2015) the Coordination Centre for Effects was requested to issue a call for data in the autumn of 2015 with a deadline in 2017. NFCs were requested to apply approaches to calculate nitrogen and sulphur critical load functions taking into account their impact on biodiversity, while updating earlier submissions on critical loads for acidification and eutrophication as appropriate.

1.2 The European critical loads database

Methods used to establish critical loads for acidification, eutrophication and biodiversity are described in De Vries, Hettelingh and Posch (2015). Fourteen Parties participated in the call for data submitting critical loads for acidification and eutrophication (see Chapter 2). Out of those, seven Parties (Ireland, Italy, France, Germany, Norway, The Netherlands, United Kingdom) also submitted critical loads for biodiversity, i.e. protecting the occurrence of plant species that are typical to habitats distinguished by these NFCs (see e.g. Dobben *et al*., 2015; Rowe *et al*., 2015; 2016). The coverage of the ecosystem area of Europe (west of 42°E) is warranted by using the European background database (see Chapter 3), compiled and maintained by the CCE in collaboration with the Wageningen Research Centre (Alterra)[2] over the past 27 years. From this database critical loads of ecosystem areas for Parties to the Convention that did not submit critical loads are included in the European critical loads database. The European background database (Chapter 3) for critical loads of biodiversity distinguishes 23 habitats including 419 ''typical species'' that were modelled by the PROPS model (see e.g. Rowe *et al*., 2015; Posch *et al*., 2015a; Reinds *et al*., 2015). This particular background database was developed by Alterra and the CCE under the EU Framework Programme-7 project "Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems" (ECLAIRE; Sutton *et al*., 2015).

It turns out that critical loads for acidification, eutrophication and biodiversity were submitted by EU countries only, plus Switzerland and Norway. Submissions by NFCs from the EU28 cover about 60%, 52% and 21%, respectively, of the ecosystem area in the EU28. NFC submissions of critical loads, including Switzerland and Norway, lead to a computed coverage in Europe (west of 42°E) of about 46% for acidification, 40% for eutrophication and 14% biodiversity critical loads ecosystem area. The relatively low coverage of NFC-submitted critical loads of biodiversity warrants that these results are, for the time being, used for research purposes only. It is recommended that the successor of the CCE moves forward to obtain more NFC submissions. The cause of the lack of submissions from EECCA countries may be alleviated in the future provided that funds, that are available for increased EECCA country participation in the Convention, include resources for the support of effect oriented tasks.

A comparison was made between 2015 and 2017 results of the 5th percentile critical loads for acidification and eutrophication (Figure 1.1.), i.e. protecting 95% of the ecosystems against these adverse effects. This comparison illustrates changes in the location, magnitude and areas of critical loads, mostly in countries for which critical loads data were submitted by NFCs. Compared to the critical load database of 2015, more areas turn out to be sensitive to acidification (Figure 1.1-top) in, for example, Ireland, northern Germany and parts of northern and southern Poland. Less acid sensitive areas can be distinguished in The Netherlands, central Germany, central Poland and in northern France. With respect to the 5th percentile critical loads for eutrophication (Figure

[2] http://www.wur.nl/en/Expertise-Services/Research-Institutes/Environmental-Research.htm

1.1-bottom) the occurrence of more sensitive areas in 2017 compared to 2015 are in central and eastern Germany and in central Poland. Less N-sensitive ecosystems turn out to occur in Ireland, northern and southern parts of Poland and in the Netherlands in particular. The 5th percentile critical loads in areas covered by the background database have not changed.

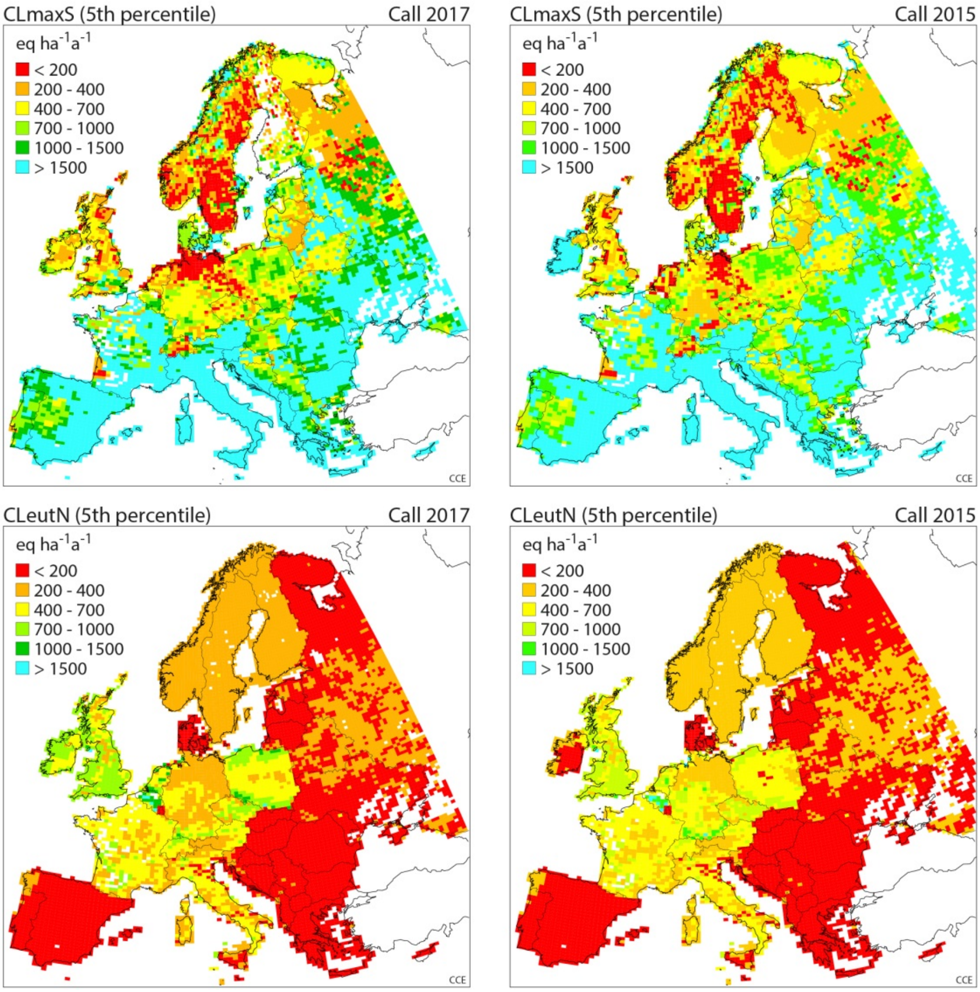

Figure 1.1 Critical loads ranges of acidity (top) and eutrophication (bottom) protecting 95% of the ecosystems of the European critical loads database in 2017 (left) and 2015 (right)

The 5th percentile critical load map of sulphur and of nitrogen protecting 95% of the areas against loss of biodiversity[3] is compiled for the first time (Figure 1.2). The comparison of the ranges and location of the 5th percentile critical loads for eutrophication (Figure 1.1, bottom left) with those of biodiversity for nitrogen (Figure 1.2, right) shows that the ranges of the latter are generally higher. However, in stating that, it should be noted that the data required for the assessment of critical loads of biodiversity need to be further completed to include more NFC submissions and more nature types.

[3] The probability of occurrence of typical species in specific habitats is the endpoint in current modelling of critical loads of biodiversity.

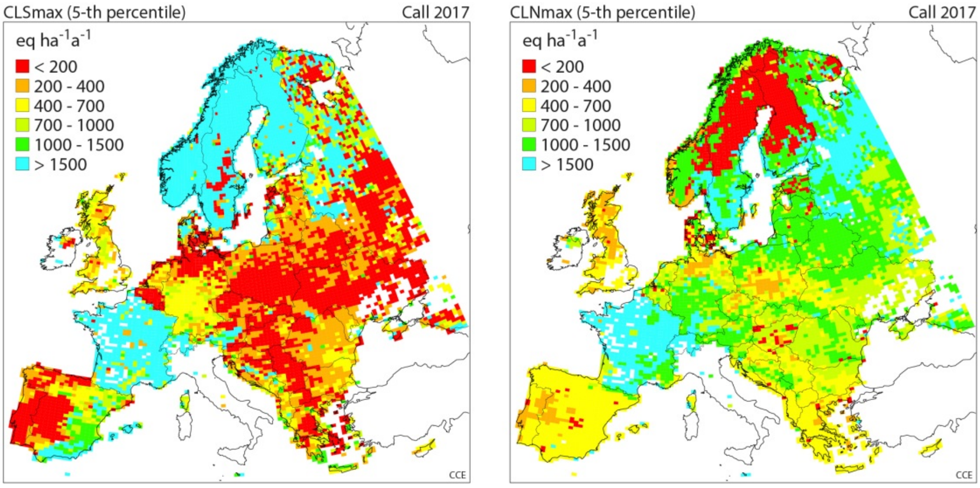

Figure 1.2 Critical load ranges for biodiversity of sulphur (left) and of nitrogen (right) protecting 95% of typical species in selected habitats

1.3 Assessments of areas at risk of excessive deposition of acidity, eutrophication and biodiversity

In this section areas are shown where – and by which magnitude - critical loads for acidification, eutrophication or biodiversity are exceeded in 2005 and 2020. Exceedances are calculated using the EMEP-computed deposition pattern that results from an emission reference scenario (GP-CLE scenario) developed for the revision of the Gothenburg protocol under the LRTAP-Convention (Amann *et al*., 2011) and updated under the Thematic Strategy on Air Pollution of the EU review (Amann, 2012; 2014; Maas and Grennfelt, 2016). Maps in this section show the Average Accumulated Exceedances (AAE: see Posch *et al*., 2001; 2015b). The AAE is computed as an area weighted sum of the differences, in each 0.50^o x 0.25^o longitude-latitude grid cell, between EMEP ecosystem-specific depositions and critical loads of different ecosystems in the grid cell. The analysis applies to the data submitted by NFCs and data from the European background database (Chapter 3) for ecosystems in other countries.

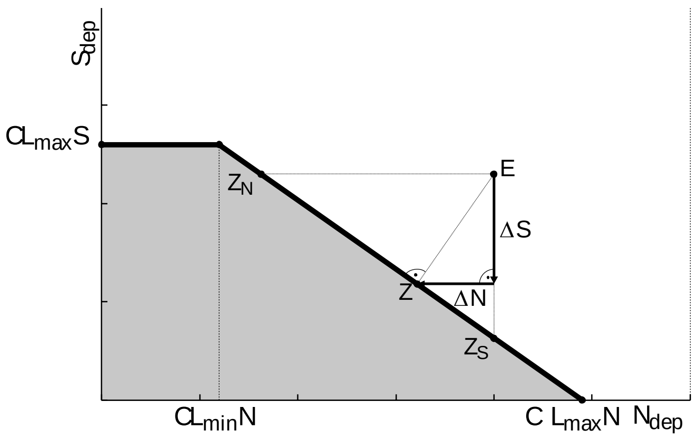

Figure 1.3 Critical load function (CLF) of acidifying nitrogen and sulphur in the (Ndep, Sdep) plane of computed nitrogen and sulphur deposition. The grey area denotes pairs for which there is non-exceedance. The critical load exceedance from point E is computed as ΔS+ΔN (Source: Fig. 6.5 in Posch et al., 2015b)

The critical load function for acidification (Figure 1.3) consists of the maximum critical load of sulphur ($CL_{max}S$), the minimum ($CL_{min}N$) and maximum ($CL_{max}N$) critical loads of nitrogen. The critical load for eutrophication ($CL_{eut}N$; not shown in Figure 1.3) would include a vertical cut-off of the critical load function for acidification, if $CL_{eut}N < CL_{max}N$. Exceedances for acidification are computed for each ecosystem for which a critical load function is available.

Exceedances of critical loads for biodiversity are computed in a similar way for each habitat for which a nitrogen-sulphur critical load function (Figure 1.4) is available. A biodiversity critical load function is derived from the chosen Habitat-Suitability (HS) index limit value (80% of the maximum HS index; see Posch *et al*. 2015a; see also Chapter 3).

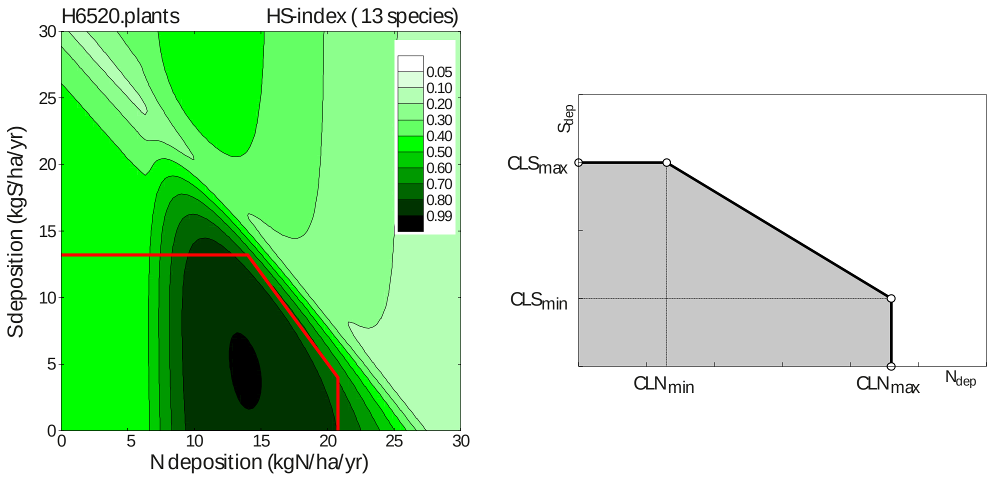

Figure 1.4 Left: A nitrogen-sulphur critical load function (N-S CLF) for biodiversity derived from the chosen HS index limit value (80% of maximum ; red line). Right: The N-S CLF defined by the maximum and minimum critical loads of biodiversity for sulphur (CLS_{max} and CLS_{min}) and for nitrogen (CLN_{min} and CLN_{max}) (Source: Posch et al. 2015a)

Using the principles summarized in Figures 1.3 and 1.4 for all European ecosystems, areas at risk of acidification, eutrophication and biodiversity can be compared between 2005 (Table 1.1) and 2020 (Table 1.2). In the next sections, the location and magnitude ranges of these are also mapped (Figures 1.5, 1.6 and 1.7).

Table 1.1 Ecosystem area (km^2) at risk (%) in 2005, i.e. ecosystem area where the critical loads, available from NFCs and the European background database in 2017, for acidification (CL_{aci}), eutrophication (CL_{eut}), and biodiversity (CL_{bio}) have a positive exceedance (computed as AAE in eq $ha^{-1}yr^{-1}$)

2005 Assessment	Acidification			Eutrophication			Biodiversity		
Country	Eco area for CL_{aci}	Exceedance of CL_{aci}		Eco area for CL_{eut}	Exceedance of CL_{eut}		Eco area for CL_{bio}	Exceedance of CL_{bio}	
	1000 km^2	%	AAE	1000 km^2	%	AAE	1000 km^2	%	AAE
Albania	18	0	0	18	92	287	17	24	61
Austria	39	1	1	51	75	277	51	19	80
Belarus	63	15	41	63	100	516	60	65	147
Belgium	5	25	119	6	11	21	12	55	561
Bosnia & Herzegovina	33	13	81	33	79	256	33	24	130
Bulgaria	51	4	25	51	100	409	50	74	495
Croatia	34	5	29	34	96	492	34	42	156
Cyprus	2	0	0	2	100	286	1	0	0
Czech Republic	6	91	560	6	100	640	32	57	317
Denmark	6	31	99	6	100	741	6	27	131
Estonia	27	0	0	27	84	122	24	13	25
Finland	<1	1	1	41	10	5	90	9	4
France	177	10	41	177	88	436	177	8	18
Germany	107	65	503	107	81	767	107	46	301
Greece	67	3	14	67	100	343	53	42	120
Hungary	28	16	75	28	100	638	28	72	313
Ireland	14	4	5	18	8	13	<1	84	104
Italy	101	1	2	106	77	393	<1	77	362
Kosovo	4	17	54	4	80	235	4	53	289
Latvia	37	13	22	37	97	246	35	7	12
Liechtenstein	<1	37	24	<1	100	500	<1	5	23
Lithuania	22	33	170	22	100	492	22	21	41
Luxembourg	1	14	115	1	100	865	1	62	297
Macedonia, F.Y.R.	15	12	44	15	92	299	14	45	211
Malta	<1	0	0	<1	100	440	<1	0	0
Moldova, Rep. of	4	1	1	4	100	418	4	48	106
Montenegro	8	0	0	8	72	150	8	11	35
Netherlands	4	90	2,029	5	76	925	4	98	1,853
Norway	320	11	20	304	9	13	205	2	3
Poland	97	64	460	97	78	438	105	38	311
Portugal	35	3	7	35	100	360	29	26	58
Romania	105	4	14	105	99	437	103	52	243
Russia	626	4	6	626	52	90	294	18	32
Serbia	30	28	154	30	95	465	30	62	507
Slovakia	24	10	43	24	100	535	24	48	220
Slovenia	13	0	0	13	100	644	13	20	95
Spain	231	2	9	231	99	442	192	27	97
Sweden	395	8	8	59	14	28	172	2	3
Switzerland	10	20	132	24	60	365	<1	9	17
Ukraine	95	4	6	95	100	575	91	55	173
United Kingdom	77	17	54	73	21	55	6	32	87
EU28	**1,707**	**14**	**82**	**1,430**	**81**	**393**	**1,371**	**28**	**144**
Europe	**2,933**	**11**	**56**	**2,653**	**67**	**284**	**2,132**	**27**	**121**

Table 1.2 Ecosystem area (km2) at risk (%) in 2020, i.e. Ecosystem area where the critical loads, available from NFCs and the European background database in 2017, for acidification (CL_{aci}), eutrophication (CL_{eut}), and biodiversity (CL_{bio}) have a positive exceedance (computed as AAE in eq $ha^{-1}yr^{-1}$)

2020 Assessment	Acidification			Eutrophication			Biodiversity		
Country	Eco area for CL_{aci}	Exceedance of CL_{aci}		Eco area for CL_{eut}	Exceedance of CL_{eut}		Eco area for CL_{bio}	Exceedance of CL_{bio}	
	1000 km^2	%	AAE	1000 km^2	%	AAE	1000 km^2	%	AAE
Albania	18	0	0	18	82	223	17	16	36
Austria	39	0	0	51	47	117	51	8	18
Belarus	63	6	10	63	100	423	60	28	34
Belgium	5	3	7	6	2	3	12	43	187
Bosnia & Herzegovina	33	2	2	33	72	157	33	6	12
Bulgaria	51	0	0	51	100	261	50	17	24
Croatia	34	2	3	34	86	297	34	11	18
Cyprus	2	0	0	2	100	253	1	0	0
Czech Republic	6	38	100	6	100	267	32	25	56
Denmark	6	1	2	6	100	409	6	16	46
Estonia	27	0	0	27	58	31	24	10	14
Finland	<1	0	0	41	1	0	90	4	1
France	177	3	3	177	76	236	177	1	2
Germany	107	35	162	107	71	439	107	25	97
Greece	67	1	1	67	96	218	53	15	18
Hungary	28	4	9	28	96	404	28	18	33
Ireland	14	0	0	18	3	4	<1	79	52
Italy	101	0	1	106	53	223	<1	77	69
Kosovo	4	0	0	4	61	100	4	17	24
Latvia	37	2	2	37	90	134	35	4	6
Liechtenstein	<1	0	0	<1	100	324	<1	5	10
Lithuania	22	27	68	22	99	363	22	7	11
Luxembourg	1	12	28	1	100	579	1	28	52
Macedonia, F.Y.R.	15	0	0	15	76	162	14	18	29
Malta	<1	0	0	<1	100	308	<1	0	0
Moldova, Rep. of	4	0	0	4	100	328	4	13	5
Montenegro	8	0	0	8	56	67	8	4	2
Netherlands	4	86	984	5	69	453	4	93	829
Norway	320	4	3	304	4	3	205	1	1
Poland	97	26	83	97	62	214	105	25	102
Portugal	35	0	1	35	100	201	29	12	12
Romania	105	0	0	105	95	279	103	5	5
Russia	626	2	1	626	40	53	294	16	19
Serbia	30	1	1	30	89	283	30	31	49
Slovakia	24	4	5	24	94	310	24	26	29
Slovenia	13	0	0	13	98	362	13	8	10
Spain	231	0	0	231	96	284	192	7	9
Sweden	395	3	1	59	12	11	172	1	1
Switzerland	10	13	64	24	53	237	<1	1	1
Ukraine	95	0	0	95	100	433	91	29	36
United Kingdom	77	3	6	73	9	12	6	18	24
EU28	**1,707**	**6**	**20**	**1,430**	**71**	**228**	**1,371**	**10**	**28**
Europe	**2,933**	**4**	**13**	**2,653**	**58**	**172**	**2,132**	**12**	**24**

1.3.1 *Exceedances in 2005 and 2020 of critical loads for acidification*

Ecosystem areas at risk of exceedances of critical loads of acidification that are higher than 1200 eq $ha^{-1}yr^{-1}$ in 2005 are found in the Czech Republic, the Netherlands, Germany, Poland and Switzerland (red shadings in Figure 1.5). Table 1.1 tells us that the areas at risk of acidification are 91%, 90%, 65%, 64% and 20% of the ecosystem areas in these countries, respectively. These percentages are relatively high in comparison to the areas at risk in 2005 in the EU28 (14%) and in the Europe (11%). Areas with peak[4] AAE in 2020 persist mostly in the Netherlands, where the areas at risk are computed (Table 1.2) to cover 86% (AAE on Dutch ecosystems = 984 eq $ha^{-1}yr^{-1}$) and 35% in Germany (AAE on German ecosystems = 162 eq $ha^{-1}yr^{-1}$). Finally, from Table 1.2 it is noted that the area with an AAE exceeding zero in Europe is 4% in 2020. In the EU28 the area at risk is computed to attain 6% of its ecosystem area.

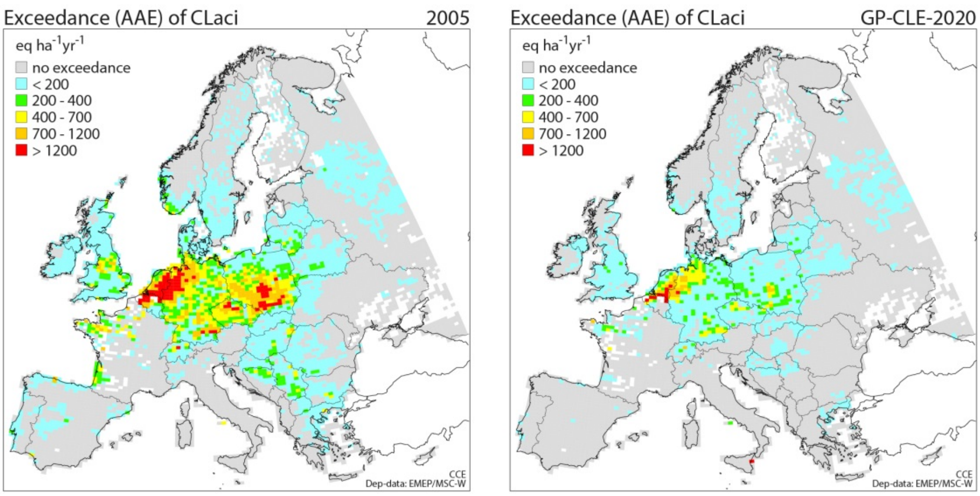

Figure 1.5 Computed area at risk of acidification in 2005 (left) covering 11% (see Table 1.1) and in 2020 (right) covering 4% (See Table 1.2) of ecosystems in Europe (2.9 million km^2)

1.3.2 *Exceedances in 2005 and 2020 of critical loads for eutrophication*

With respect to the area at risk of eutrophication many countries suffer from large shares of their ecosystem area where the AAE exceeds zero (all colour shaded areas in Figure 1.6). Highest peaks in 2005 (Figure 1.6, left) occur on the border area of The Netherlands, Germany and Belgium and scattered over ecosystem areas in France, Spain, Switzerland, southern Germany and in Poland. The three highest national AAEs in 2005 (Table 1.1) are in The Netherlands (925 eq ha^{-1} yr^{-1}), Luxemburg (865 eq ha^{-1} yr^{-1}), and Germany (767 eq ha^{-1} yr^{-1}), values relatively high compared to 284 eq ha^{-1} yr^{-1} in European and 393 eq ha^{-1} yr^{-1} in the EU28. The area at risk of eutrophication in 2005 is computed to cover 67% and 81% in the ecosystem area of the Convention and of the EU28, respectively. In 2020 (Table 1.2) the latter percentages are 58% and 71%, respectively.

[4] Note that countries with the highest range of AAEs occurring in one or more (e.g. red shaded) grid cells, may not necessarily have the largest national area at risk, nor the highest national AAE.

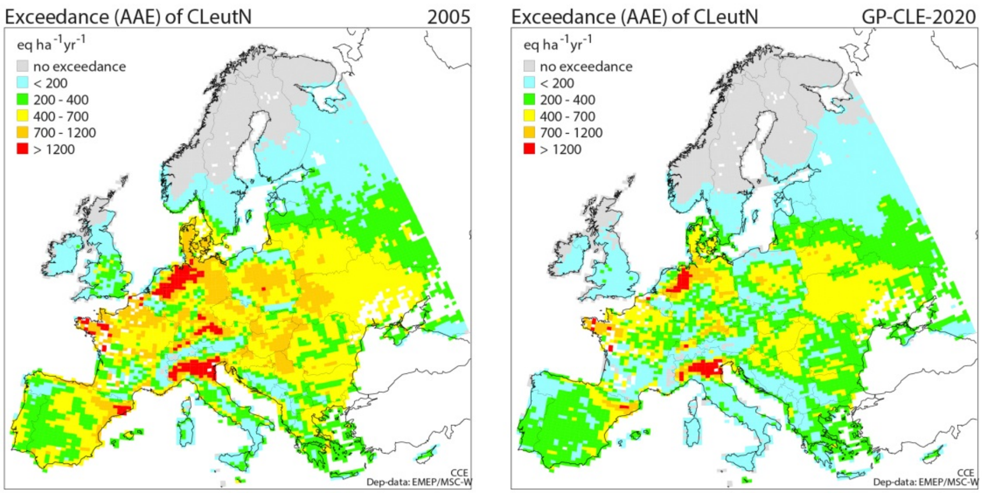

Figure 1.6 Computed ecosystem area at risk of eutrophication in 2005 (left) and 2020 (right) covering 67% and 58% respectively of 2.6 million km^2 for which $CL_{eut}N$ data are available in Europe

1.3.3 *Exceedances in 2005 and 2020 of critical loads of biodiversity*

The use of the novel 2017 critical loads of biodiversity for the computation of AAE reveals the highest exceedances (Figure 1.7, red shaded areas, i.e. AAE > 1200 eq ha^{-1}yr^{-1}) in 2005 to occur in the Netherlands, Belgium, Bulgaria, Germany, Romania and Serbia. However, the occurrence of peaks in a country can be ''compensated '' by the low or zero AAE of other ecosystem areas in a country, leading to a relatively low AAE for a country as a whole. Hence, the percentage area at risk of loss of biodiversity[3] and AAE (eq ha^{-1}yr^{-1}) vary greatly (Table 1.1) between the Netherlands (98%; 1.853 eq ha^{-1}yr^{-1}), Belgium (55%; 561 eq ha^{-1}yr$^{-1,}$ Bulgaria (74 %; 495 eq ha^{-1}yr^{-1}), Germany (46 %; 301 eq ha^{-1}yr^{-1}), and Serbia (62 %; 507 eq ha^{-1}yr^{-1}).

These AAE results are relatively high in comparison to the European AAE (121 eq ha^{-1}yr^{-1}) computed for 2005, affecting 27% of the ecosystem area. The same holds true in comparison to the EU28 numbers, for which an AAE of 144 eq ha^{-1}yr^{-1} is obtained. In the EU28, 28% of the ecosystem area at risk of biodiversity loss in 2005.

For 2020 (Table 1.2) the AAE-peaks occur on the border area of Belgium, the Netherlands, and Germany, whereas the highest national exceedances occur in the Netherlands (829 eq ha^{-1}yr^{-1}), Belgium (187 eq ha^{-1}yr^{-1}), Germany (97 eq ha^{-1}yr^{-1}) and in Poland (102 eq ha^{-1}yr^{-1}), putting 93%, 43%, 25% and 25% of the national ecosystem areas at risk of biodiversity loss in these countries, respectively. For comparison, note that in 2020, the European AAE is 24 eq ha^{-1} yr^{-1} affecting 12% of the ecosystem area. For the EU28 these results are 28 eq ha^{-1} yr^{-1} and 10%, respectively.

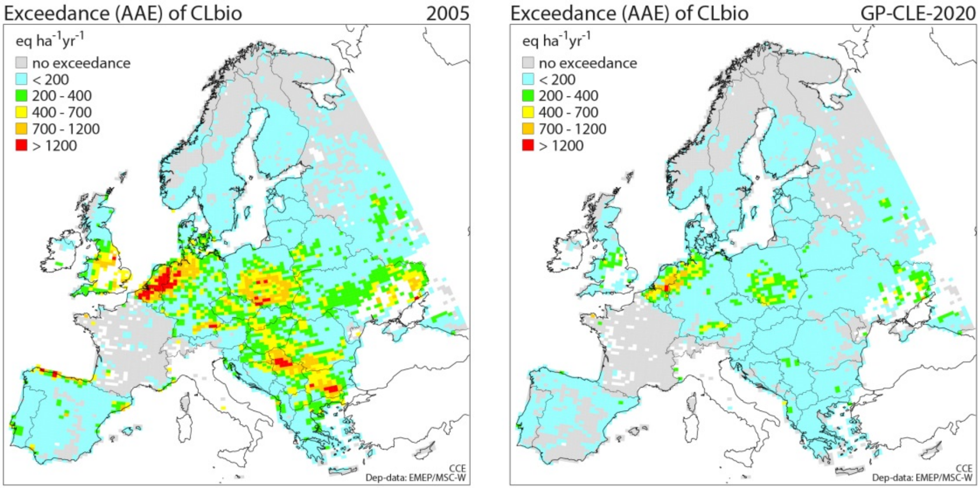

Figure 1.7 Computed ecosystem area at risk of loss of biodiversity in 2005 (left) and 2020 (right) affecting 27% and 12%, respectively, of an ecosystem area of 2.1 million km^2 covering 23 habitats including data submitted by NFCs

Field or experimental data are currently lacking to enable verification of the effects of exceedances of critical loads of biodiversity. However, we can use the empirical critical loads (Bobbink and Hettelingh, 2011) as best available basis of field experiment related results. In doing that, it turns out that the exceedance computed for 2010 (Table 1.2 in Hettelingh *et al.*, 2015a) leads to an AAE of 95 eq ha^{-1} yr^{-1} which lies in the interval between 110 eq ha^{-1}yr^{-1} and 27 eq ha^{-1}yr^{-1} currently computed for 2005 and 2020 respectively. However, the area at risk in 2010 was computed (Hettelingh *et al.*, 2015a) to be 33%, which is higher than the area computed both for 2005 (27%) and 2020 (12%).

The uncertainty of critical load exceedances depends on the reliability of methods and data involved in the assessment of critical loads and depositions. The uncertainty of deposition also depends on that of the country emissions and dispersion approaches, while that of critical loads depends on the quality of information of many entities of soil chemistry and vegetation, including involved temporal, spatial and process scales. In short, acquiring knowledge on the accumulation of uncertainties of exceedances would require scrutiny of the input-output chains and pedigrees involved in the propagation of error and bias through the modelling approaches and data quality behind critical loads and depositions. However, it is not realistic to assume that the analysis of the propagation of uncertainties could be sufficient, if not impossible as implied by Oreskes *et al.* (1994), to increase confidence in the reliability of exceedance computations and mapping. In the face of this reality, multi-model ensemble approaches, i.e. applying several methods to explain a single phenomenon, are increasingly considered in earth system sciences, including by the IPCC[5].

In the next section an application of 'ensemble modelling' is illustrated as a means to make the reliability of information on the location and magnitude of exceedances more robust for use in policy support.

[5] https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-5-4-1.html

1.4 Analysing the robustness of the identification of areas at risk of exceedance

The 'Ensemble Assessment of Impacts' method applied to critical load exceedance aims for estimating the likelihood of exceedance (see Hettelingh *et al.*, 2015b) from knowledge on whether one or more critical loads are exceeded. The approach is inspired from IPCC (2005; 2010).

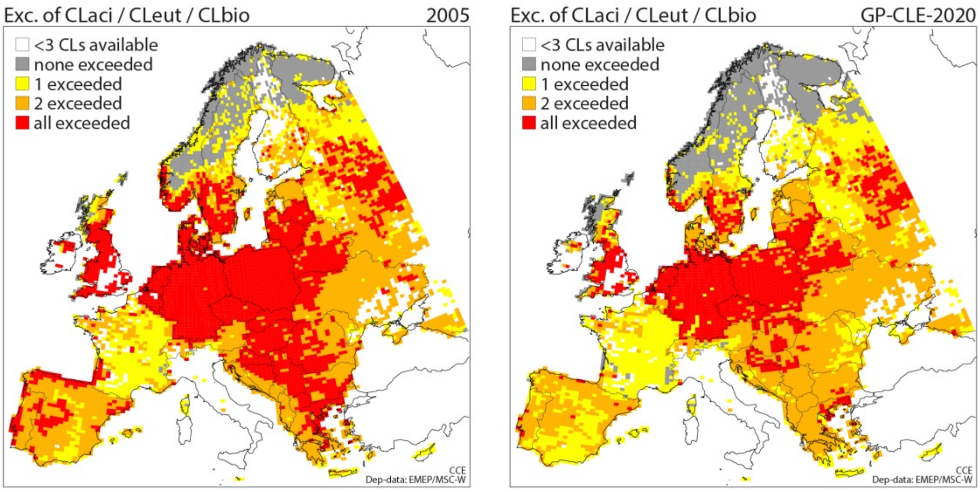

Figure 1.8 Distribution of areas where one, two or three critical loads, i.e. the CL_{aci}, CL_{eut} and CL_{bio} are exceeded

Areas where all three critical loads, i.e. for nitrogen acidification (CL_{aci}), eutrophication (CL_{eut}) and of biodiversity (CL_{bio}), are mostly exceeded in grid cells of central-western Europe (Figure 1.8, red shading)

The accuracy of these maps can be increased by taking the ecosystem areas into account that are at risk of exceedances of the critical load functions (Figures 1.3 and 1.4). This approach enables the assessment of exceedances of combinations of nitrogen and sulphur depositions, thus determining whether in any ecosystem area one or both of the critical loads for acidification (CL_{aci}; Figures 1.3) and biodiversity (CL_{bio}; Figure 1.4) are exceeded. The joint probability of an exceedance of CL_{aci} and of CL_{bio} is assumed to be the geometric mean of both percentages of area at risk. This assumption is valid because in each grid cell it can be assumed that the area at risk computed using CL_{aci} is independent from that computed with CL_{bio}. Using a similar terminology as introduced by IPCC (2005; 2010) the likelihood of an exceedance (i.e. AAE >0) is described as "likely", "very likely" or "virtually certain", if the geometric mean of the area percentages is in the range of 0-33%, 33-67% and >67%, respectively (see also Hettelingh *et al.,* 2015b). The likelihood is "unlikely" if none of both critical loads is exceeded and "as likely as not" if only one of the two[6] critical loads is exceeded. In this way, the likelihood of exceedances of CL_{aci} and Cl_{bio}

[6] Note that a similar approach could theoretically be applied to more than two critical loads. However, this would necessitate an (arbitrary) appraisal of the likelihood of exceedances for cases where one or two critical loads out of three are exceeded, i.e. where the geometric mean is zero. This is not attempted in the context of the final activities of the CCE located at RIVM. Instead the joint likelihood of exceedances of different pairs of critical loads are compared.

(Figure 1.9), CL_{aci} and CL_{eut} (Figure 1.10) and finally CL_{eut} and CL_{bio} (Figure 1.11) can be reviewed.

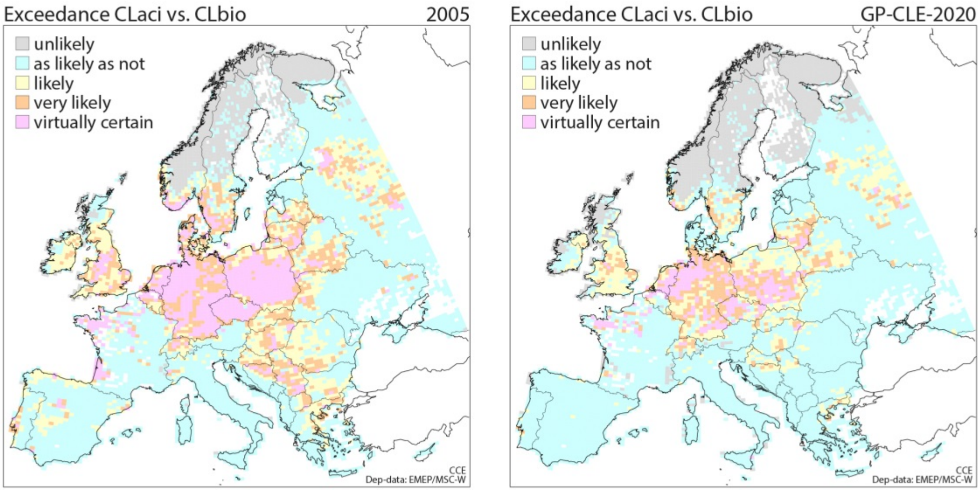

Figure 1.9 Likelihood of an exceedance of CL_{aci} and CL_{bio} in grid cells in 2005 (left) and 2020 (right)

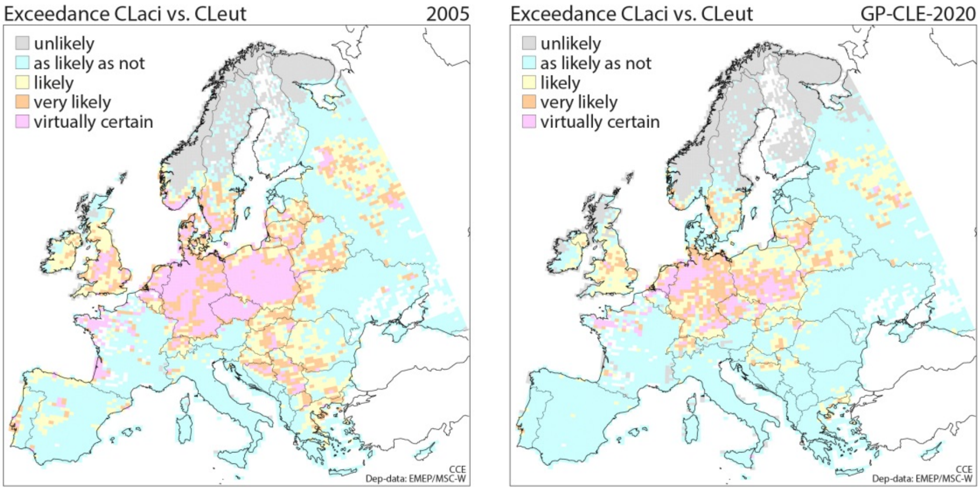

Figure 1.10 Likelihood of an exceedance of CL_{aci} and CL_{eut} in grid cells in 2005 (left) and 2020 (right)

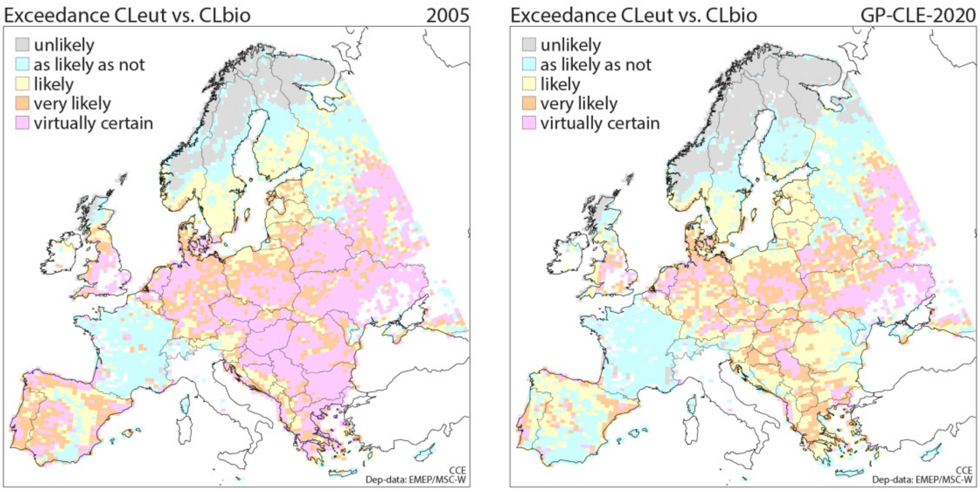

Figure 1.11 Likelihood of an exceedance of CL_{eut} and CL_{bio} in grid cells in 2005 (left) and 2020 (right)

Areas which are “virtually certain” (purple) to be at risk of acidification and loss of biodiversity in 2005 (Figure 1.9) are mostly in central-western Europe, evolving in 2020 to become “likely” or “very likely” at risk, especially in Germany and Poland. With respect to the risk of eutrophication and acidification (Figure 1.10) or the risk of eutrophication and biodiversity (Figure 1.11) a similar trend can be noted between 2005 and 2020. However, in the latter case ecosystems in Eastern Europe turn out to be particularly affected by either the risk of eutrophication or the risk of biodiversity loss both in 2005 and 2020. The risk of an exceedance of two critical loads in Eastern European ecosystems and of three critical loads in broad areas in central-west was already indicated in Figure 1.8, but with Figures 1.9-1.11 more information is obtained of the endpoint of the risk for effects on ecosystems in 2005 and 2020.

While the risk of effects under GP-GLE emission scenarios until 2020, is of interest in the short run, the more pressing question is what effects could be occurring in the long run, by which time ecosystems are likely to also be affected by climate change. This is tentatively addressed in the next section.

1.5 A glimpse at possible risks of European air pollution under climate change in Natura 2000 areas

Effects of air pollution under climate change are receiving increasing attention in Europe (see e.g. Dirnböck et al., 2016; 2017; Rizzetto, 2017). In this section an illustration, using the European background database only, is provided of the possible change of exceedances in Natura2000 areas, caused by (a) changes in critical load magnitudes due to an increase of temperature and related changes in soil humidity, as could be the case under climate change, and (b) a deposition according to a well -known scenario of European emission reduction measures which are assumed constant as of 2020. This illustrative analysis merely reflects a “glimpse at possible risks”, as the pattern of deposition is assumed, in this assessment, not to be affected by climate change. Moreover, the critical load computations do not take into

account possible climate-induced changes in precipitation patterns and amounts. Therefore, the main objective of this section is to show that climate change can be incorporated in critical load computations and exceedance assessments. The reason for including this paragraph in this Final CCE report is that the assessment of the combined effects of air pollution, the change of climate and of biodiversity[7] could be the next level of effect-oriented policy support under the LRTAP Convention, as expressed in its long term strategy. It would, for example, imply air pollution abatement policies to also be driven by the 2015 UNFCCC Climate Conference (COP21, Paris, 30 Nov – 12 Dec 2015) on one hand and nature policies on the other hand, the latter with a focus on protecting Natura 2000 areas.
While in practice this could mean a review and possible revision of the collaboration between policy institutions and conventions (e.g. LRTAP Convention, UNFCCC, CBD) and policy strategies (e.g. EU policy packages), this is clearly an issue which lies in the realm of policy and is not part of the remit of scientific effect-oriented policy support. Therefore, this section is limited to technical considerations, applied to the CCE-Alterra background database (Chapter 3) which also identifies Natura 2000 areas. Information, used in this section, on characteristics that are relevant for an analysis of exposure of Natura 2000 areas to acidification and eutrophication, can be found in earlier CCE work (Hettelingh *et al.*, 2014) conducted in support of an EEA study (EEA, 2014).

Here, the effect of climate change on critical loads is assumed to be driven by a temperature increase and the corresponding change of runoff patterns. Temperature increase leads, e.g., to higher base cation weathering (and thus higher critical loads for acidification), while decreasing runoff leads to lower critical loads for eutrophication; and it affects the occurrence of typical plant species (changed critical loads of biodiversity). For an earlier study of the impacts of climate change on (classical) critical loads see Posch (2002).

However, the effect of climate change on the geographical pattern and magnitude of critical loads and exceedances should be considered with great caution. Multiple interactions between climate change and biodiversity have been explored in general (Franklin *et al.*, 2016), which are not considered in this simple analysis. Important interactions between effects of air pollution and climate change should perhaps include considerations of the (potential) change of land cover (see e.g. Pitelka *et al.*, 1997), changes of localized ecosystems (see, e.g., Barnosky *et al.*, 2012) or the combination of different environmental drivers (including N deposition) on the trade-off between global biodiversity and local diversity (see, e.g., Bernhardt-Römermann *et al.*, 2015). The modelling of climate change impacts on critical loads, as described in this section, has been limited to using temperature and precipitation surplus (runoff) as drivers, with the ambition to help unfold interactions between air pollution impact indicators and climate change.

[7] The endpoint of the loss of biodiversity in this report is plant species occurrence. However, other endpoints could be considered for effect-oriented policy support in the framework of the LRTAP Convention or the EU biodiversity strategy, e.g. to protect specified traits of plant species, or related ecosystem services, from impacts of air pollution with an aim to increase resilience against climate change.

Here temperature increase was chosen on the basis of ranges of mean annual surface air temperature anomalies that have been considered in the 5th Assessment Report of the IPCC (2014). These are based on four "Representative Concentration Pathways" (RCPs), which are scenarios that provide a range of emissions and concentrations developed for the climate modelling community (Van Vuuren *et al.*, 2011). The RCPs reflect a widely accepted range of radiative forcing values and their names refer to the radiative forcing target level for 2100, i.e. RCP2.6 (~ 490 ppm CO_2 eq), RCP4.5 (~ 650 ppm CO_2 eq)[7], RCP6 (~ 850 ppm CO_2 eq) and RCP8.5 (~ 1370 ppm CO_2 eq.)[8]. Since this section focuses on the effect of climate change on the sensitivity of Natura 2000 ecosystems, RCP4.5 and RCP6 seem to be of particular interest for our purpose. The reason is that these pathways lead to a similar and slightly increasing global area of natural vegetation in 2100 compared to 2000 (see Van Vuuren *et al.*, 2011, p. 19, Fig. 5). The EU target of no-net-loss of biodiversity applied to Natura 2000 areas could be compatible with that trend. Moreover, RCP4.5 and RCP6 are so-called stabilizing, i.e. in which total radiative forcing is stabilized after 2100, while SO_2 and NO_x emissions show similar downward trend between 2000 and 2100, and of which the share of fossil fuels is likely to be compatible with GP-CLE. Under a RCP4.5 and RCP6 world, the global mean annual surface air temperature on land is forecasted to increase between 2081 and 2100 by 2.4 ± 0.6°C and 3.0 ± 0.7°C, respectively (see Table 12.2 in Collins *et al.*, 2013). Therefore, for our analysis described here, a temperature increase of +3°C was chosen to be representative of the forecasted temperature anomaly that could occur in both RCP4.5 and RCP6 and used to re-compute critical loads. However, the time period that applies to RCP4.5 and RCP6, is not relevant for an assessment that explores how exceedances may change under temperature increase. Figure 1.12 illustrates the cumulative distribution of critical loads for acidification and eutrophication (left), and critical loads of biodiversity for sulphur and nitrogen (right) in Natura 2000 areas in comparison to cumulative distributions of these critical loads resulting from a temperature increase of +3°C.

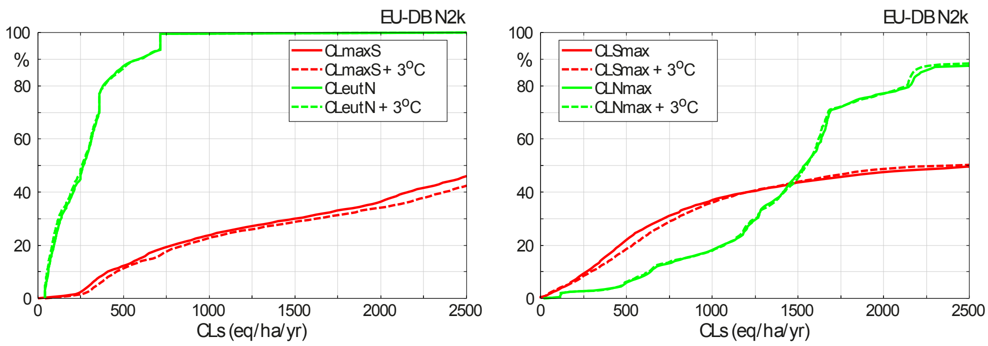

Figure 1.12 Left: Cumulative distributions of critical loads for acidification ($CL_{max}S$) without (solid red line) and including a temperature increase of 3°C (red dotted line) and of critical loads of eutrophication ($CL_{eut}N$) without (green solid line) and with a temperature increase of 3°C (green dotted line). Right: critical loads of biodiversity for sulphur (CLS_{max}) without (solid red line) and

[8] ppm ranges for each RCP have been taken from Van Vuuren *et al.* (2011), Table 2.

including a temperature increase of +3℃ (red dotted line) and of a critical load of biodiversity for nitrogen (CLN_{max}) without (green solid line) and with a temperature increase of +3℃ (green dotted line).

Under a temperature increase of +3°C it can be seen that critical loads of sulphur for biodiversity (Figure 1.12, right, red dotted line) is higher in about 40 % of the Natura 2000 areas with critical loads lower than 1250 eq $ha^{-1}yr^{-1}$; and the critical load of nitrogen for biodiversity is indicated to become lower (Figure 1.12, right, green dotted) in the range exceeding 2200 eq $ha^{-1}yr^{-1}$. This corresponds to a nitrogen deposition of about 31 kg ha^{-1} which hardly ever occurs. The geographical pattern of ranges of biodiversity critical loads in Natura 2000 areas illustrates that critical loads of sulphur for biodiversity are lower than 2000 eq $ha^{-1}yr^{-1}$ in broad areas of the EU28 (Figure 1.13, left, red shading), whereas critical loads of nitrogen for biodiversity fall in ranges of 400 eq $ha^{-1}yr^{-1}$ or higher (Figure 1.13, right, yellow-green shading). It should be noted, that this general pattern holds also for the non-forested parts of Natura 2000 areas (not shown). Note the lack of model results in south-western Spain. This is because the temperature increase violates the system domain in which the PROPS model can describe the occurrence of some plant species.

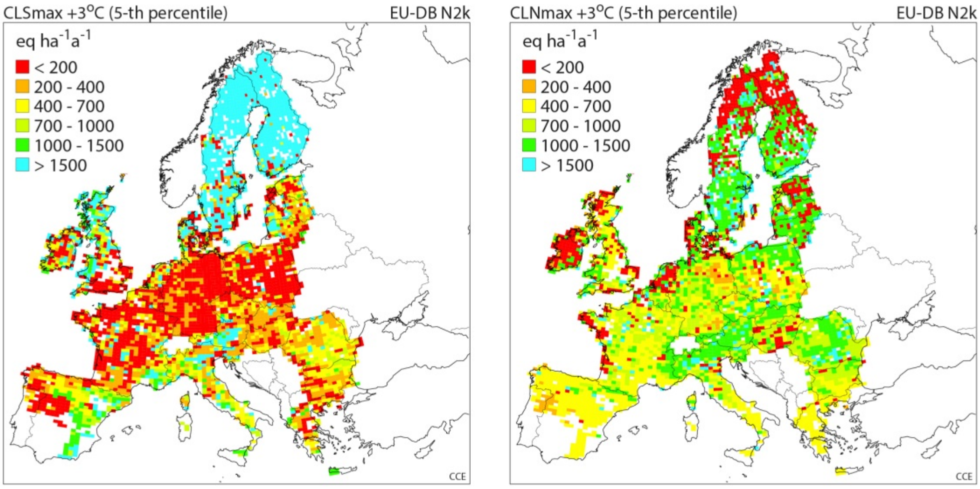

Figure 1.13 Natura 2000 critical loads of biodiversity using the European background database for sulphur (left) and for nitrogen (right) under a +3℃ increase of the annual mean surface air temperature

For critical loads in Natura 2000 areas and using 2005 and 2020 deposition, it turns out (Table 1.3) that the average accumulated exceedances of eutrophication and of biodiversity tend to be slightly higher under a +3°C temperature increase. The contrary is true when critical loads for acidification are compared to acidifying depositions.

Table 1.3 Natura 2000 area (km^2) at risk (%) of GP-CLE depositions of 2005 and 2020 (and kept constant thereafter), i.e. the area where critical loads from the European background database, for acidification (CL_{aci}), eutrophication (CL_{eut}), and biodiversity (CL_{bio}) have a positive Average Accumulated Exceedance (AAE in eq $ha^{-1}yr^{-1}$) at present and under an increase of the mean annual surface air temperature by +3°C*

Natura 2000 areas	Deposition year	Exceedances using critical loads at Present temperature							Exceedances using critical loads at a 3°C temperature increase					
		Exceedance of CL_{aci}		Exceedance of CL_{eut}		Exceedance of CL_{bio}			Exceedance of CL_{aci}		Exceedance of CL_{eut}		Exceedance of CL_{bio}	
		%	AAE	%	AAE	%	AAE		%	AAE	%	AAE	%	AAE
EU28	2005	11	86	83	464	32	160		10	80	83	466	32	164
	≥ 2020	7	30	79	299	13	35		6	28	79	301	13	40

*The Natura 2000 area for which CL_{aci} and CL_{eut} data are available in the European CCE-Alterra background database covers about 540.000 km^2. For CL_{bio} the area is about 474,000 km^2 at present and 424.000 km^2 under temperature increase. The latter is due to the system domain of the PROPS model being violated (no occurrence of typical species) in certain areas, south-western Spain in particular.

Finally, it is important to note that the assessment of exceedances of critical loads may lead to incomplete conclusions about the vulnerability of ecosystems that are subjected to an interaction between (effects of) climate change and air pollution. Indeed, under the ECLAIRE project, this finding was formulated as "climate warming is found to be likely to increase the vulnerability of ecosystems towards air pollutant exposure or atmospheric deposition. Such effects may occur as a consequence of combined perturbation, as well as through specific interactions, such as between drought, ozone, N and aerosol exposure" (Sutton *et al.*, 2015, part 1, first page).

1.6 Conclusions and Recommendations

In this chapter the focus was on the assessment of exceedances in 2005 and 2020 of the "classical" critical loads for acidification, eutrophication and of novel critical loads for biodiversity, that were established in 2017 following the Call for Data in 2015. For countries that did not respond to that call, use was made of an updated background database of critical loads to enable the assessment of exceedances in all European countries. These background database critical loads were then recomputed assuming an effect of climate change, whereby the temperature would increase by +3°C and the corresponding precipitation surplus. The corresponding exceedance assessments provide a first insight into the risk of interaction between air pollution and climate change. By choosing receptors to be in Natura 2000 areas the relevance of these computed exceedances under climate change can also be considered in the context of the European biodiversity strategy[9].

Finally, depositions used for the calculation of exceedances were obtained for the years 2005 and 2020 from the emission pathways used in support of the EU Thematic Strategy on Air Pollution[10].

[9] http://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm
[10] http://ec.europa.eu/environment/air/review_air_policy.htm

The areas at risk of acidification in Europe in 2005 and 2020 are 11% and 4%, respectively, and of eutrophication 67% and 58%. The risk of biodiversity loss affects 27% and 12% of the ecosystem area in 2005 and 2020 respectively.

The EU28 area at risk of acidification, eutrophication and biodiversity loss in 2020 is 6%, 71% and 10%, respectively. Under climate change these risks in 2020 for Natura 2000 areas in particular are computed to be 6%, 79% and 13%, respectively.

"Ensembles" of exceedances calculated by using any or all of the critical loads have enabled a robust identification that broadly distributed European ecosystem areas are at risk of either acidification, eutrophication or loss of biodiversity, and that a simultaneous risk of these adverse effects occurs especially in western-central European regions stretching towards the east.

It is recommended that knowledge of effects of interactions between air pollution and climate change is further strengthened by improving critical loads of biodiversity. Furthermore it is recommended that the assessment of air pollution effects, risks and trends include specific interactions, such as between drought, ozone, N and aerosol exposure. These assessments should be aimed at the support effect-oriented policies that are jointly framed under UN-Conventions and EU strategies for air pollution, climate and biodiversity.

The successor of the Coordination Centre for Effects is encouraged to continue the coordination and programming of this scientific challenge in collaboration with other effect-based programmes under the LRTAP Convention.

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2 Summary of National Data submitted in 2017

Jaap Slootweg, Maximilian Posch, Jean-Paul Hettelingh

2.1 Introduction

In recent years, the scientific community of the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends (ICP M&M) has made progress in supporting the effects-related work by linking biodiversity of plant species to nitrogen and sulphur deposition. Consequently, at the 1st joint session of the Steering Body to the EMEP and the Working Group on Effects (Geneva, 14-18 September 2015) the Coordination Centre for Effects (CCE) was requested to issue a Call for Data in the autumn of 2015 with a deadline in 2017. The purpose of the call was to:

- derive nitrogen and sulphur critical load functions taking into account their impact on biodiversity (critical loads for biodiversity),
- and offer the possibility to NFCs to update their 'classical' national critical load data on eutrophication and acidity, the first consisting of (the minimum of) the critical load of nutrient nitrogen and the empirical critical load at a site.

This chapter presents the results of the call for data. Details on the call, including a description of the data formats, can be found in Appendix A "(reprint of) Call for Data 2015-17: Instructions."

2.2 National responses

The CCE received responses from 14 European Parties to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention). All 14 countries submitted 'classical' critical loads data, and 7 submitted also data for effects on biodiversity. Data have first been presented at the 33rd ICP M&M Task Force meeting (Wallingford, 4-6 April 2017), after which National Focal Centres (NFCs) were given the opportunity to complete their submissions by May 2017.

Table 2.1 lists the countries and their choice of receptor/effect combinations. The receptors are classified by the European Nature Information (EUNIS) system (Davies and Moss, 1999). The top level of the EUNIS hierarchy (EUNIS-1) is used most maps and tables in this report. Table 2.2 lists also the second level (EUNIS-2). It reveals that most of the submitted critical loads are for forests (EUNIS class G, 74%) and grasslands (EUNIS class E, 12%), however varying over countries (Figure 2.1). Effects in this context are for biodiversity, eutrophication and acidification.

In addition to the national data, a 'background database' with critical load (CL) data at a European scale is applied for countries that have not submitted critical loads (see Chapter 3). The ecosystem area for each of the top-level EUNIS classes used in the European CL database, can be found in Annex 2.A to this chapter for all three effects.

Table 2.1 Country submissions by effect and EUNIS class; every single character refers to the top-level EUNIS class (see Table 2.2)

Country	Biodiversity	Eutrophication	Acidification
Austria (AT)		CDEFGX	G
Belgium (BE,Wallonia)		DEFG	G
Czech Republic (CZ)		G	G
Finland (FI)		ABCDEFG	C
France (FR)	DEG	DEG	DEG
Germany (DE)	ADEFG	ADEFG	ADEFG
Ireland (IE)	DEF	ADEFG	CEFG
Italy (IT)	G	BEFG	BEFG
Netherlands (NL)	ABCDEFG	ABCDEFG	ABCDEFG
Norway (NO)		CDEFGH	C
Poland (PL)		DEFG	DEFG
Sweden (SE)		Y	C
Switzerland (CH)	G	CDEFG	CG
United Kingdom (GB)	DEF	ABDEFG	CDEFG

Table 2.2 Number of records for ecosystems (ecords) submitted by NFCs per EUNIS class (up to level 2)

EUNIS-1	EUNIS-2	# ecords
A – Marine habitats	A2	8,372
B – Coastal habitats	B	1,563
	B1	10,248
C – Inland surface water habitats	C	26,676
	C1	34,539
	C2	3,395
	C3	28
D – Mire, bog and fen habitats	D1	80,396
	D2	23,815
	D3	2,881
	D4	7,051
	D5	39
E – Grasslands and lands dominated by forbs, mosses and lichens	E	551
	E1	158,539
	E2	10,822
	E3	87,103
	E4	50,296
F – Heathland, scrub and tundra habitats	F2	22,783
	F3	26
	F4	114,500
	F5	2,084
G – Woodland, forest and other wooded land	G1	785,007
	G2	848
	G3	697,677
	G4	437,495
Other	H4	4,798
	X0	18
	Y (unknown)	9,189

The bar charts in Figure 2.1 show the percentage of coverage of the different ecosystems relative to the total country area.

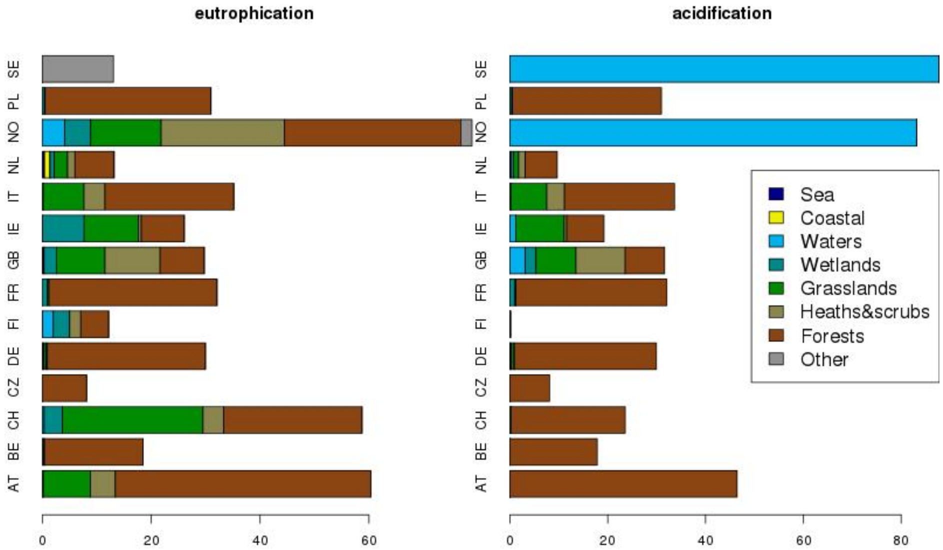

Figure 2.1 Coverage of submitted ecosystems (by EUNIS class) as percentage of country area for eutrophication (left) and acidification (right)

2.3 Eutrophication

A critical load for eutrophication (*CLeutN*) can be modelled, based on a limiting nitrogen concentration, or based on observed effects of an increased nitrogen deposition (i.e. empirical critical load). The call for data stipulated (see Appendix A) that *CLeutN* should be the minimum of the modelled and empirical critical loads at every site (if both are estimated). Figure 2.2 shows the distributions of the submitted eutrophication CLs grouped by country and (top level) EUNIS class. The cumulative distribution functions (CDFs) shows values in the range of 200 eq $ha^{-1}yr^{-1}$ up to 1200 for most ecosystems. The vast majority of Belgian (Walloon) forests have values exceeding 1200 eq $ha^{-1}yr^{-1}$.

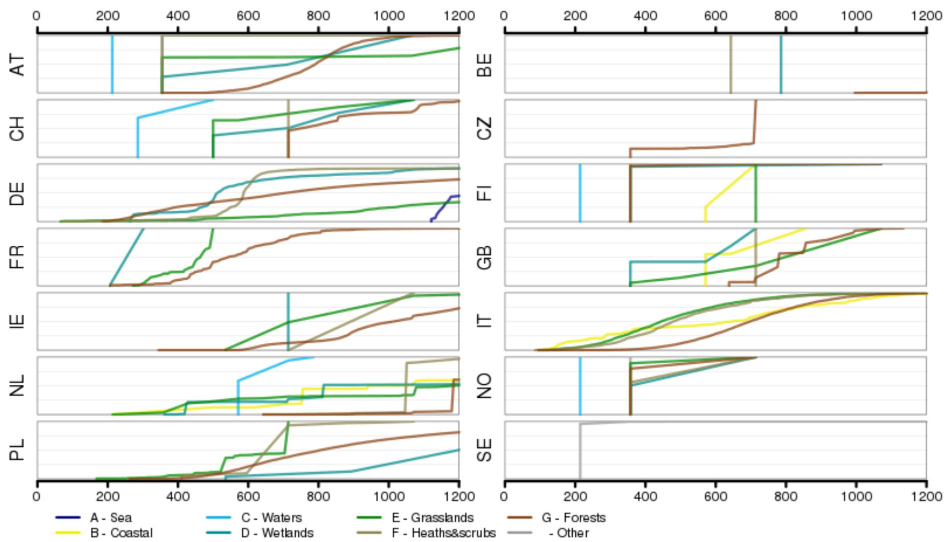

Figure 2.2 CDFs of submitted critical loads for eutrophication by country and EUNIS class.

Critical loads are limits to depositions below which adverse effects (acidification, eutrophication, loss of biodiversity) do not occur, and therefore location is essential. To enable a comparison to gridded depositions of various resolutions, the loads are given within 0.10°×0.05° longitude-latitude grid cells. This is too high a resolution to print European maps; all maps presented in this report are therefore shown on a 0.5°×0.25° longitude-latitude grid. Each grid cell can only reflect a single number on a choropleth map; therefore the CLs within a grid cell has to be characterised by a single number. Figure 2.3 on the left shows a map of the 5th percentile values in each grid cell of the critical loads for eutrophication; and right map the 25th percentile.

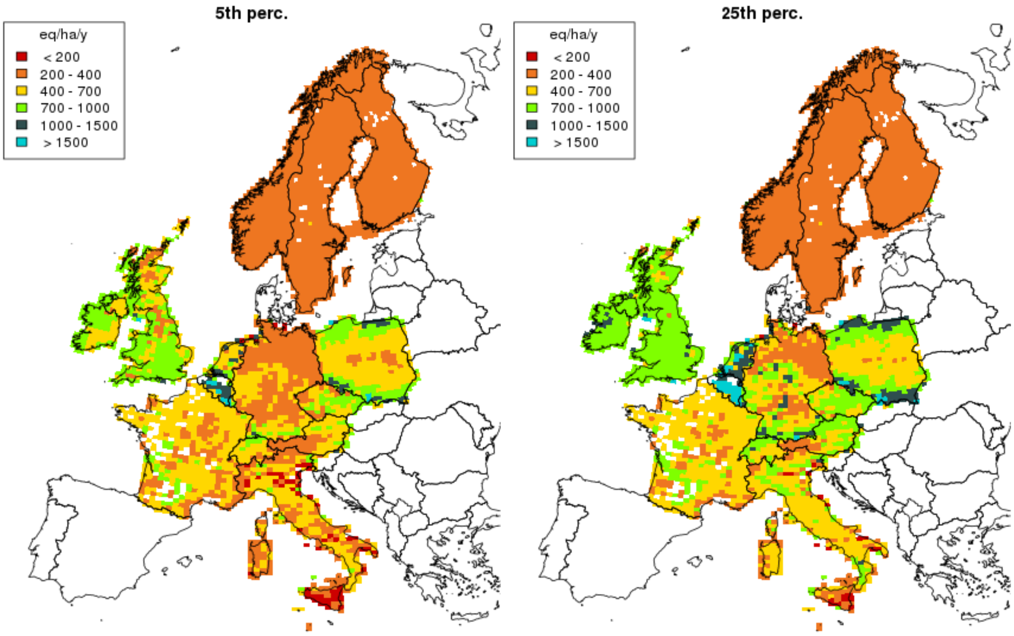

Figure 2.3 The 5th (left) and 25th percentile (right) of the critical load for eutrophication

The maps look similar because many grids have CL values for the 5th and 25th percentile in the same legend class. This is often the case in areas where (predominantly) empirical CLs are applied. Empirical CLs have fixed values (independent on soil and meteorological parameters) for a type of ecosystem. More information on empirical CLs can be found in Bobbink and Hettelingh (2011), while earlier NFC submissions of empirical critical loads are found in Slootweg *et al.* (2015).

While in 2015 both empirical and nutrient N critical loads could be submitted, the 2017 call requested the minimum of both. To see the changes in comparison to the previous submissions (Slootweg *et al.*, 2015), Figure 2.4 shows the 5th percentile of the 2015 empirical critical loads on the left, and the CLs of nutrient nitrogen (the 'classical' *CLnutN*) on the right. Mind the difference in classes compared to Figure 2.3. From the maps it is clear that the Nordic countries kept their choice (and values) of empirical CLs. Italy re-submitted their nutrient nitrogen CLs as eutrophying CL; and, e.g., Germany selected the CL to use for ecosystems individually.

A parameter of recent interest is nitrogen immobilisation (*Nimm*), to which an expert workshop was dedicated (Olten, Switzerland, 23-24 February 2017). This workshop reviewed available data and methods to assess the 'long-term immobilisation of nitrogen' as a sink in the SMB equation. Consensus was reached at the 33rd Task Force meeting (Wallingford, UK, 2017) leading to an update of the Mapping Manual (www.icpmapping.org). Figure 2.5 shows CDFs of *Nimm* per EUNIS class as submitted by the countries. The UK assumes a high immobilisation (and probably carbon sequestration) in wetlands. Belgium assumes a *Nimm* of 400-550 eq $ha^{-1}yr^{-1}$ (for forest ecosystems). In the European background database recommended values from the Mapping Manual are used (see Chapter 3).

More information on the critical loads submitted by Parties can be found in the national reports in Part 2 of this report.

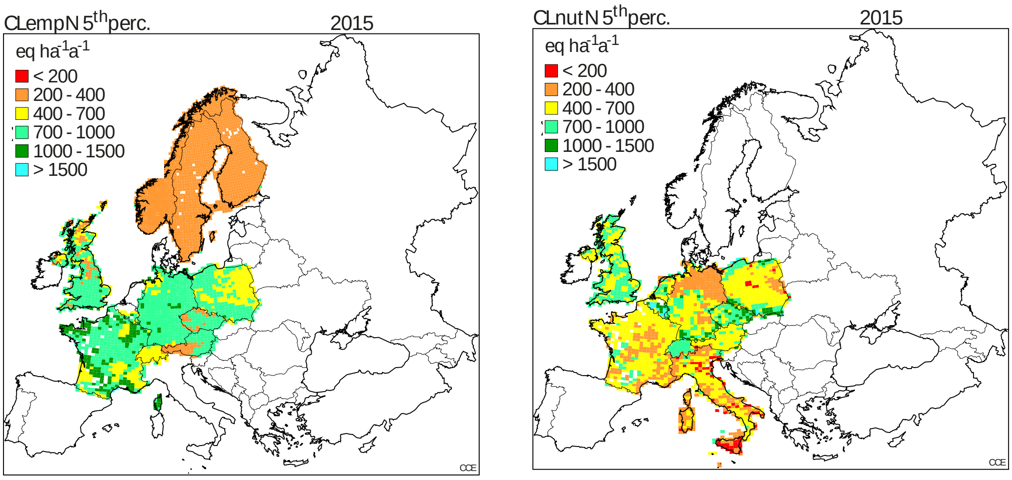

Figure 2.4 Critical loads from the 2015 submission for empirical (left) and nutrient (right) nitrogen

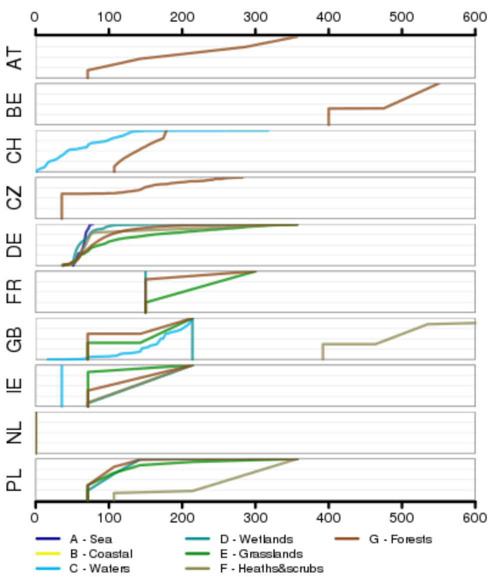

Figure 2.5 CDFs of 'long-term immobilisation of nitrogen' as submitted by the countries.

2.4 Acidification

Critical loads for acidification consist of deposition limits for both sulphur and nitrogen. The three parameters defining the N-S critical load function are *CLmaxS*, *CLminN* and *CLmaxN*. The CDFs of *CLmaxS* as submitted by the NFCs are shown in Figure 2.6.

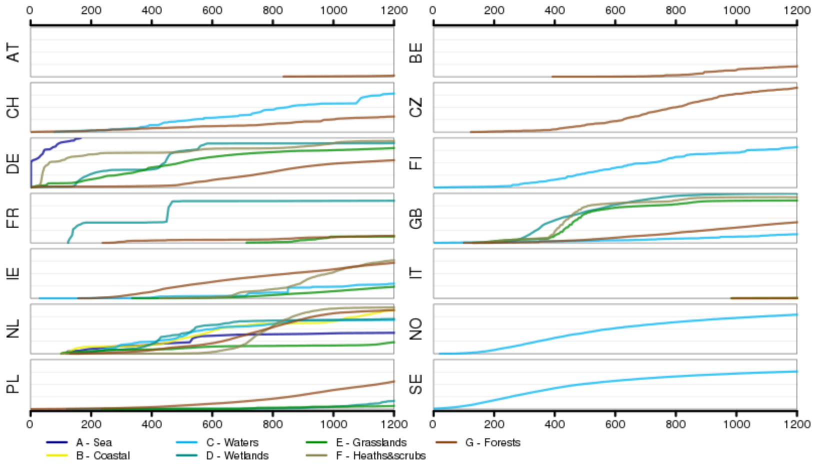

Figure 2.6 CDFs per EUNIS class of submitted maximum critical loads of S, CLmaxS, by country.

Countries with relatively little risk of acidification (i.e. with a relatively small percentage of the ecosystem areas where low critical loads occur) focus mainly on forests, whereas countries with more sensitive ecosystems submitted also critical loads for other ecosystem types. Nordic countries focus on acidification of surface waters. Note that the CDFs do not reflect the ecosystem area covered by the respective EUNIS class; e.g. the very sensitive Sea-ecosystems (EUNIS class A) in Germany cover only 109 km^2 of a total ecosystem area of 106,976 km^2 (see Table 2.A).

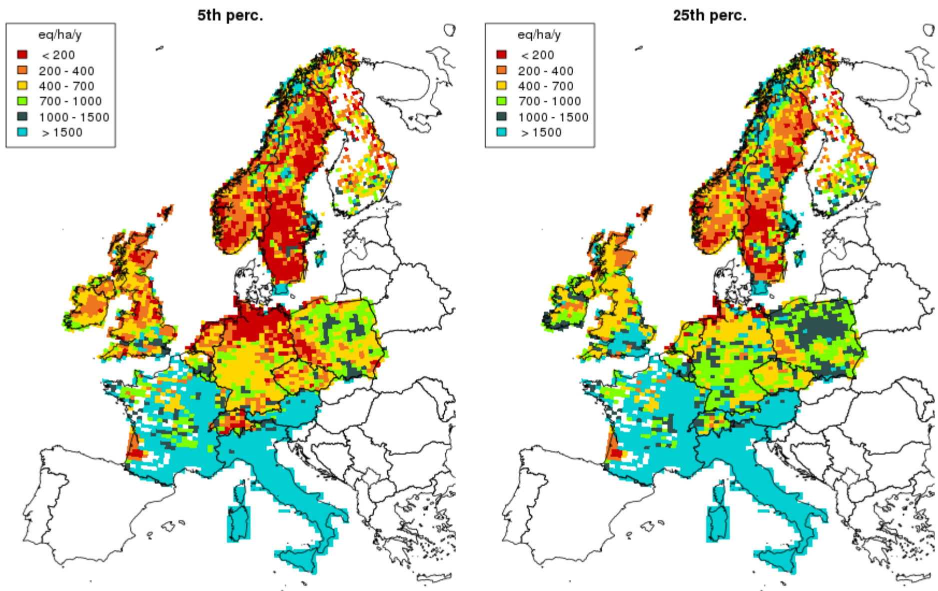

Figure 2.7 The 5th (left) and 25th percentile (right) of CLmaxS

Maps of the 5th and 25th percentiles of *CLmaxS* are shown in Figure 2.7. As can be seen from the differences between the 5th and the 25th percentile, in central Europe the sensitive regions also contain a fair amount of less sensitive ecosystems. For the northern countries this difference between the 5th and 25th percentile is smaller, indicating a large number of sensitive ecosystems. Compared to the 2015 submission (see Figure 2.8), one can note several changes: Ireland did not submit data in 2015, but did so for this call. The Irish submission in 2012 (Posch *et al*. 2012) showed critical loads in the same range and regions. Other clear changes can be seen for Germany and Norway.

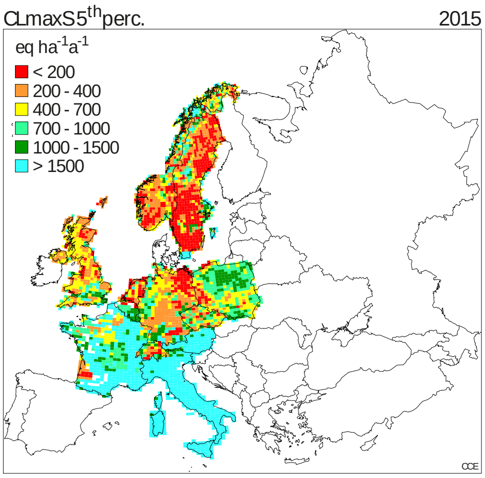

Figure 2.8 The 5th percentile of CLmaxS, as submitted by the countries in 2015

2.5 Biodiversity

Critical loads of biodiversity (see Posch et al. 2015) set minimum levels for an indicator for the occurrence of typical plant species in specific habitats, translate these back into limits for pH and nitrogen parameters and applies the Simple Mass Balance model to calculate the critical loads for sulphur and nitrogen depositions. The critical load function (CLF) for biodiversity is similar to the CLF for acidification, defined by four parameters, *CLNmin*, *CLNmax*, *CLSmin*, *CLSmax* (see Figure 2.9).

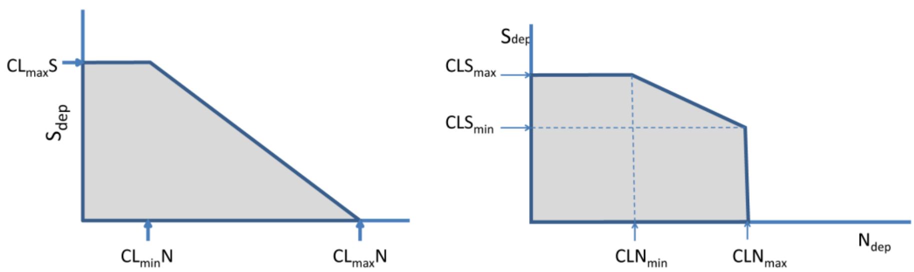

Figure 2.9 The 'classical' critical load function for acidification (left) and the critical load function for biodiversity (right).

Figure 2.10 shows the CDF for each EUNIS class of *CLSmax* and *CLNmax* grouped by country. Typical plant species (plant species of which the occurrence is deemed critical for specified habitats) are generally more sensitive to sulphur than nitrogen.

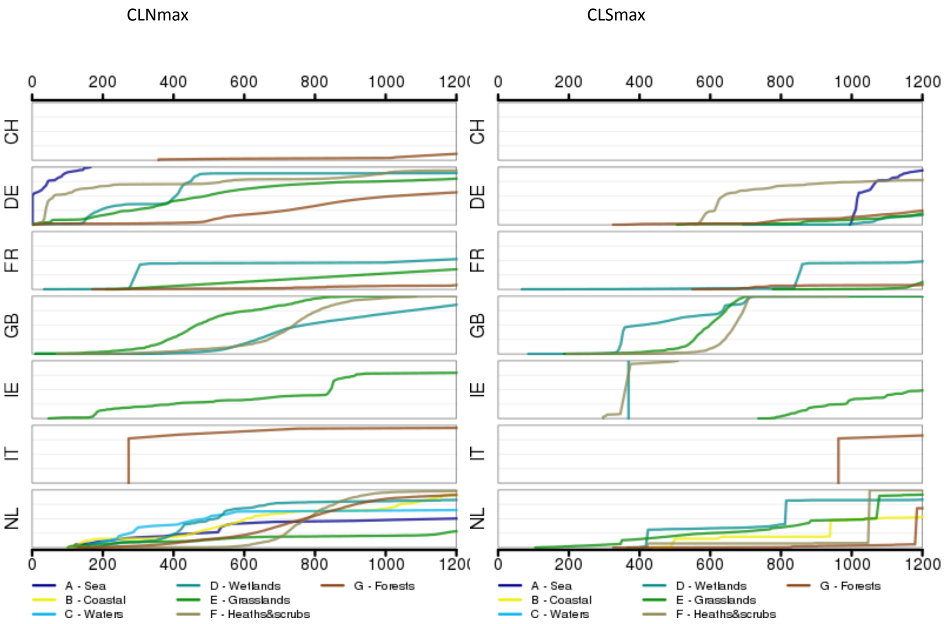

Figure 2.10 CDFs per EUNIS class of critical loads for biodiversity of nitrogen, CLNmax (left), and of sulphur, CLSmax (right), grouped by country.

The minimum levels of the occurrence probability for typical plant species is calculated from the individual species as an index ranging from 0 to 1, the Habitat Suitability index (HSi), according to

$$HS = \frac{1}{N}\sum_{i=1}^{N}\frac{p_i}{p_{i,max}}$$

with p_i equals the occurrence probability for species *i* of *N* typical species, and $p_{i,max}$ its maximum occurrence probability; as agreed at the 2014 Task Force meeting of the ICP Modelling & Mapping.

The level considered ‘safe’ is the critical Habitat Suitability (*HScrit*). Figure 2.11 demonstrates that Germany, Ireland and the Netherlands applied a single value, whereas the ranges for other countries differ considerably.

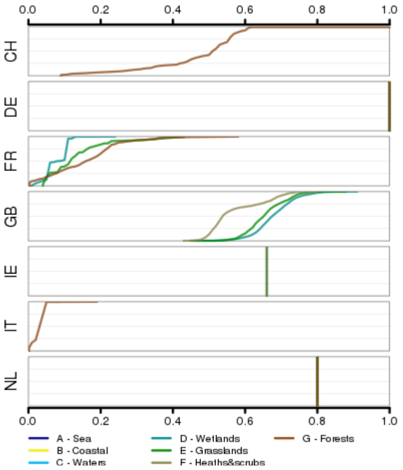

Figure 2.11 CDFS of HScrit per EUNIS class by country.

2.6 Concluding remarks

Fourteen (14) countries responded to the 2015-2017 Call for Data, of which seven (7) also submitted biodiversity-based critical loads. This is quite an increase since 2015. While National Focal Centres are clearly making progress in their assessment of critical loads of biodiversity, consensus was reached at the 33rd Task Force meeting of the International Cooperative Programme on Modelling and Mapping critical Levels and Loads and Air Pollution Effects, Risks and Trends that more data is needed, and the methodology further refined, before applications in support of policies can be considered under the Task Force on Integrated Assessment Modelling of the LRTAP Convention.

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Annex 2.A

Table 2.A Total ecosystem area (km^2) in a country (in bold) and area of the level-1 EUNIS classes covered by critical loads (CLs) of eutrophication, acidification and biodiversity, either from national data (NFC) or the European background database (EU-DB). Note: Areas given are those used in the European CL database.

Country / EUNIS	Eutrophication		Acidification		Biodiversity	
	NFC	EU-DB	NFC	EU-DB	NFC	EU-DB
Albania		17 741		17 741		17 308
D		21		21		19
E		6 840		6 840		6 837
F		4 304		4 304		4 052
G		6 577		6 577		6 399
Austria	50 588		38 957			51 065
C	1					
D	135					196
E	7 277					13 718
F	3 823					2 320
G	39 350		38 957			34 831
X	1					
Belarus		63 474		63 474		59 912
D		2 686		2 686		2 686
E		3 685		3 685		3 685
F		95		95		90
G		57 008		57 008		53 451
Belgium	5 642		5 447			11 621
D	58					85
E	6					5 764
F	53					145
G	5 526		5 447			5 627
Bosnia & Hercegovina		33 097		33 097		33 097
D		42		42		42
E		9 845		9 845		9 845
F		2 875		2 875		2 874
G		20 336		20 336		20 336
Bulgaria		51 240		51 240		50 309
D		101		101		89
E		13 986		13 986		13 285
F		1 789		1 789		1 789
G		35 363		35 363		35 146
Croatia		34 146		34 146		33 739
D		145		145		143
E		13 177		13 177		13 021
F		2 008		2 008		1 940
G		18 816		18 816		18 635
Cyprus		1 701		1 701		846
E		436		436		422
F		603		603		239
G		661		661		185
Czech	6 396		6 396			31 982

Country / EUNIS	Eutrophication		Acidification		Biodiversity	
	NFC	EU-DB	NFC	EU-DB	NFC	EU-DB
Republic						
D						85
E						7 712
F						25
G	6 396		6 396			24 159
Denmark		5 703		5 703		5 505
D		483		483		481
E		1 586		1 586		1 518
F		448		448		401
G		3 186		3 186		3 106
Estonia		27 232		27 232		23 955
D		1 336		1 336		1 323
E		6 582		6 582		6 538
F		126		126		115
G		19 188		19 188		15 979
Finland	41 141		286			90 276
A	125					
B	11					
C	6 645		286			
D	10 160					18 622
E	<1					36 442
F	6 859					9 250
G	17 340					25 963
France	177 006		177 006		177 006	
D	5 115		5 115		5 115	
E	1 577		1 577		1 577	
G	170 314		170 314		170 314	
Germany	106 976		106 976		106 976	
A	109		109		109	
D	870		870		870	
E	1 477		1 477		1 477	
F	833		833		833	
G	103 686		103 686		103 686	
Greece		67 744		67 744		53 247
D		215		215		214
E		27 580		27 580		26 464
F		18 688		18 688		10 451
G		21 261		21 261		16 119
Hungary		28 012		28 012		27 575
D		936		936		935
E		10 724		10 724		10 288
F		17		17		17
G		16 336		16 336		16 336
Ireland	18 320		13 516		345	
A	16					
C			838			
D	5 374				275	
E	7 017		6 972		69	
F	355		351		1	

Country / EUNIS	Eutrophication		Acidification		Biodiversity	
	NFC	EU-DB	NFC	EU-DB	NFC	EU-DB
G	5 558		5 355			
Italy	105 946		101 030		<1	
B	410		525			
E	22 584		22 159			
F	11 632		10 830			
G	71 320		67 516		<1	
Kosovo		4 163		4 163		4 141
E		614		614		614
F		4		4		4
G		3 545		3 545		3 523
Latvia		36 630		36 630		35 202
D		1 399		1 399		1 397
E		12 677		12 677		12 662
G		22 555		22 555		21 142
Liechtenstein		99		99		99
E		33		33		33
F		10		10		10
G		56		56		56
Lithuania		22 198		22 198		22 085
D		480		480		479
E		5 692		5 692		5 691
F		37		37		29
G		15 988		15 988		15 886
Luxembourg		1 211		1 211		1 211
E		405		405		405
G		806		806		806
Macedonia, F.Y.R		14 554		14 554		14 418
D		13		13		13
E		5 383		5 383		5 378
F		1 873		1 873		1 851
G		7 285		7 285		7 176
Malta		35		35		14
E		1		1		
F		32		32		13
G		2		2		1
Moldova, Rep. of		3 646		3 646		3 569
E		1 820		1 820		1 819
F		55		55		6
G		1 770		1 770		1 744
Montenegro		8 149		8 149		8 139
E		1 403		1 403		1 394
F		1 242		1 242		1 241
G		5 505		5 505		5 504
Netherlands	5 428		3 748		3 735	
A	157		4		4	
B	414		79		77	
C	8		5		3	

Country / EUNIS	Eutrophication		Acidification		Biodiversity	
	NFC	EU-DB	NFC	EU-DB	NFC	EU-DB
D	313		191		189	
E	1 012		341		338	
F	554		522		521	
G	2 969		2 607		2 604	
Norway	304 028		320 450			204 841
C	15 793		320 450			
D	18 353					568
E	49 874					6 813
F	87 370					149 199
G	124 753					48 260
H	7 884					
Poland	96 858		96 858			105 211
D	1 193		1 193			945
E	324		324			26 821
F	41		41			174
G	95 299		95 299			77 271
Portugal		35 752		35 752		29 361
D		9		9		9
E		12 021		12 021		11 927
F		4 086		4 086		3 661
G		19 637		19 637		13 765
Romania		104 732		104 732		102 964
D		10		10		10
E		32 001		32 001		30 630
F		3 445		3 445		3 348
G		69 275		69 275		68 977
Russia		625 616		625 616		294 047
D		7		7		7
E		106 833		106 833		92 719
F		13 769		13 769		13 117
G		505 007		505 007		188 204
Serbia		30 112		30 112		29 958
D		12		12		12
E		11 927		11 927		11 857
F		343		343		343
G		17 830		17 830		17 746
Slovakia		24 393		24 393		24 385
D		39		39		39
E		3 865		3 865		3 860
F		1 339		1 339		1 336
G		19 150		19 150		19 150
Slovenia		13 424		13 424		13 416
D		23		23		23
E		2 574		2 574		2 567
F		309		309		309
G		10 518		10 518		10 517
Spain		231 307		231 307		191 912
D		561		561		561
E		91 480		91 480		91 045

Country / EUNIS	Eutrophication		Acidification		Biodiversity	
	NFC	EU-DB	NFC	EU-DB	NFC	EU-DB
F		54 549		54 549		36 321
G		84 717		84 717		63 985
Sweden	58 688		395 226			172 411
C			395 226			
D						20 171
E						29 410
F						22 977
G						99 853
Y	58 688					
Switzerland	24 248		9 733		76	
C	133		85			
D	1 385					
E	10 668					
F	1 566					
G	10 496		9 648		76	
Ukraine		94 693		94 693		90 938
D		56		56		56
E		21 631		21 631		21 620
F		1 084		1 084		871
G		71 922		71 922		68 392
United Kingdom	72 811		77 412		5 738	
A	422					
B	323					
C			7 657			
D	5 514		5 390		4 962	
E	21 890		20 002		207	
F	24 780		24 663		569	
G	19 882		19 700			
TOTAL	1 074 077	1 580 803	1 353 042	1 580 803	293 877	1 838 757

3 The European Background Database of N and S Critical Loads

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3.1 Introduction

A main task of the Coordination Centre for Effects (CCE), the data centre of the ICP on Modelling & Mapping, is to collect and collate national data on critical loads, and to provide European maps and databases to the relevant bodies under the LRTAP Convention, especially for the purpose of policy support through integrated assessment. Ideally, all those data are based on national data submissions by National Focal Centres (NFCs) upon a Call for Data. However, if a country does not contribute national data, values from the European background database (EU-DB), which is held and maintained by the CCE in collaboration with Wageningen Environmental Research (Alterra), are used instead. Descriptions of earlier versions of the background database can be found in Posch et al. (2003a) and Reinds et al. (2008), while (minor) updates were reported in the CCE Status Reports 2008 (Chapter 2.7), 2009 (Chapter 2.3), 2011 (Chapter 2.6) and 2015 (Chapter 2.9).

In the following sections the procedures and data sources used for deriving the critical loads (CLs) of nitrogen (N) and sulphur (S) and associated variables held in the European background database are described. For the EU-DB, CLs are only derived for terrestrial ecosystems. Section 3.2 shortly summarises the equations of the Simple Mass Balance (SMB) model for critical loads of nutrient N and of (N and S) acidity, and describes the data sources and their processing to derive the inputs to the SMB model. Section 3.3 summarizes the empirical critical loads used in the EU-DB, whereas Section 3.4 deals with CLs of N and S for biodiversity.

In addition to the Mapping Manual (ICP Modelling & Mapping 2017), which in the EU-DB is followed as closely as possible, a summary of the critical loads work over the last three decades can be found in De Vries et al. (2015).

3.2 Simple Mass Balance Critical Loads of N and S

The derivation of SMB critical loads can be found in Chapter 5 of the Mapping Manual (ICP Modelling & Mapping 2017); in addition, a concise description is given in in Posch et al. (2015a). Here we only provide the final equations in order to show which variables are needed for their calculation. In all critical load equations, CLs and other fluxes are in eq $ha^{-1}yr^{-1}$.

3.2.1 The critical load of nutrient N

Starting from the mass balance of total N and making a few simplifying assumptions (e.g. the complete nitrification of ammonium), the critical load of nutrient N, $CL_{nut}N$, is obtained as:

(3-1) $$CL_{nut}N = N_i + N_u + \frac{Q \cdot [N]_{acc}}{1 - f_{de}}$$

where N_i is the long-term net immobilisation of N in the soil, N_u is the net removal of N in harvested vegetation, f_{de} ($0 \le f_{de} < 1$) is the fraction of the net N input denitrified, Q is the precipitation surplus (runoff) leaving the soil compartment (rooting zone), and $[N]_{acc}$ is the acceptable (critical) N concentration to avoid 'harmful effects' on the chosen 'sensitive element of the environment'. In the EU-DB, $[N]_{acc}$ values of 0.20, 0.25 and 0.30 gN/m^3 are used for coniferous, mixed and deciduous forests, resp., and the last value also for (semi-)natural vegetation. These values are at the lower end of those listed in the Mapping Manual (Table V.5), reflecting the adherence to the cautionary principle.

3.2.2 Critical loads of N and S acidity

Starting from the charge balance in the soil leaching flux and inserting the (simplified) mass balances for S, N, chloride (Cl) and base cations (Bc=Ca+Mg+K, BC=Bc+Na), we obtain as the maximum critical load of S, $CL_{max}S$:

(3-2) $$CL_{max}S = BC_{dep} - Cl_{dep} + BC_w - Bc_u - ANC_{le,crit}$$

where the subscripts *dep* and *u* refer to deposition and net uptake, resp., BC_w is the weathering of base cations, and $ANC_{le,crit}$ the critical ANC (acid neutralising capacity) leaching (see below). For N, two CLs are defined: the minimum CL of N, $CL_{min}N$, and the maximum CL of N, $CL_{max}N$, derived as:

(3-3) $$CL_{min}N = N_i + N_u \quad \text{and} \quad CL_{max}N = CL_{min}N + \frac{CL_{max}S}{1 - f_{de}}$$

The three quantities $CL_{min}N$ and $CL_{max}N$ and $CL_{max}S$ define the so-called *critical load function* (CLF; Figure 3.1); and every deposition pair (N_{dep},S_{dep}) lying on the CLF are critical loads of acidifying N and S. The ANC leaching is computed as:

(3-4) $$ANC_{le} = -H_{le} - Al_{le} + HCO_{3,le} + Org_{le}$$

with $H_{le} = Q[H]$ and the other three leaching terms (aluminium, bicarbonate and organic acids) given by $X_{le}=[X]/Q$, and their concentrations computed as function of $[H]$:

(3-5a) $$[Al] = K_{Alox} \cdot [H]^a$$

with an equilibrium constant K_{Alox} and an exponent a; furthermore

(3-5b) $[HCO_3] = \dfrac{K_1 \cdot K_H \cdot p_{CO2}}{[H]}$

where K_1 is the first dissociation constant, K_H is Henry's constant and p_{CO2} is the partial pressure of CO_2 in the soil solution, and

(3-5c) $[Org] = \dfrac{m \cdot DOC \cdot K_{org}}{K_{org} + [H]}$

where *DOC* is the concentration of dissolved organic carbon (in molC m^{-3}), *m* is the concentration of functional groups ('charge density', in mol $molC^{-1}$) and K_{org} the dissociation constant. Note that bicarbonates and organic acids are often neglected in CL calculations, but their contribution can be non-negligible, as can be inferred from Figure 3.1b.

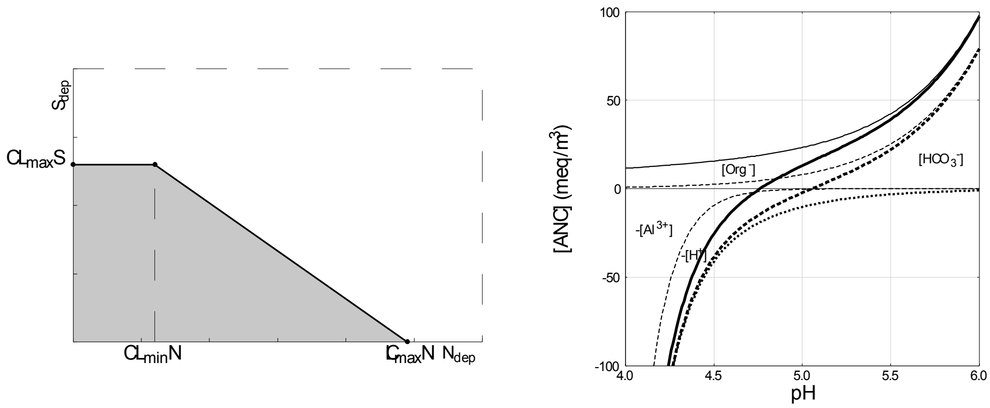

Figure 3.1: (a) Critical load function (CLF) of acidifying N and S, defined by the three quantities CLminN, CLmaxN and CLmaxS, in the (Ndep,Sdep)-plane; (b) ANC concentration as a function of pH with [ANC] = –[H]–[Al]+[HCO3] +[Org] (thick solid line). Also shown is the ANC when neglecting organic anions (thick dashed line) and the ANC solely defined as –[H]–[Al] (thick dotted line). The thin dashed lines show [HCO3] and –[Al], and the thin solid line is [HCO3]+[Org], all as a function of pH (computed with a=3, log10Kgibb=8 and m·DOC=20 mol/m3).

The ANC-leaching becomes the critical ANC-leaching after selecting the critical chemical variable and inserting its value. In the EU-DB we use a critical Bc:Al-ratio, $(Bc/Al)_{crit}$, of 1 mol/mol for all sites; and from this the critical Al-leaching is derived as:

(3-6) $Al_{le,crit} = Q \cdot [Al]_{crit} = 1.5 \cdot \dfrac{Bc_{le}}{(Bc/Al)_{crit}}$

where Bc_{le} is the sum of Ca_{le}, Mg_{le} and K_{le}, each of which is computed as:

(3-7) $X_{le} = \max\{0, X_{dep} + X_w - X_u - Q[X]_{min}\}, \quad X = Ca, Mg, K$

where the subscript w refers to weathering flux of X, and $[X]_{min}$ is a minimum concentration set to 0.0001 eq/m^3. From eq.3-6 $[H]_{crit}$ is obtained by inverting eq.3-5a, and from this $ANC_{le,crit}$ is derived.

In the sequel we describe the data sources and assumptions made for obtaining the values of the parameters needed to compute $CL_{nut}N$ and the acidity CLs according to the above equations.

3.3 Input Data for Calculating Critical Loads of N and S

The input data used for calculating CLs for the EU-DB are of two sorts: (i) Geographical (GIS) data bases in vector format (e.g. the soil map) or grid format, (ii) (modelled) data sets provided for a regular grid (e.g. meteorology) and transfer functions (models), evaluated with site-specific parameters contained in the data bases. In the following we describe those data in turn.

3.3.1 Geographical databases

Land cover:
The harmonised LRTAP land cover map (Cinderby et al. 2007; Slootweg et al. 2009) is used, on which land cover is classified according to EUNIS codes (Davies and Moss 1999). In the EU-DB we compute critical loads for forests (EUNIS code 'G') and (semi-)natural vegetation ('D': mires, bogs and fens, 'E': natural grasslands and 'F': heathland, scrub and tundra).

Soils:
Soil properties are needed to estimate *inter alia* weathering rates. The European Soil Database v2 map (ESDB 2004) at a scale 1:1 M was used, which includes Belarus, the Ukraine and the entire Russian territory. The soil map is composed of associations; each map polygon representing one soil association consists of several soil typological units (soil types) that each occupy a known percentage of the soil association, but with unknown location within the association. Soil topological units are classified into more than 200 soil types (ESDB 2004), with associated attribute data such as soil texture, parent material class and drainage class. Six texture classes (including peat) are defined, based on clay and sand content (FAO-UNESCO 2003). The drainage classes, which are used to estimate the denitrification, were derived from the dominant annual soil water regime (ESDB 2004; FAO-UNESCO 2003).

Forest growth regions:
The uptake of N and base cations is determined by forest growth and harvesting. Forest growth regions for Europe were taken from the EFI database (Schelhaas et al. 2006) that provides data for about 250 regions in (most of) Europe for various species and age classes. For the parts of Russia mapped, we used the forest regions from Alexeyev et al. (2004), who compiled data for 74 administrative regions within Russia.

Distance to coast:
The distance to coast is needed for deriving base cation deposition; it was taken from a NASA dataset (see https://oceancolor.gsfc.nasa.gov/docs/distfromcoast/).

Nature 2000 areas:
Critical loads are of particular interest for nature protection areas. For EU assessments the European Union's Natura 2000 (N2k) areas were integrated into the EU-DB (Tamis et al. 2008). The borders of the Natura 2000 areas can be found at ec.europa.eu/environment/nature/natura2000/data.

Altitude:
Altitude was obtained from a global map of detailed elevation data (on a 30"×30" grid) from NOAA/NGDC (Hastings and Dunbar 1998). It is needed for the estimation of the soil C:N ratio (se below).

Habitat suitability:
To compute biodiversity CLs, typical species for a habitat are used (see below). The spatial distribution of habitats is derived from the BioScore project (Van Hinsberg et al., 2014), which provides detailed gridded maps with predicted habitat suitability across Europe, based on the relationship between habitat suitability and climate, soil type, land use and external drivers such as agricultural intensity and forest management type. These gridded maps were combined with the EUNIS map for Europe to arrive at combinations of EUNIS and ANNEX 1 habitats. A translation table of habitat types to EUNIS classes was constructed based on expert judgement. The set of combinations obtained from the map overlay was then cleaned to eliminate implausible combinations of EUNIS and ANNEX 1 habitats caused by map inaccuracies. All relevant (up to 6) habitat types were assigned to the EUNIS class based on the map overlay and the list of plausible combinations of habitat type and EUNIS class.

Overlaying the above maps with European country borders and merging resulting polygons with common soil, vegetation and region characteristics within blocks of 0.10° × 0.05° leads to about 8.45 million computational units with EUNIS classes D-G, with a total area of 3.66 million km^2 for the European land area west of 42°E. The computation of critical loads was limited to units larger than 0.2 km^2 (except for N2k areas for which all units are used), reducing the total number of computational units to 4.94 million, representing 91% of the study area.

3.3.2 *Other data (bases)*

Meteorology and hydrology:
The annual water flux leaving the soil at the bottom of the rooting zone (runoff or precipitation surplus) is required to compute the concentration and leaching of compounds. The bottom of the rooting zone was set at 50 cm, except for lithosols which were assumed to have a depth of 10 cm only. Soil properties (see above) and meteorological data are needed to estimate the runoff. Long-term (1961–90) average monthly temperature, precipitation and cloudiness were derived from a high resolution global database (New et al. 2002) that contains monthly values for the years 1901–2001 for land-based grid-cells of 10' × 10' (approx. 15 km × 18 km in central Europe).

Runoff (Q in Eq.3-1) was calculated with the MetHyd model, which is based on concepts used in the IMAGE global change model (Leemans and Van den Born 1994). A short description of this model can be found in Reinds et al. (2008), and details on MetHyd in the Supporting Information of Bonten et al. (2016).

Base cation deposition:
Base cation (BC) deposition (BC_{dep} in Eq.3-2) for Europe was obtained from an atmospheric dispersion model for BC (Van Loon et al. 2005). For some eastern parts of Europe not covered by this data set, calcium (Ca) deposition was taken from the global model of Tegen and Fung (1995) based on estimates of soil Ca content (Bouwman et al. 2002). Magnesium (Mg) and potassium (K) deposition for these areas was derived from Ca using regression equations (including distance to the nearest coast) as described by Reinds et al. (2008). Since S-depositions from EMEP do not include natural emissions from the sea, base cation and chloride depositions in eq.3-2 are sea-salt corrected, assuming that all Cl originates from sea salts (for the methodology see Mapping Manual or Posch et al. 2015b).

Base cation weathering:
Weathering of base cations (BC_w in Eq.3-2) was computed as a function of parent material and soil texture classes and corrected for temperature, as described in UBA (2004). Soil texture is an attribute of the soil map, distinguishing 5 mineral and one organic texture classes; parent material classes have been assigned to soil types in Posch et al. (2003a) (see also Mapping Manual).

Nutrient uptake:
It is assumed that both stems and branches are removed by tree harvesting. The net growth uptake (in eq/ha/yr) of base cations (Bc_u in Eq.3-2) and N (N_u in Eq.3-3) is computed as:

(3-8) $$X_u = G_{st} \cdot \left(ct_{X,st} + f_{brst} \cdot ct_{X,br} \right), \quad X = Ca, Mg, K, N$$

where G_{st} is the annual growth rate of stems, $ct_{X,st}$ and $ct_{X,br}$ the contents of element X in stems and branches, resp., and f_{brst} the branch-to-stem ratio of the tree species. This equation assumes that stems and branches grow at the same rate.

The element contents are taken from the literature review by Jacobsen et al. (2002). Forest growth in EU countries was taken from the European Forest Information Scenario (EFISCEN) model (Schelhaas et al. 2007). Forest growth for the rest of Europe was derived from the EFI database (Schelhaas et al. 2006). Forest growth for Russia was estimated from data by Alexeyev et al. (2004), who compiled statistical data on growing stock and areas of stocked land from available data sources (for more details see Reinds et al. (2008)). The land cover map distinguishes only between coniferous, broad-leaved (deciduous) and mixed forests. EFISCEN, on the other hand, distinguishes 7 species; these are assigned to these 3 forest categories, and the uptake of these categories is computed using the area-weighted average growth of the assigned species (area per species for each region is provided by EFISCEN). The net uptake for non-forests is set to zero, because it is assumed that no harvesting takes place, i.e. all nutrients are recycled.

Nitrogen immobilization:
The long-term net N immobilization (*N_i in Eq.3-3)* was set at 0.5 kg N ha^{-1} yr^{-1}, which is at the upper end of the estimated annual long-term accumulation rates for Swedish forest soils (Rosén et al. 1992; see also Höhle and Wellbrock 2017).

Denitrification:
The denitrification fraction f_{de} (see Eq.3-1) was estimated as a function of soil drainage status (Reinds et al. 2001; Table V.7 in the Mapping Manual) and varies between 0.1 for well drained soils to 0.8 for peaty soils.

H-Al equilibrium:
For the H-Al equation (Eq.3-5a) we assume that it is a gibbsite equilibrium, i.e. for the exponent we use the constant value a=3. The gibbsite equilibrium constants are texture-dependent values (for soil texture classes 1 2 and ≥3) derived from measured soil solution concentrations in the ICP Forest Intensive Monitoring database (see De Vries et al. 2003). The effect of temperature on the equilibrium constant is taken into account with an Arrhenius equation according to Mol-Dijkstra and Kros (2001).

Organic acids:
The concentration of dissolved organic carbon (DOC; in mgC/L; see Eq.3-5c) is also estimated from soil solution measurements in the ICP Forest Intensive Monitoring data as a function of texture class and 'characteristic' soil pH:

(3-9) $$DOC = \max\{54.02 + a_{tex} - 6.67\,pH, 0\}$$

where the texture-dependent constants are given in Table 3.1; *DOC* in $molC/m^3$ is obtained by dividing by 12. The charge density *m* (see eq.3-5c) is set to 0.023 mol/molC, using data from Santore et al. (1995). And the dissociation of organic acids is computed with eq.3-5 using pK_{org} = 4.5.

Table 3.1: Texture class dependent constants for estimating DOC (see eq.3-8).

Texture class	1	2	3	≥4
a_{tex}	0	-12.7	-8.1	-11.8

To compute the bicarbonate concentration (eq.3-5b) the following parameters are used (after Harned and Davis (1943)):

(3-10a) $$\log_{10} K_1 = -3404/T - 0.0328 \cdot T + 14.844$$
(3-10b) $$\log_{10} K_H = 2386/T + 0.0153 \cdot T - 14.018$$

where *T* is the absolute temperature (in K); eqs.3-10 results in $K_1 \cdot K_H$= $10^{-1.8}$ $(mol/m^3)^2$/atm at 25°C. Also the partial pressure of CO_2 in soil solution is computed as a function of temperature (after Gunn and Trudgill (1982); see also Mapping Manual):

(3-10c) $$\log_{10} p_{CO2} = 0.031 \cdot \vartheta - 2.38$$

where ϑ is the temperature in degrees Celsius.

In Figure 3.2 maps of the $CL_{nut}N$ and $CL_{max}S$ values held in the EU-DB are shown. They are presented as the 5-th percentile of the data on a 0.50° × 0.25° longitude-latitude grid.

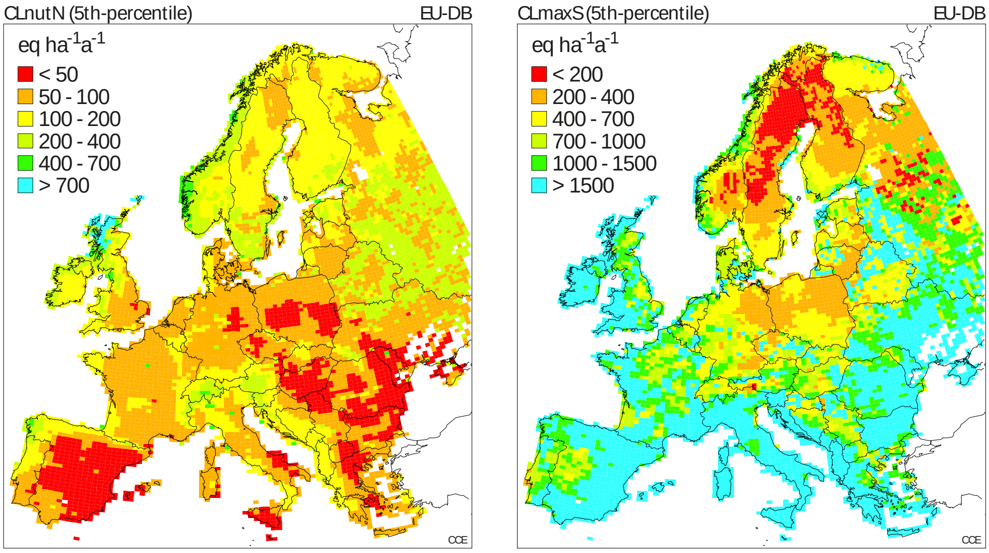

Figure 3.2: 5-th percentile of $CL_{nut}N$ (left) and $CL_{max}S$ (right) of the EU-DB on a 0.50°×0.25° longitude-latitude grid.

3.4 Empirical Critical Loads of N

In the EU-DB also empirical CLs for nutrient (eutrophying) N are determined. They are taken from Table V.1 in the Mapping Manual, which is based on Bobbink and Hettelingh (2011). Empirical CLs are determined for EUNIS classes and are given as ranges. In the EU-DB the lower end of the range is used, i.e. no so-called modifying factors are applied.

In the current EU-DB, $CL_{nut}N$ (see Section 3.2) and the empirical CL, $CL_{emp}N$, are not stored separately any more, but the critical load for eutrophication, $CL_{eut}N$, is computed at every site as the minimum of the two (if both exist), i.e.

(3-11) $$CL_{eut}N = \min\{CL_{nut}N, CL_{emp}N\}$$

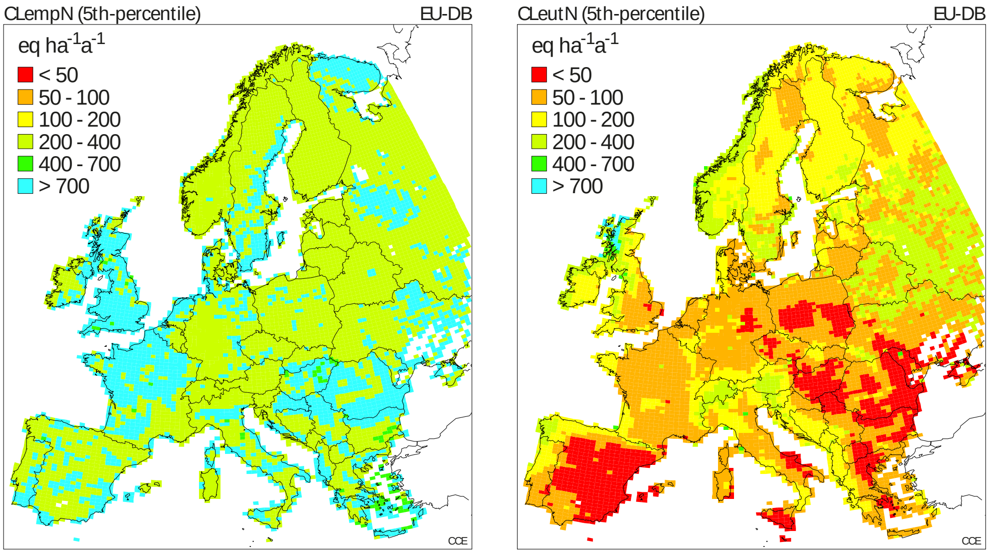

Figure 3.3: 5-th percentile of $CL_{emp}N$ (left) and $CL_{eut}N$ (right) of the EU-DB on a 0.50°×0.25° longitude-latitude grid.

From Figure 3.3 it seems that $CL_{emp}N$ will hardly influence the calculation of $CL_{eut}N$ (eq.3-9). However, this is not the case in all grid cells. Figure 3.4 shows the percentage of the ecosystem area in the 0.50°×0.25° grid cells, for which $CL_{eut}N$ is given by $CL_{emp}N$, i.e. $CL_{emp}N < CL_{nut}N$.

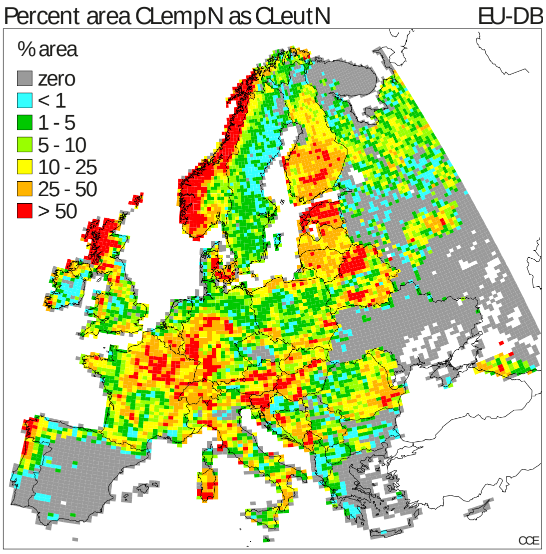

Figure 3.4: Percent of ecosystem area in 0.50°×0.25° grid cells for which $CL_{eut}N$ is given by $CL_{emp}N$, i.e. $CL_{emp}N < CL_{nut}N$.

3.5 Critical Loads of N and S for Biodiversity

For a definition and derivation of biodiversity CLs see Chapter 3 (Posch et al. 2015) and Chapter 4 (Reinds et al. 2015) in the 2015 CCE Status Report. Here we only give a short summary of the methods and describe the data used in the EU-DB.

Biodiversity is characterised by the occurrence (probabilities) of typical plant species in specified habitats (see Table 3.2). The calculation of biodiversity CLs is based on the Habitat Suitability index (HS index or

HSI), defined as the arithmetic mean of the 'normalised' probabilities of occurrence of the species of interest, i.e.:

$$HS = \frac{1}{K}\sum_{k=1}^{K}\frac{p_k}{p_{k,max}} \quad (3\text{-}12)$$

where K is the number of species, p_k the occurrence probability of species k, and $p_{k,max}$ the maximum occurrence probability of that species.

For the EU-DB, the occurrence probabilities entering the HS index are modelled with the PROPS model as a function of five abiotic variables: pH, soil C:N, N deposition, annual average precipitation and temperature. To be able to derive biodiversity CLs of N and S, the PROPS variables have to be converted into N and S depositions. Nitrogen deposition is a PROPS variable, and the dependence on S deposition is derived with the SMB model, i.e. the same equations as used for deriving 'classical' CLs. This allows to compute the HSI as a function of N and S deposition at a given site (for defined C:N ratio, precipitation and temperature). For precipitation and temperature see above; the C:N ratio at a site was estimated by transfer function that uses a set of environmental variables, e.g., soil texture, forest type, altitude, climate, Na and N-deposition (Posch et al. 2003b).

As an example, in Figure 3.5 (left) isolines of the HSI for 'Mountain hay meadows' (characterised by 13 typical plant species) as a function of N_{dep} and S_{dep} are displayed. By selecting a HSI limit value (e.g., 80% of the maximum), a critical load function of biodiversity N and S CLs can be derived, which is characterised by 4 values CLN_{min}, CLN_{max}, CLS_{min} and CLS_{max} (see Figure 3.5 right). For the technical details of the CL computation see Posch (2016).

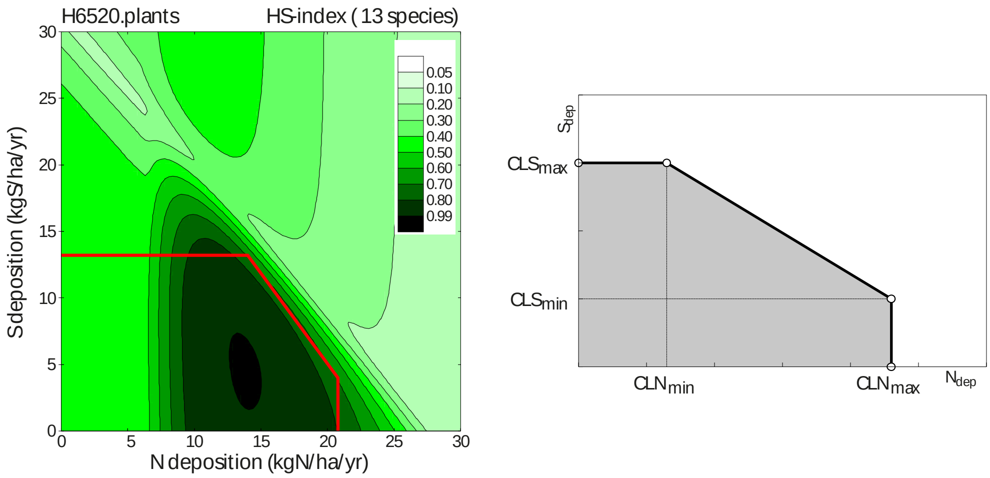

Figure 3.5: Left: HSI isolines of 'Mountain hay meadows' as function of N_{dep} and S_{dep}; also shown is a critical load function (N-S CLF) derived from a chosen HSI limit value (red line). Right: The N-S CLF defined by two points (four values): (CLN_{min}, CLS_{max}) and (CLN_{max}, CLS_{min}).

In the EU-DB, the HSI is computed for 'typical' plants in the BioScore habitats (see above). For every habitat a set of typical species is defined (see also Table 3.2 for their number and coverage). Species selection in the BioScore project was based on the Interpretation Manual of European Union habitats (EC 2013) and various literature sources. For each 'site' the typical species (if available in PROPS) for the habitat with the highest suitability are used to compute the HSI, from which the biodiversity CLs are derived (Figure 3.5). The 5-th percentiles of CLN_{max} and CLS_{max} of the biodiversity CL functions derived for the EU-DB are shown in Figure 3.6 on a 0.50° × 0.25° longitude-latitude grid. The remarkably high values for CLS_{max} in some regions are caused by the fact that the dominant habitats are acidophilic and the associated plants still have high probabilities at low pH, which allows high inputs of S.

Table 3.2: Habitats and number of plant species distinguished in the EU-DB of critical loads for biodiversity.

Habitat type	# typical plants	# plants in PROPS	Area (1000 km^2)	N2k area (1000 km^2)
H9100	26	25	428	64
H9150	17	17	391	114
H9190	13	13	342	32
H4060	27	24	289	36
H6210	35	34	262	35
H6230	23	23	146	17
H9160	14	14	140	30
H6430	30	30	125	6.2
H9410	10	9	95	25
H6220	27	20	79	22
H5210	21	16	63	24
H7110	15	14	52	20
H6510	19	19	41	5.0
H4030	14	12	35	11
H6120	18	15	30	7.4
H6170	42	34	25	2.0
H5130	9	7	21	5.7
H4010	17	15	18	2.9
H6410	20	20	11	1.6
H7210	1	1	8.6	4.3
H6150	12	12	6.7	1.4
H6240	16	15	4.8	0.66
H7230	28	28	3.7	1.9
H6520	16	16	3.1	0.76
H6110	24	24	2.6	0.58
H4070	8	8	1.9	1.2
H7130	6	6	1.5	0.81
H7150	1	1	1.5	0.86
H5420	22	7	0.95	0.52
Total	531	479	2,630	475

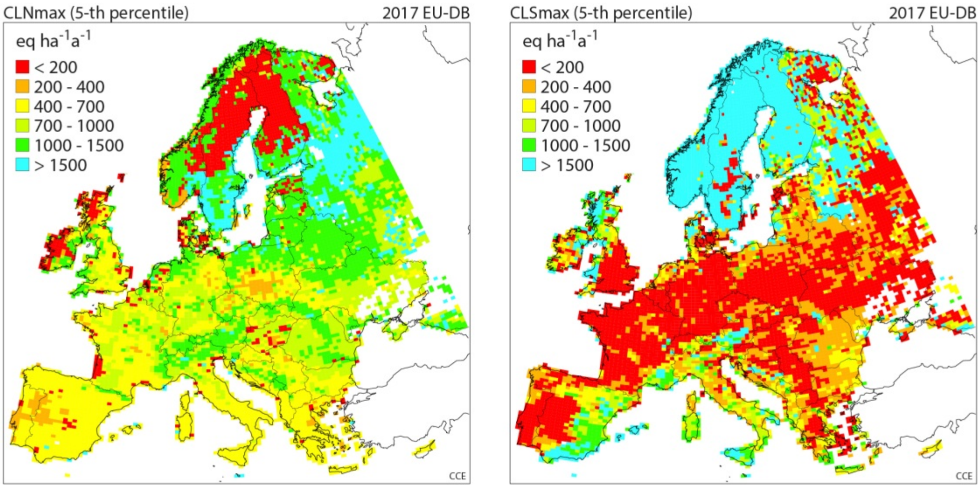

Figure 3.6: 5-th percentile of CLN_{max} (left) and CLS_{max} (right) of the biodiversity CL-functions in the EU-DB on a 0.50°×0.25° longitude-latitude grid.

3.6 Concluding Remarks

The critical loads in the EU-DB are derived from consistent European datasets, using uniform criteria over the whole of Europe. However, as mentioned in the Introduction, they are only used for countries that have not submitted national data. Since a country can choose the type of ecosystem(s) it wants to protect (e.g. lakes) as well as the critical limits pertaining to a particular element of that ecosystem (e.g. fish), these national critical loads can differ substantially from those derived for the EU-DB (which are not used then).

The European background database for CLs (EU-DB) has been developed over the last two decades, with many of the data (bases) derived many years ago (this does not hold for the biodiversity CLs). Thus, it might be a worthwhile re-visiting the databases used and assumptions made and update where appropriate. The successor of the Coordination Centre for Effects (CCE), located at RIVM (the Netherlands) until the end of 2017, is encouraged to tackle that task.

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4 Evaluating an alternative to logistic regression to estimate the occurrence probability of plant species

Jaap Slootweg, Maximilian Posch

4.1 Introduction

Critical loads for biodiversity are limits for nitrogen (N) and/or sulphur (S) deposition to prevent plant species from being lost to ecosystems. Calculating these critical loads is a two-step process: 1) establish the abiotic parameters at which relevant plant species are at risk of disappearing, and 2) apply a soil chemistry model to translate those abiotic parameters into the N and S deposition values. For step 1, the probability of species to occur as a function of those abiotic parameters needs to be established.

Such ‘occurrence probability functions’ are frequently established by logistic regression, using presence/absence data from releves with simultaneous measurements of the abiotic parameters. However, these regressions frequently predict maxima for the occurrence probabilities at the extremes of the ranges of the abiotic variables. One of the most common abiotic parameters depending on the deposition of N and S is pH. Consequently, the N-S critical load function depends on the pH which is optimal for biodiversity. Thus results using logistic regression are frequently favouring either very high or very low critical loads of N and S.

In this Chapter we investigate an alternative to logistic regression for the calculation of the occurrence probabilities as a function of pH to avoid this problem. We also compare the most promising method with the logistic regression. The last section suggests the way forward to extend the presented methodology to include more abiotic variables .

4.2 Dataset and software

The data used in this chapter are part of the PROPS database that consists of more than 10,000 sets of observations (releves) for which, in addition to the list of species present, also abiotic parameters (such as pH, ...) have been determined (see Reinds et al., 2014 for more information). All calculations and graphs shown here are made with the R software (R Core Team 2015). Functions outside of the core software (the packages) are referenced separately.

4.2.1 Logistic regression

Logistic regression uses generalised linear modelling (GLM) where, for presence/absence data, the binomial distribution is used. Each plant species is modelled for its presence/absence in the releves of the PROPS database for which pH measurements are available. Here, like in the PROPS model (Reinds et al. 2015), a quadratic polygon is fitted to a ‘link’ function, in this case ’the log of odds’:

(4-1) $$\log\frac{p}{1-p} = a_0 + a_1 \cdot pH + a_2 \cdot pH^2$$

The fitting optimises the likelihood of the occurrence of a given species x over all releves:

(4-2) $$L(p) = \prod_{i=1}^{n} p^{x_i} \cdot (1-p)^{1-x_i}$$

where x_i is the presence (=1) or absence (=0) of plant species x in releve *i* (i=1,…,*n*).

4.2.2 *The convoluted trapezoid*

There is, obviously, a wide choice for the shape of the function modelling the probability of the occurrence of a species for pH values within a well-defined range. As the abiotic variable (pH) lies in a finite interval (its 'support'), a linear function restricted to a finite interval can be used, thus assuming a trapezoid shape of the occurrence probability density function. However, the reliability of using a trapezoid may be affected by pH measurement errors. These we model with a Gaussian distribution with standard deviation σ and zero mean (i.e. no bias in the errors). The mathematical procedure to combine these two functions is to take their convolution (or 'Faltung'); and the convolution of two functions, $f(x)$ and $g(x)$ is defined as:

(4-3) $$(f * g)(x) = \int_{-\infty}^{\infty} f(x`) \cdot g(x - x`)dx`$$

The convolution of a trapezoid (with parameters (x_1,p_1) and (x_2,p_2)) with such a Gaussian distribution is illustrated in Figure 4.1.

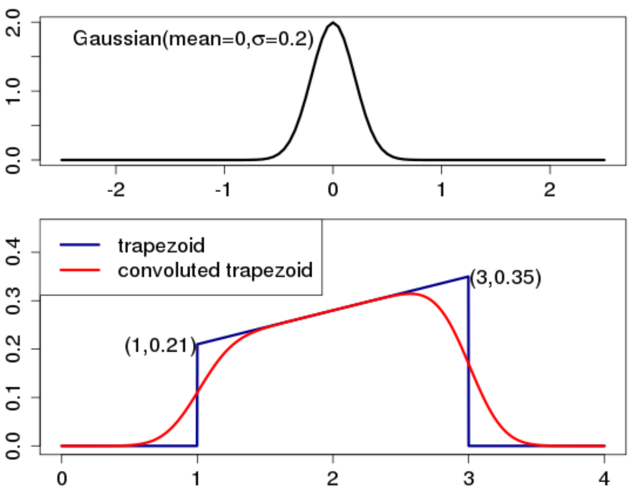

Figure 4.1 Example of a trapezoid (defined by (x1,p1) and (x2,p2), in blue) convoluted with a Gaussian distribution (zero mean and standard deviation σ in black, top graph) resulting in the convoluted trapezoid (red graph).

The 5 parameters (x_1=pH_1, x_2=pH_2, p_1, p_2 from the trapezoid and σ from the Gaussian distribution) are obtained by maximizing the likelihood of the presence/absence in the releves, as is done for fitting the logistic regressions.

We also tried the convoluted beta-distribution, presented and discussed at the 2017 ICP M&M Task Force meeting in Wallingford (UK, 4-6 April 2017). The reasons for not further pursuing that function are (a) it's computationally more involved, and (b) the resulting models are often bi-modal, which was considered unlikely/undesirable. Furthermore, the generalisation to higher dimensions, i.e. more variables and their interactions, is far from straight-forward.

4.3 Comparing the logistic regression and the convoluted trapezoid as functions for occurrence probability

In order to compare the two methods, the modelled cumulative distribution is compared to the empirical cumulative distribution function (cdf) of the species occurrences. This was done by calculating and comparing the maximum distance (D; as used in the Kolmogorov-Smirnov test) for each of the species (see Figure 4.2 for an example).

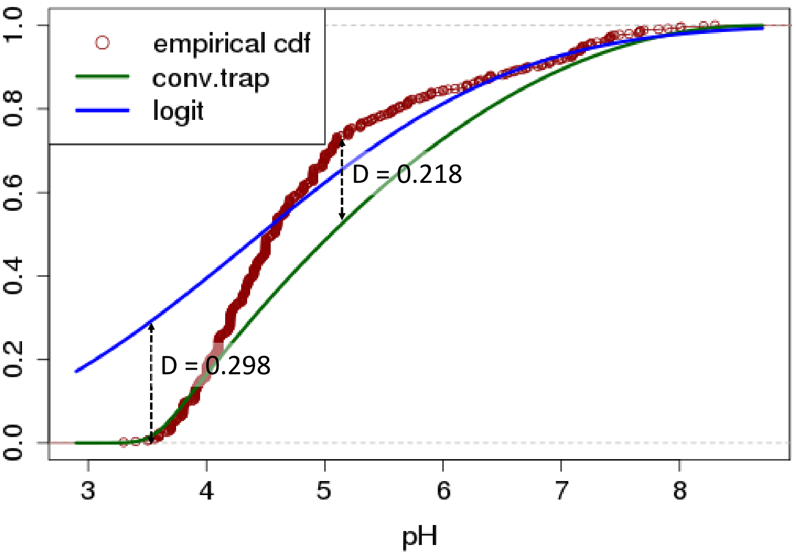

Figure 4.2 Example of an empirical cdf of the pH-es at occurrences of a plant species (Athyrium filix-femina, red circles) and the fitted cumulative distributions of the logit (blue) and the convoluted trapezoid (green) functions. Also shown are the two maximum vertical distances.

When the two sets of resulting D values are correlated as shown in Figure 4.3, it can be seen that those for the convoluted trapezoid (conv.trap) functions are mostly lower than the equivalent for the logistic regression (logit).

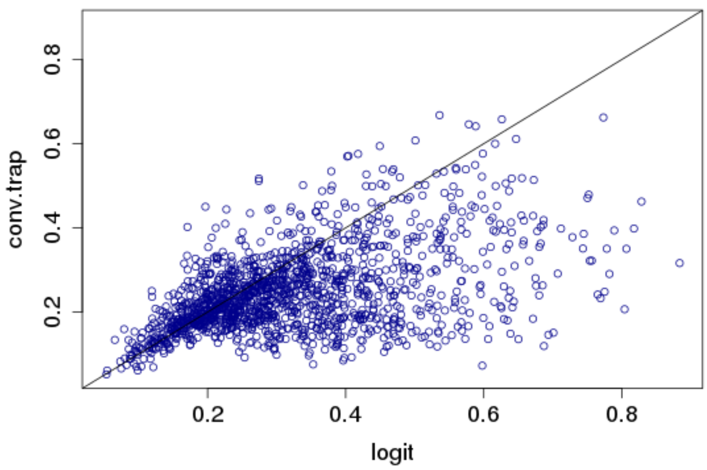

Figure 4.3 Correlogram of the D-values for each species between the logistic regression (logit; x-axis) and the convoluted trapezoid (conv.trap; y-axis).

Logistic regression frequently tends to predict maxima for the occurrence probability at the extremes of the ranges of the abiotic variables. This is demonstrated in Figure 4.4, showing, for each species, the pH at which the occurrence probability has its maximum (its mode), within a range of realistic pH values. Many of these modes occur at the limits set in the software (here: $2 \leq pH \leq 9.5$). On the y-axis the probabilities at the modes, normalised with the respective overall occurrence probabilities of the species, are shown.

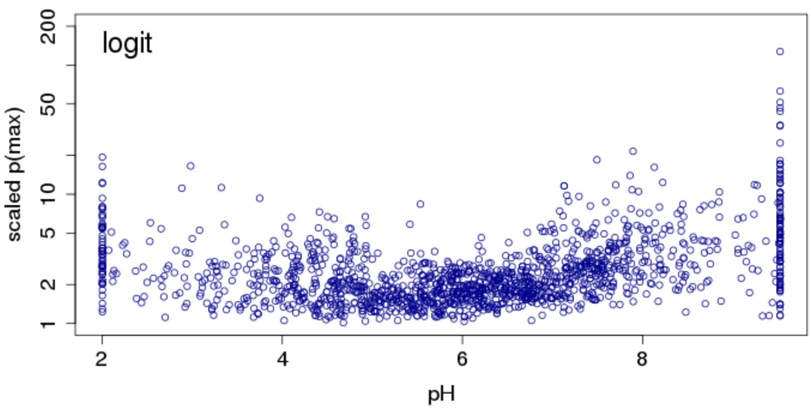

Figure 4.4 Each dot, representing a species, is located at the pH where its occurrence probability – modelled with logistic regression – is maximal (the mode). The y-values are the values of those maxima, normalised with the respective overall occurrence probabilities of the species.

For the convoluted trapezoids, the locations of the maximum probabilities are different, showing that the maximal occurrence probabilities are clustered around two pH values (Figure 4.5). This may point to a distinction between certain characteristics such as between oligotrophic and eutrophic species. However, this needs to be further explored.

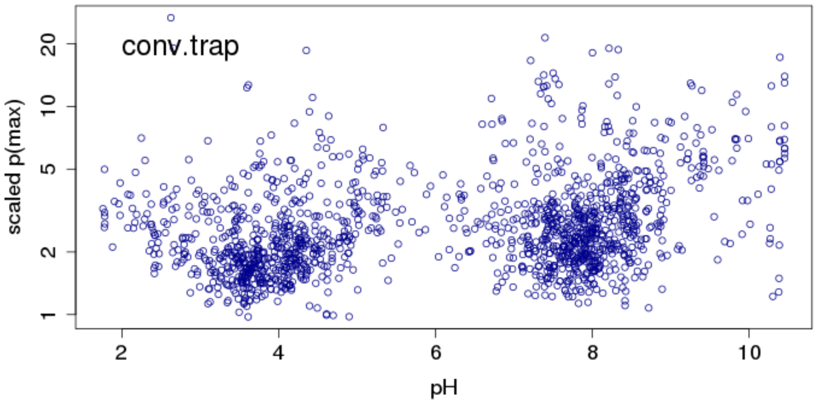

Figure 4.5 Each dot, representing a species, is located at the pH where its occurrence probability – modelled with the convoluted trapezoid regression – is maximal (the mode). The y-values are the values of those maxima, normalised with the respective overall occurrence probabilities of the species.

The modelling of the occurrence probability of a species with the convoluted trapezoid gives generally better results than logistic regression with a 2nd order polynomial function (equation 4-1). The maxima do not occur at the pre-set pH boundaries, which may lead to less extreme HS indices, and related critical loads (e.g. Chapter 1, Figure 1.4).

4.4 Outlook

The trapezoid can be easily extended to model a probability of the occurrence of species as a function of two variables, including a term for interaction between the two variables (the resulting surface is called a paraboloid). See Annex 4A to this chapter for the mathematical derivation of the convoluted paraboloid. The species occurrence can also be calibrated for two dimensions, e.g. for pH and N C ratio (i.e. the inverse of the widely used C N ratio), by optimum likelihood (fitting 6 parameters). An example of such a resulting occurrence probability function is shown in Figure 4.6. The modelling of the probability of species occurrence as a function of more than two abiotic variables requires further work.

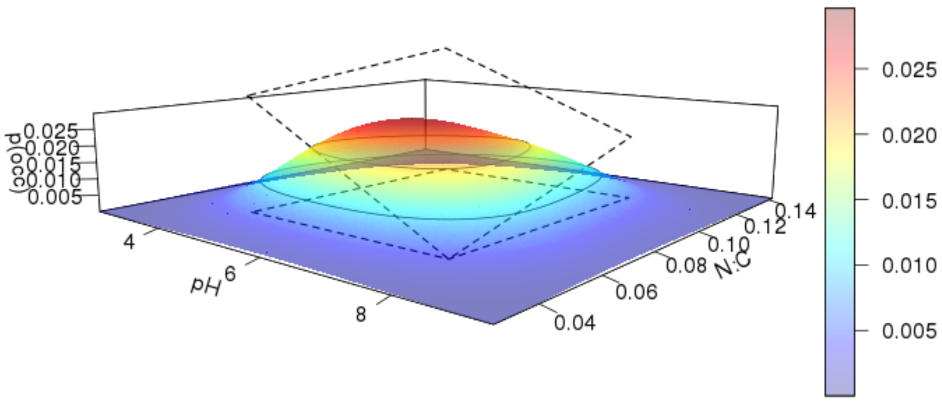

Figure 4.6 Example of the occurrence probability as a function of pH and N C ratio, modelled as a 2-dimensional convoluted paraboloid. The dotted rectangle on the "floor" shows the x1, x2 (pH) and y1, y2 (N:C) limits; the elevated dotted lines indicate the shape of the paraboloid before convolution.

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Annex 4A: Convoluted trapezoid and paraboloid

Here we derive the convolutions ('Faltungen') used in Chapter 4.

The normal ('Gaussian') distribution with mean zero and standard deviation σ is given as:

(A1) $$G(x) = G(x,\sigma) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{x^2}{2\sigma^2}\right)$$

Its cumulative distribution Φ, also known as error-function, is given as:

(A2) $$\Phi(x) = \Phi(x,\sigma) = \int_{-\infty}^{x} G(z)dz = \frac{1}{\sqrt{2\pi}\sigma}\int_{-\infty}^{x}\exp\left(\frac{-z^2}{2\sigma^2}\right)dz$$

which has the values $\Phi(-\infty)=0$, $\Phi(0)=1/2$ and $\Phi(\infty)=1$. The truncated linear function L in the interval $x_1 \le x \le x_2$ (and zero outside), is defined as:

(A3) $$L(x) = (Ax+B)\theta(x-x_1)\theta(x_2-x) = (Ax+B)\vartheta(x)$$

where A and B are the slope and intercept of the linear function, and θ is the unit-step function:

(A4) $$\theta(x) = \begin{cases} 0 & \text{for } x < 0 \\ 1 & \text{for } x \ge 0 \end{cases}$$

and ϑ is defined as $\vartheta(x) = \vartheta(x,x_1,x_2) = \theta(x-x_1)\theta(x_2-x)$.
We want to obtain the convolution function of the Gaussian (eq.A1) and the truncated linear function (eq.A3), i.e.

(A5) $$(G*L)(x) = (L*G)(x) = \int_{-\infty}^{\infty} G(z)L(x-z)dz$$

Straight-forward integration yields:

(A6) $$(G*L)(x) = (Ax+B)\,\mathrm{dE}(x,\sigma,x_1,x_2) + A\,\mathrm{dG}(x,\sigma,x_1,x_2) = A\,\mathrm{dF}(x) + B\,\mathrm{dE}(x)$$

where we defined (see eqs.A1,A2):

(A7a) $$\mathrm{dE}(x) = \mathrm{dE}(x,\sigma,x_1,x_2) = \Phi(x-x_1,\sigma) - \Phi(x-x_2,\sigma)$$

(A7b) $$\mathrm{dG}(x) = \mathrm{dG}(x,\sigma,x_1,x_2) = \sigma^2\left(G(x-x_1,\sigma) - G(x-x_2,\sigma)\right)$$

(A7c) $$\mathrm{dF}(x) = \mathrm{dF}(x,\sigma,x_1,x_2) = x\,\mathrm{dE}(x) + \mathrm{dG}(x)$$

Note: If the linear function in eq.A3 is defined by the 2 points (x_1,y_1) and (x_2,y_2), i.e. $y_1=Ax_1+B$ and $y_2=Ax_2+B$, then A and B are obtained as:

(A8) $$A = \frac{y_2-y_1}{x_2-x_1}, \quad B = y_1 - Ax_1 = \frac{x_2y_1 - x_1y_2}{x_2-x_1}$$

Next we consider the paraboloid in 2 dimensions, defined as:

(A9) $$P(x,y) = cxy + b_1x + b_2y + a$$

We want to derive the 2-dimensional convolution function of the paraboloid restricted to the rectangle $x_1 \le x \le x_2$ and $y_1 \le y \le y_2$, i.e. $P(x,y)\vartheta(x)\vartheta(y)$, and the 2-dimensional uncorrelated normal distribution with standard deviations σ_x and σ_y, i.e. $G_2(x,y)=G(x,\sigma_x)G(y,\sigma_y)$. We observe that the restricted paraboloid can be written as $[L_1(y)x+L_2(y)]\vartheta(x)$, where $L_1= (cy+b_1)\vartheta(y)$ and $L_2= (b_2y+a)\vartheta(y)$; i.e. – seen as function of x – the paraboloid is a restricted linear equation as in eq.A3. Convoluting with respect to x (using eq.A6) yields the two restricted linear functions $L_1(y)$ and $L_2(y)$ (with factors depending on x). Convoluting both functions with respect to $G(y,\sigma_y)$ and collecting terms yields:

(A10a) $$(G_2 * P_\#)(x,y) = c\,\mathrm{dF}(x)\,\mathrm{dF}(y) + b_1\,\mathrm{dF}(x)\,\mathrm{dE}(y) + b_2\,\mathrm{dE}(x)\,\mathrm{dF}(y) + a\,\mathrm{dE}(x)\,\mathrm{dE}(y)$$

where $P_{\#}$ denotes the restricted paraboloid. Inserting for dF (eq.A7c) this can be also written as:

(A10b)
$$(G_2 * P_{\#})(x,y) =$$
$$= P(x,y)\,\mathrm{dE}(x)\,\mathrm{dE}(y) + (cy+b_1)\,\mathrm{dG}(x)\,\mathrm{dE}(y) + (cx+b_2)\,\mathrm{dE}(x)\,\mathrm{dG}(y) + c\,\mathrm{dG}(x)\,\mathrm{dG}(y)$$

Part 2 NFC Reports

Part 2 of this final CCE report contains the reports of National Focal Centres about their work in response to the call for data 2015-2017 (see Appendix A for the instructions of this call).

The reports have not been thoroughly edited; only minor corrections were made and a limited harmonization of the layout carried out.

Please note, that the responsibility for the substance of the country reports of PART 2 remains solely with the National Focal Centres and not with the National Institute for Public Health and the Environment.

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Status

Introduction

In response to the 2015-17 call for data the NFC for Austria provides 1) a report on the status quo regarding biodiversity critical loads, and 2) re-reports the critical load data on acidity (Simple Mass Balance, SMB) and eutrophication (SMB and empirical critical loads) in the new EMEP grid resolution of 0.10° Lon × 0.05° Lat from the previous call for data. The NFC of Austria is not yet reporting regionalized biodiversity critical loads because of a lack of data and knowledge for many of the existing protected forest and grassland habitats.

Method

For the assessment of biodiversity critical loads we applied dynamic soil-vegetation- modelling and species response function analysis as implemented in PROPS-CLF, recently developed by Posch (2016). The critical load data on acidity and eutrophication were reported without changes to the previous version in the last Annual Report.
For dynamic soil-vegetation modelling we use the dynamic biochemical soil model VSD+ (version 5.4, Bonten et al., 2016) together with the two plant response models PROPS (Reinds et al., 2014) and BERN (Schlutow et al., 2015) (the latter only for validation). The VSD+ model includes cation exchange and organic C and N dynamics according to the RothC-Model (version 26.3, Coleman and Jenkins, 2005). We applied the Habitat Suitability Index (HSI) that describes the degree of suitability of site conditions for a set of typical species to co-occur. The HSI is defined as the arithmetic mean of the normalised probabilities of occurrence of these species (Posch et al., 2014). In our study, we adopted phyto-sociological plant community descriptions approach (European Commission DG Environment, 2013) to define distinctive plant species for each of the sites. Please note that this approach deviates from the species per habitat selection implemented in PROPS-Select (Reinds, 2016) as it is more detailed, resulting in different sets of species within the same EU habitat.
In addition to dynamic soil-vegetation modelling the simple mass balance (SMB) model was used to derive biodiversity critical loads for selected habitat types. We applied the PROPS-CLF model, developed by the Coordination Centre of Effects (Posch, 2016), to the 18 forest sites and also to a number of additional grassland sites (Figure AT-1, Table AT-1). For the purpose of comparison with empirical CLs (Bobbink &

Hettelingh 2011) and CLs based on soil solution criteria we focussed on CLN_{max} of the N-S critical load function. We used a threshold of 0.8 for the Habitat Suitability Index (HSI) to calculate CLN_{max}.

Data sources

For assessing biodiversity critical loads we used 18 forest sites which are part of ICP Forests and ICP Integrated Monitoring in the framework of effects monitoring within the UNECE Convention on Long-range Transboundary Air Pollution. These sites comprise 5 of totally 8 forest types protected under the European Habitat Directive in Austria (Directive 92/43/EEC, Annex 1 and others). In addition, 11 grassland sites grouped to three habitats protected under the EU Directive were used (Figure AT-1, Table AT-1).

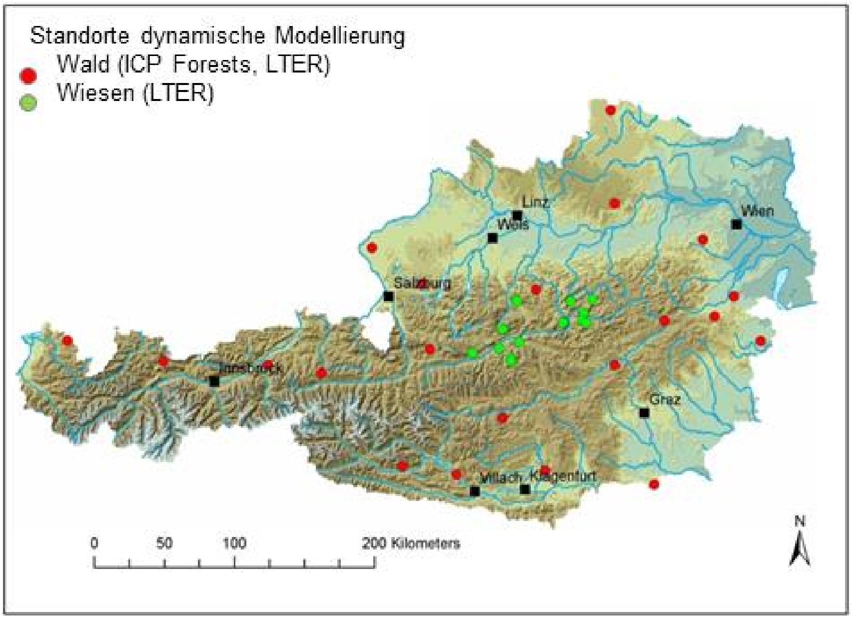

Figure AT-1. Location of forest (red) and grassland (green) sites used for dynamic soil-vegetation modelling.

Discussion regarding biodiversity critical loads

In the course of this and the previous calls for data, dynamic soil-vegetation models were applied to existing long-term forest monitoring sites (ICP Forests, ICP IM) in order to infer biodiversity effects of airborne reactive nitrogen deposition. These activities were supported by an additional research project (CCN-Adapt, Austrian Climate Research Program), which focussed on interacting effects of climate change and air pollution.

Table AT-1. Site characteristics and habitat type according to the European Habitat Directive (Directive 92/43/EEC).

EU Habitat type	Site code	Altitude (m)	Lat	Lon	Plant community
6170: Alpine and subalpine calcareous grasslands	GL_AL40	1487	47.69	14.89	Caricetum ferrugineae LÜDI 1921
	GL_AL55	1676	47.65	14.88	
	GL_AL88	1677	47.63	14.91	
6210: Semi-natural dry grasslands and scrubland facies on calcareous substrates(Festuco-Brometalia)	GL_HT12	880	47.78	14.24	Onobrychido-Brometum erecti TH. MÜLLER 1966
	GL_HT13	885	47.77	14.26	
	GL_HT38	680	47.52	14.27	
	GL_HT43	810	47.61	14.13	
	GL_HT45	815	47.6	14.1	
6230 *: Species-rich Nardus grasslands, on siliceous substrates in mountain areas	GL_AL29	1585	47.64	14.7	Homogyno alpinae-Nardetum Mráz 1956
	GL_AL30_1	1591	47.64	14.7	
	GL_AL30_2	1070	47.77	14.77	
9110: Luzulo-Fagetum beech forests	IF_AT05	720	46.72	13.68	Luzulo-Abieto-Fagetum (typ. Subass.) HARTM. et JAHN 1967
	IF_AT08	630	48.93	15.19	Calamagrostio villosae-Fagetum syvatici MIKUSKA 1972
	IF_AT10	960	48.1	12.87	Luzulo-Abieto-Fagetum (typ. Subass.) HARTM. et JAHN 1967
	IF_AT13	670	46.63	15.52	
9130: Asperulo-Fagetum beech forests	IF_AT03	930	46.74	14.50	Asperulo-Fagetum SOUGNEZ et THILL 1959
	IF_AT04	1190	46.77	13.17	
	IF_AT09	510	48.12	16.05	Hordelymo-Fagetum sylvatici TX. 1937 (Dryopteris-Subass.)
	IF_AT11	860	47.88	13.35	Asperulo-Abieti-Fagetum sylvatici (Dryopteris-Subass.) TH. MÜLLER 1966 and Luzulo-Abieto-Fagetum (typ. Subass.) HARTM. et JAHN 1967
	IF_AT15	715	47.63	15.66	Helleboro nigri-Fagetum sylvatici ZUKRIGL 1973
	IM_AT01	900	47.84	14.44	Cardamino trifoliae-Fagetum sensu WILLNER 2002
	IM_AT02	880	47.84	14.44	Adenostylo glabrae-Fagetum sensu WILLNER 2002
9150: Medio-European limestone beech forests of the Cephalanthero-Fagion	IF_AT07	500	47.65	16.13	Cyclamini (purpurascentis)-Fagetum sylvatici SOÓ 1962
91G0 *: Pannonic woods with Quercus petraea and Carpinus betulus	IF_AT01	390	47.77	16.32	Carici pilosae-Carpinetum NEUH. & NEUH.-NOV.1964
	IF_AT02	290	47.49	16.56	Sorbo torminalis-Quercetum (petraea) SVOBODA ex BLAZKOVA 1962 incl. Festuco heterophyllae-Quercetum Neuh. & Neuh.-Nov. 1964
9410: Acidophilous Picea forests of the montane to alpine levels (Vaccinio-Piceetea)	IF_AT12	920	47.49	13.42	Bazzanio-Piceetum (SCHMIDT et GAISBERG 1936) BR.-BL. et SISSINGH in BR.-BL. et al. 1939
	IF_AT14	960	47.37	15.17	Galio rotundifolii-Abietetum WRABER 1959
	IF_AT16	1540	47.06	14.11	Homogyno alpinae-Piceetum (Rhytidiadelphus loreus-Subass.) ZUKRIGL 1973
	IF_AT18	1020	47.39	10.91	Calamagrostio variae-Piceetum SCHWEINGRUBER 1972

We were able to model the soil chemistry of these sites in a reasonable way using the dynamic soil model VSD+ (Bonten et al., 2016). Yet, management driven changes in the soil solution chemistry and in the HSI could not be modelled appropriately (Figure AT-2A). However, when comparing the results of PROPS with those from a second plant response model (BERN), which is based on an independent empirical data set and which is rather different as to its statistical approach (Schlutow et al., 2015), they showed a very high relation (Figure AT-2B). We note that BERN generally resulted into higher values because species occurrence calculations are not based on a genuinely probabilistic approach. Hence, the niche functions, which are implemented in PROPS are, in general, reliable for they are statistical representations of observed species occurrence data. However, on a site scale, and particularly when forest management is involved, which is changing the species composition, predictions are inherently difficult and hard to validate.

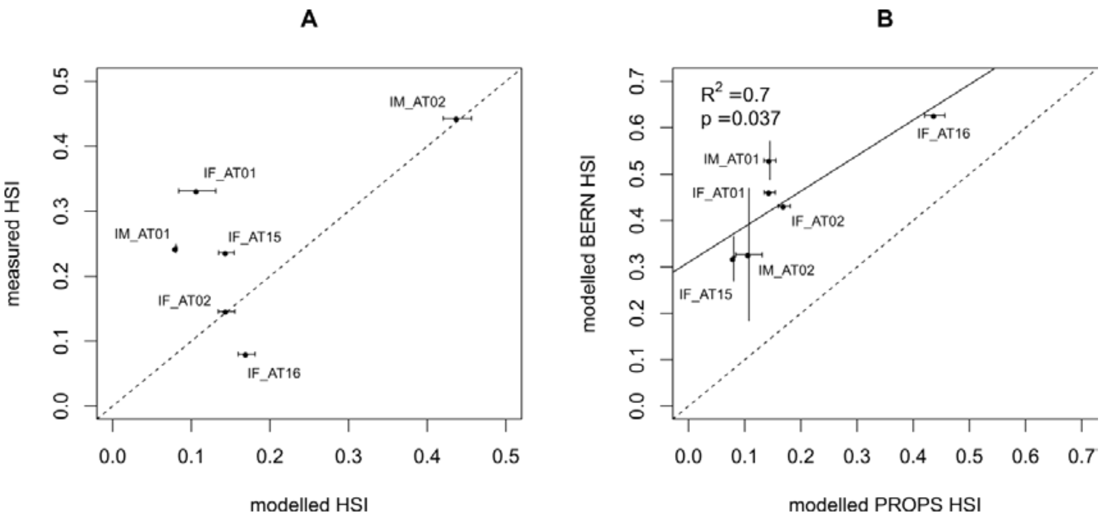

Figure AT-2. Comparison of the modelled Habitat Suitability Index (mean and standard deviation) using PROPS with A) observed data and B) with modelled HSI from BERN (using the same soil and climate data as PROPS). Six sites with vegetation records between 1996 and 2007 were used. The 1:1 line is dashed, the regression line is solid.

When applying climate and deposition scenarios to the calibrated models the HSI was predominantly driven by expected future climate change and only to a low extent by deposition. In line with our expectations, among the distinctive species climate changes increased the occurrence probability of the most thermophilic plant species while the most cold-tolerant species decreased. Also, climate change improved the occurrence probability of the oligotrophic species while species preferring sites with higher nutrient availability declined in response to decreasing soil C:N ratios indicating a tightening of the nutrient cycle. As a consequence, HSI decreased in all habitat types in response to climate change (Figure AT-3A). On the other hand, N deposition increased the occurrence probability of plant species preferring nutrient rich sites. However, the HSI increased to a small extent in all habitat types, meaning that additional N improved habitat suitability at these forest sites (Figure AT-3B). This surprising result is due to the fact that N deposition is rather low in most of the sites but might also be due to the fact that N deficiency is still widespread in Austria because of historic overuse and acidification during the last part of the 20^{th} century (Jandl et al., 2012). As to critical loads, this result means that current and future deposition does not exceed a biodiversity threshold in the majority of the sites.

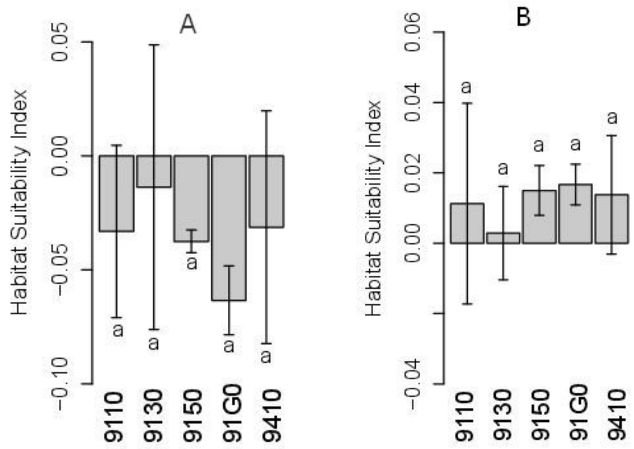

Figure AT-3. Effects of climate change (A) and N deposition (B) on the Habitat Suitability Index (mean and standard deviation of effects in the year 2100 as derived from 5 different climate change scenarios) in different EU habitat directive types. Means with different letters are significant different (Tukey's HSD p < 0.05). Effects are given in the form of ANOVA coefficients describing the difference between the mean values of all baseline climate model runs and the respective climate change scenario by the year 2100 and the difference between the mean values of all Maximum Feasible Reduction deposition scenarios and the respective CLE and B10 deposition scenario by the year 2100 at each site. Positive coefficients represent increasing, negative coefficients decreasing effects. Note that MFR scenarios have the lowest N deposition. 9110: Luzulo-Fagetum beech forests, 9150: Medio-European limestone beech forests of the Cephalanthero-Fagion, 9130: Asperulo-Fagetum beech forests, 91G0: Pannonic woods with Quercus petraea and Carpinus betulus, 9410: Acidophilous Picea forests of the montane to alpine levels (Vaccinio-Piceetea).

The biodiversity CL (CLN_{max}) calculated with PROPS-CLF for the same forest sites corroborate this finding. CLs were much higher than current deposition. Median CLN_{max} reached a magnitude between 28 and 38 kg N ha^{-1} y^{-1} (Figure AT-4). These loads were substantially higher than $CL_{emp}N$ ((5)10-(15)20 kg N ha^{-1} y^{-1}) and also much higher than the median $CL_{nut}N$ derived from the soil solution criterion SMB approach across Austrian forests (11 kg N ha^{-1} y^{-1}). The median CLN_{max} for the grassland habitats were between 17 and 21 kg N ha^{-1} y^{-1}. Similar to forests, $CL_{emp}N$ was substantially lower than CLN_{max} but not so for semi-natural dry grasslands (6210) where $CL_{emp}N$ were in accordance with the calculated biodiversity CLs or even higher (Figure AT-4).

Conclusions regarding biodiversity critical loads
Dynamic modelling suggests that while climate change will clearly lower the species' suitability of Austrian forest habitats which are protected under the European Habitat Directive (Directive 92/43/EEC), N deposition effects will be comparably weak. The reasons are twofold. First, N deposition in these forests will not exceed loads at which major changes in the soil chemistry occur, and, second, climate driven increase in N immobilisation (particularly through tree growth) will offset soil N enrichment (Butler et al., 2012). While climate change is not the focus of this report, it is however important to note that biodiversity CLs, as defined by the Habitat Suitability Index, seem to be higher than

current and future N deposition in the more widespread forest types in Austria.

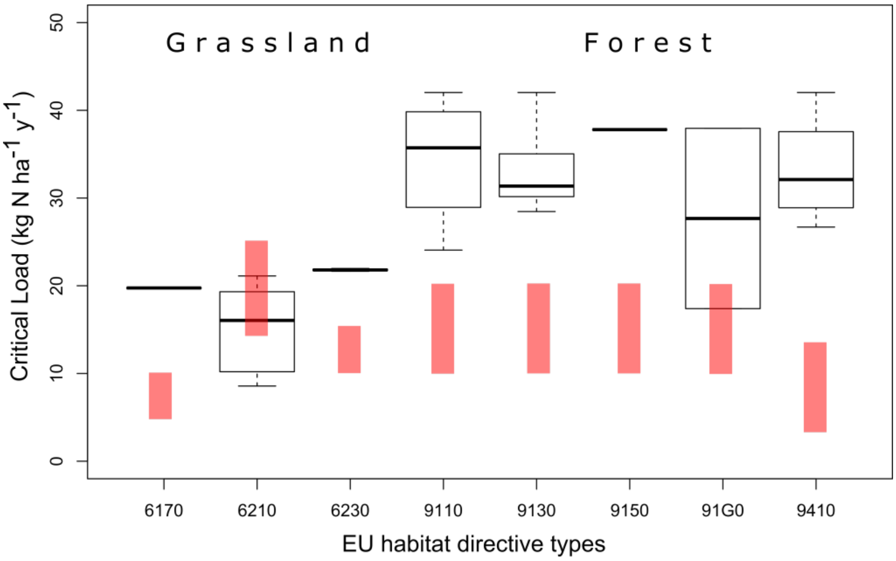

Figure AT-4. Comparison of Biodiversity Critical Loads (CLN_{max} boxplots) and empirical Critical Loads for Nitrogen (red bar with maxima and minima $CL_{emp}N$). 6170: Alpine and subalpine calcareous grasslands, 6210: Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia), 6230: Species-rich Nardus grasslands, on siliceous substrates in mountain areas, 9110: Luzulo-Fagetum beech forests, 9150: Medio-European limestone beech forests of the Cephalanthero-Fagion, 9130: Asperulo-Fagetum beech forests, 91G0: Pannonic woods with Quercus petraea and Carpinus betulus, 9410: Acidophilous Picea forests of the montane to alpine levels (Vaccinio-Piceetea).

When using the species response functions of PROPS to derive HSI, the CLs for the different forest habitat types were substantially higher than empirical CLs and mass balance CLs for N. This was also true for two of the three grassland types. Only the CL for semi-natural dry grassland corresponded well with $CL_{emp}N$.

The forest sites used for these analyses are from the Austrian ICP Forests and ICP Integrated Monitoring network. They represent the major forest habitats in Austria with a wide distribution but these networks were not designed to cover rare habitats under conservation protection. Hence, only one of totally 8 Annex I priority habitats could be included due to a lack of data. The knowledge base for grassland is even scarcer. Although we were able to use data for some grassland habitats, which are sensitive to air pollution, only one of totally five Annex I priority habitats could be included. Also many other habitat types protected under the Directive (natural alpine habitats, raised bogs, etc.) could not be included.

Owing to the discrepancy between modelled and empirical CL, which calls for more in-depth analyses, and particularly because of the scarcity of Annex 1 priority habitats in our analysis, we do not yet calculated regionalized biodiversity CLs.

Reported CL data sets

The here reported CL data is the same data as reported in the year 2015:

- Critical loads of acidity: $CL_{max}S$, $CL_{min}N$ and $CL_{max}N$ as computed with the SMB model. Only forest sites with an area >0.01 km² were included;
- Critical loads of nutrient nitrogen ($CL_{nut}N$): also here the SMB was applied. Only forest sites with an area >0.01 km² were included;
- Empirical critical loads ($CL_{emp}N$): based on a habitat map and empirical values given in Bobbink and Hettelingh (2011). Only forest sites with an area >0.01 km² were included;
- The two N critical loads are reported in the new database format. For all but forests empirical critical loads for eutrophication effects ($CL_{emp}N$) were used. For forests, mass balance critical loads ($CL_{nut}N$) were used because the detail in EUNIS forest types was too coarse to differentiate sufficiently.

Acknowledgements

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

Mapping procedure Wallonia
From Walloon Land Cover Map, 27.344 forest ecosystems area (>1 ha) were extracted and overlaid with thematic maps in order to calculate critical loads parameters. From Corine Land Cover 2005, four natural ecosystem types (representing 136 ecosystems area) were extracted and assigned to a theoretical value according to ecosystem type. Next, critical loads maps were overlaid with new EMEP grid (0.10° x 0.05° Longitude-Latitude grid) as requested.

Calculation methods & results Wallonia
A. Forest Soils
Calculation methods

Critical loads for forest soils were calculated according to the method as described in UBA (1996) and Manual for Dynamic Modelling of Soil Response to Atmospheric Deposition (2003):

$CL_{max}(S) = BCwe + BC_{dep} – BC_u – ANC_{le(crit)}$
$CL_{max}(N) = N_i + N_u + CL_{max}(S)$
$CL_{nut}(N) = N_i + N_u + N_{le} + N_{de}$
$ANC_{le(crit)} = -Q_{le} ([Al^{3+}] + [H^+] - [RCOO^-])$

Where :
$[Al^{3+}] = 0.2\ eq/m^3$
$[H^+]$ = concentration of $[H^+]$ at the pH critique (Table BE-1).

$[RCOO^-]$ = 0.044 molc/molC x $DOC_{measured}$ (Table BE-1)

The equilibrium K = $[Al^{3+}]/[H^+]^3$ criterion: The Al^{3+} concentration was estimated by 1) experimental speciation of soil solutions to measure rapidly reacting aluminium, Alqr (Clarke et al.,1992) ; 2) calculation of Al^{3+} concentration from Alqr using the SPECIES speciation software. The K values established for 10 representative Walloon forest soils (Table BE-1) were more relevant than the gibbsite equilibrium constant recommended in the manual (UBA, 1996). The difference between the estimated Al^{3+} concentrations and concentration that causes damage to root system (0.2 eq Al^{3+}/m^3; de Vries et al., 1994) gives the remaining capacity of the soil to neutralise the acidity. For the majority of Walloon soils, the range of critical pH is 4.3-4.4.

The Tables BE-1 and BE-2 summarise the values given to some of the parameters.

Table BE-1. Aluminium equilibrium constants, weathering rates and critical pH limit calculated for Walloon soils; and pH and DOC measured.

Site	**Soil type**	**K**	**BCwe** eq ha^{-1} yr^{-1}	**Critical pH limit calculated**	**pH measured**	**DOC** g/m^3
Bande (1-2)	Podzol	140	610	3.95	5.16	42.59
Chimay (1)	Cambisol	414	1443	4.10	5.61	64.81
Eupen (1)	Cambisol	2438	2057	4.36	4.81	29.6
Eupen (2)	Cambisol	25	852	3.70	3.5	26.47
Hotton (1)	Cambisol	2736	4366	4.38	8.19	45.47
Louvain-la-Neuve (1)	Luvisol	656	638	4.17	4.37	99.35
Meix-dvt-Virton (1)	Cambisol	2329	467	4.35	5.4	32.21
Ruette (1)	Cambisol	5335	3531	4.47	6.12	26.12
Transinne (1)	Cambisol	3525	560	4.41	4.61	26.38
Willerzie (2)	Cambisol	2553	596	4.37	4.67	29.91

(1) deciduous; (2) coniferous forest

Table BE-2. Constants used in critical loads calculations in Wallonia.

Parameter	Value
N_i	5.6 kg N ha^{-1} yr^{-1} coniferous forest 7.7 kg N ha^{-1} yr^{-1} deciduous forest 6.65 kg N ha^{-1} yr^{-1} mixed forest
$N_{le\ (acc)}$	2.5 mg N L^{-1} for coniferous forest 3.5 mg N L^{-1} for deciduous forest 3 mg N L^{-1} for mixed forest
N_{de}	fraction of (N_{dep} – Ni – Nu)

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

Weathering rates: In *Wallonia*, the base cation weathering rates (BC_{we}) were estimated for 10 different representative soil types (Table BE-1) through leaching experiments. Increasing inputs of acid were added to soil columns and the cumulated outputs of lixiviated base cations (Ca, Mg, K, Na) were measured. Polynomial functions (Table BE-3) were used to describe the input-output relationship. To estimate BC_{we}, an acid input was fixed at 900 $eqH^+ ha^{-1} yr^{-1}$ in order to keep a long-term balance of base content in soils.

Table BE-3. Polynomial functions used in critical loads calculations in Wallonia.

Site	Polynomial function y = BC (eq ha^{-1} yr^{-1}) ; x = input d'H^+ (eq ha^{-1} yr^{-1})	Depth considered to establish the function (m)
Bande (2)	$y = -5.509E-10x^3 + 7.023E-06x^2 + 0.6721x$ $R^2 = 0.9999$	0.50
Chimay (1)	$y = -1.075E-09x^3 + 2.510E-05x^2 + 1.261x$ $R^2 = 0.9991$	0.40
Eupen (1)	$y = -3.294E-10x^3 - 4.338E-06x^2 + 1.147x$ $R^2 = 0.9998$	0.25
Eupen (2)	$y = 1.581E-10x^3 - 1.130E-05x^2 + 0.4835x$ $R^2 = 0.9989$	0.25
Hotton (1)	$y = 8.288E-10x^3 - 4.336E-05x^2 + 4.889x$ $R^2 = 0.9998$	0.50
Louvain-la-Neuve (1)	$y = 3.614E-10x^3 - 2.054E-05x^2 + 0.7267x$ $R^2 = 0.9985$	0.50
Meix-dvt-Virton	$y = -3.545E-10x^3 + 1.675E-06x^2 + 0.5180x$ $R^2 = 0.9976$	0.50
Transinne (1)	$y = 3.729E-10x^3 - 2.627E-05x^2 + 0.6454x$ $R^2 = 0.9818$	0.50
Ruette (1)	$y = 1.111E-09x^3 - 5.334E-05x^2 + 3.970x$ $R^2 = 0.9995$	0.50
Willerzie (2)	$y = 6.326E-10x^3 - 3.396E-05x^2 + 0.6921x$ $R^2 = 0.9976$	0.50

(1) deciduous; (2) coniferous forest

The flux of drainage water leaching, Q_{le}, from the soil layer (entire rooting depth) was estimated from EPICgrid model (Faculté Universitaire des Sciences Agronomiques de Gembloux). The results of the EPICgrid model are illustrated at the Figure BE-1. The flux drainage of the 2009-2013 period was used.

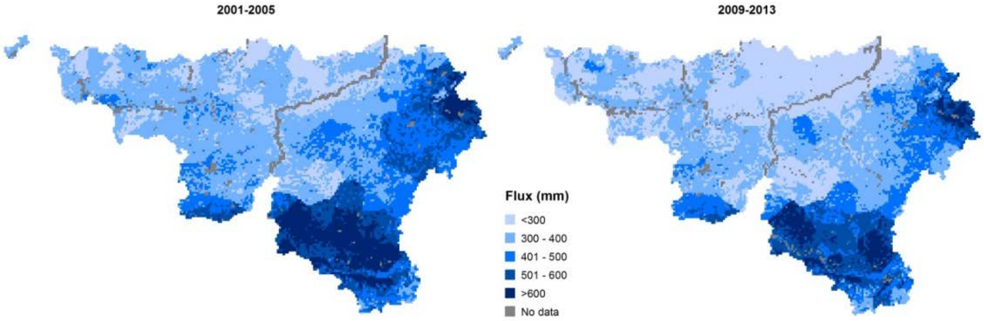

Figure BE-1. Flux of drainage at 50 cm depth in Wallonia for the 2001-2005 and 2009-2013 periods.

The critical (acceptable) N concentration was taken from the CCE/Alterra Report (De Vries et al., 2007):
Coniferous forest: 2.5-4.0 mgN L^{-1}
Deciduous forest: 3.5-6.5 mgN L^{-1}
The minimum recommended values (Table BE-2) are applied for the calculations of $CL_{nut}N$.

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

The net growth uptake of nitrogen ranges between 260 and 1090 eq ha^{-1} yr^{-1}, while base cations uptake values vary between 255 and 838 eq ha^{-1} yr^{-1} depending on trees species and location in Belgium.

Base cation deposition: In *Wallonia*, actual throughfall data collected in 8 sites, between 1997 and 2014, were used to estimate BCdep parameters. The marine contribution to Ca^{2+}, Mg^{2+} and K^{+} depositions was estimated using sodium deposition according to the method described in UBA (1996). The BCdep data of the 8 sites was extrapolated to all Walloon ecosystems depending on the location and the tree species.

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

B. Natural vegetation
For Walloon ecosystems, considering the lack of accurate data, we use critical values established in Flanders with SMB method (Meykens and Vereecken, 2001). The critical loads for N and S deposition to natural vegetation are reported in Table BE-4.

Table BE-4. Critical loads for natural vegetation in Wallonia.

Ecosystem type	**EUNIS code**	**CLmaxN**	**CLmaxS**	**CLnutN**
Natural grassland	E1	4572	1893	1286
Moors and heathland	F4.2	2185	1645	643
Inland marshes	D5	2339	1655	786
Peat bogs-Fens	D2	2339	1655	786

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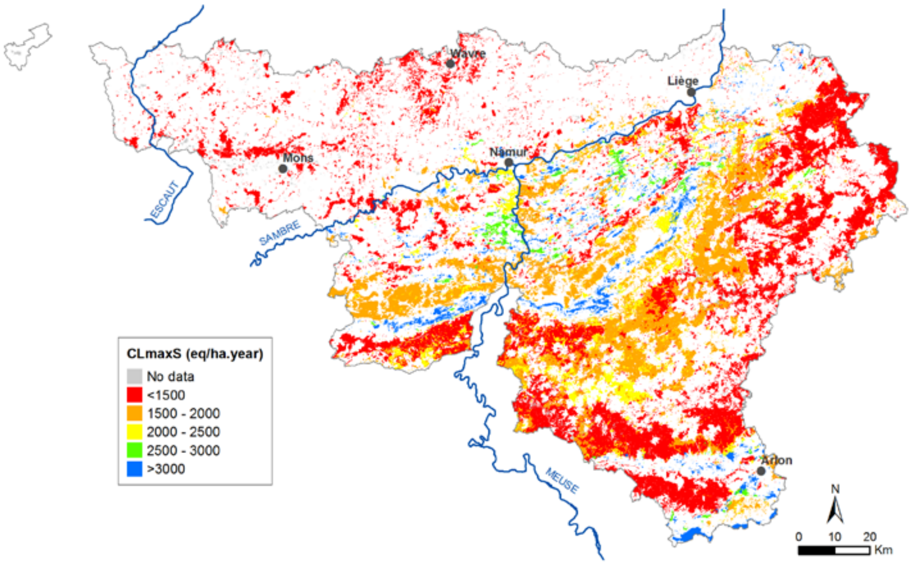

Figure BE-2. Maximum critical loads of sulphur for forests, CLmaxS.

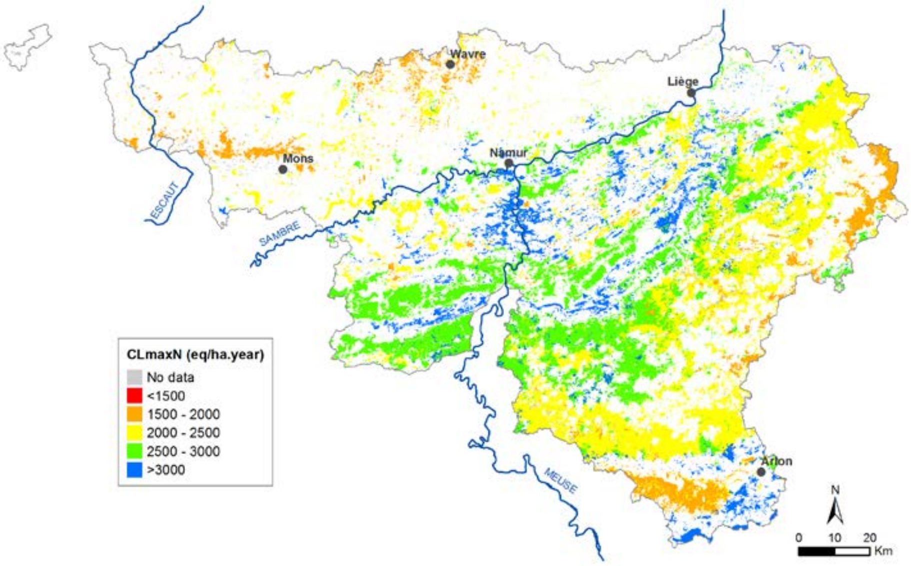

Figure BE-3. Maximum critical loads of nitrogen for forests, CLmaxN.

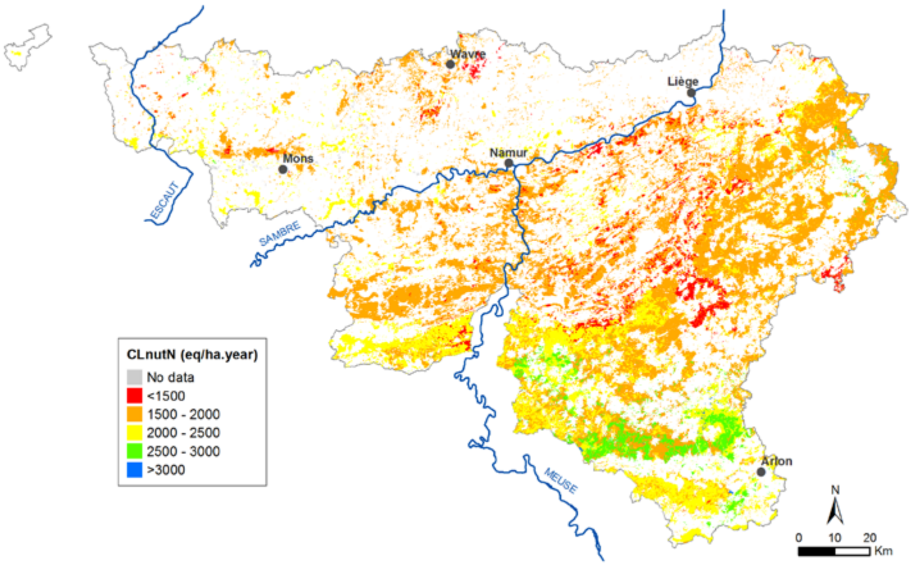

Figure BE-4. Critical loads of nutrient nitrogen for forests, CLnutN.

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Introduction

The aim of the elaboration is to update critical loads of sulphur and nitrogen. The data incorporated in the elaboration were prepared for the last Call for Data 2015/2017 and processed with the use of the both measurement and modelled data in 957 forest localities. Some of them are results of the grant entitled “Forest soil state as a determining factor of health state development, biodiversity and filling productivity and outside productivity functions of forests” solved under the sponsorship of the Ministry of Agriculture of the Czech Republic (Novotný et al., 2014).

Updating the critical loads has been called out by two main reasons - for changes in meteorological situation from the previous elaboration of critical loads and changes in forest ground floor vegetation. Increase in temperatures and different precipitation amounts in forests are presented in Figures CZ-1 and CZ-2. The period involving long-term meteorological data (1960-90) was compared to the recent period (2011-14). The vegetation change is mainly realized by a gradual increase in nitrophilous species and decrease in oligotrophic species. The total number of species seems to increase with atmospheric deposition of nitrogen (Buriánek et al., 2013). The occurrence of nitrophilous vegetation species in the herbal floor of forests in the Czech Republic is shown in Figure CZ-3. Most data were compiled for the years of the phenological survey (1999 and 2014).

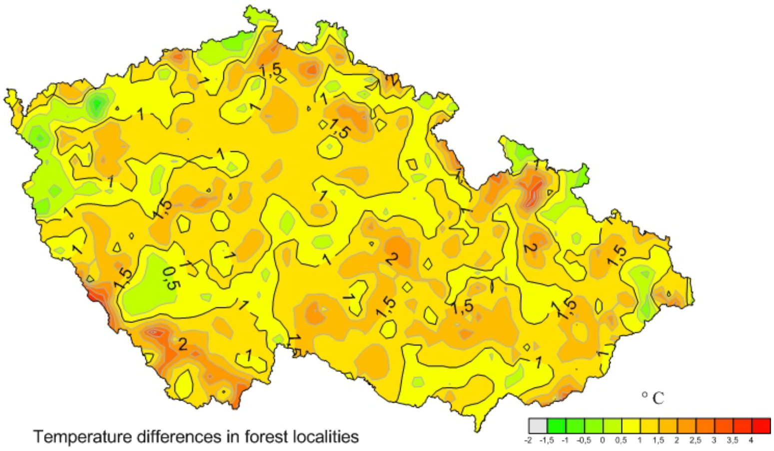

Figure CZ-1. Differences in temperatures in forests between the periods1960-90 and 2011-14.

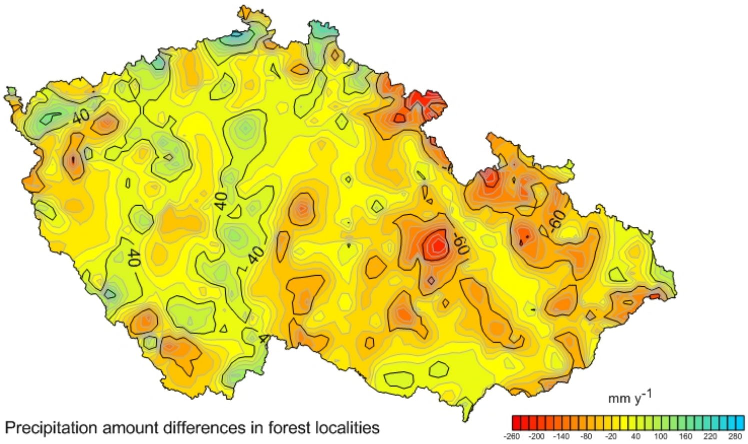

Figure CZ-2. Differences in precipitation amounts in forests between the periods1960-90 and 2011-14.

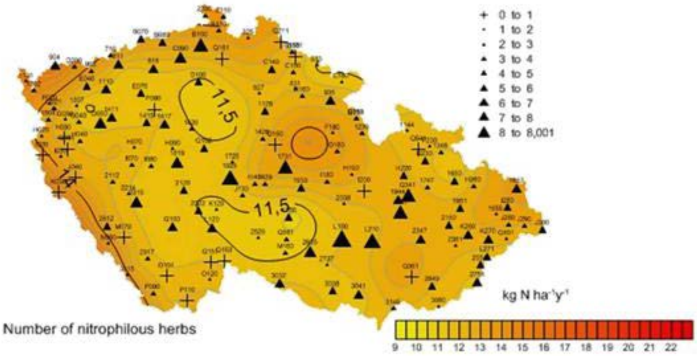

Figure CZ-3. Occurrence of nitrophilous vegetation species in the herbal floor of forests.

Methods
Updated critical loads for acidification and eutrophication are involved in tables 'CLacid' and 'CLeut'. Critical loads of sulphur CLmaxS and critical loads of nitrogen CLminN, CLmaxN in the table 'CLacid' are based on the SMB method (CLRTAP, 2015). The table 'CLeut' contains CLeutN values - the minimum values between CLnutN (computed by the SMB method) and CLempN. Only forest areas are taken into account. Data on critical loads are in eq ha^{-1} a^{-1}.

Maximum critical load of sulphur, CLmaxS:
$CLmaxS = BC_{dep} - Cl_{dep} + BC_{we} - Bc_{upt} - (-ANC_{lecrit})$
BC_w weathering rate
BC_{dep} base cation deposition
Cl_{dep} chloride deposition
Bc_{upt} base cation uptake
ANC_{lecrit} alkalinity leaching (Al criterion)

Atmospheric deposition of base cations was revised. The data of wet and bulk depositions in 2009-13 (www.chmi.cz) were processed in maps with the help of Surfer 12. Depositions of base cations including chlorides into coniferous and mixed forest localities were multiplied by factors 1.7 and 1.3, respectively (based on the analysis of bulk and throughfall data). Weathering rates were obtained from texture and parent material classes and computed with use so-called weathering rate classes WRc and average annual temperature (CLRTAP, 2015). Uptake fluxes equal average annual removal of Ca^{2+}, Mg^{2+}, K^+ and N in 2003-10 (from databases presented on the web site of UHUL in 2011, www.uhul.cz). Uptake of these elements involves the removal of stems including branches (CLRTAP, 2015). The aluminium criterion [Al]=0.02 eq m^{-3}, especially useful for drinking water protection, was considered in the calculation of critical alkalinity leaching values.

Minimum critical load of nitrogen, CLminN:
$CLminN = N_{upt} + N_{imacc}$
N_{upt} nitrogen uptake
N_{imacc} acceptable immobilization of N in the soil

Temperature-dependent immobilisation rate of nitrogen proposed by the NFC of Germany was applied to the calculation of acceptable immobilisation of nitrogen in the soil given in the table 'SiteInfo'. The calculation includes the soils of C/N ratios higher than 21. Soils of lower C/N ratios were supplied by the value of 0.5 kg N ha^{-1} a^{-1} (background value).

Maximum critical load of nitrogen, CLmaxN:
$CLmaxN = CLminN + CLmaxS/(1-f_{de})$
f_{de} denitrification fraction ($0 \leq f_{de} < 1$)

Critical load of nutrient nitrogen, CLnutN:
$CLnutN = N_{upt} + N_{imacc} + N_{leacc}/(1-f_{de})$
N_{leacc} acceptable leaching of N (1 mg 1^{-1})

Empirical critical load of nitrogen, CLempN:
Forests of the Czech Republic, characterized by selected plots according to forest typological classification, fall into the following main types of forest habitats. They are Alder carrs (short cut in Czech L1), Alluvial forests (L2), Oak-hornbeam forests (L3), Ravine forests (L4), Beech forests (L5), Thermophilous oak forests (L6), Acidophilous oak forests (L7), Dry pine forests (L8), Spruce forests (L9) and Bog forests (L10). These types of habitats can be classified by the EUNIS as Riverine ash-alder woodland and Mixed oak-elm-ash woodland of great revers (G1.4), Alder swamp woods and Sphagnum birch woods (G1.6), Medio-European acidophilous and neutrophile beech forests and Medio-European subalpine beech woods (G1.7), Medio-European acidophilous oak forests and Sub-continental oak-hornbeam forests (G1.8), Euro-Siberian steppe oak woods (G1.9), Hercynian slope forests (G1.H), Mire spruce woods and Hercynian subalpine spruce forests (G3.2), Scots pine mire woods and Middle European Scots pine forests (G3.5). Classification to the EUNIS is based on the transfer of typology of forests carried out according to the Catalogue (Chytrý et al., 2001).

Empirical critical loads of N range from 5 kg ha^{-1} a^{-1} for habitats with coniferous tree species (including Sphagnum birch woods – only one locality) to 10 kg ha^{-1} a^{-1} for habitats covered by deciduous tree species. Values of nitrogen empirical critical loads agree with critical loads for eutrophication CLeutN in 87.5 % of localities.

The table 'SiteInfo' gives partial results for calculation of critical loads for acidification and eutrophication such as base cation depositions, weathering rates, uptake, denitrification rates and so on. The important values are for example the flux of drainage water leaching from the soil layer Q_{le} (or precipitation surplus), equilibrium constant K_{Alox} and exponent, concentration of organic acids Corgacids (or m*DOC). The flux of drainage water was computed according to the relationship described in De Vries et al. (2004). The values of equilibrium constants K_{Alox} (in the form of decadic log) were taken from the Mapping Manual (CLRTAP, 2015). The values of K_{Alox} and exponent were derived from analyses of the soil solution of Dutch forests. Data presented in $\log_{10}K_{Alox}$ also involve values for loess and clay soils. Values for loess soils, especially, are important for the territory of the Czech Republic for a large number of forest localities covered by leached loess soils relatively.

Concentrations of DOC in the soil solution are measured only in a small number of forest localities. Measurements proceed only in forest plots including intensive monitoring (level II) performed by the Forestry and Game Management Research Inst5tute in Prague – Zbraslav and included in the International Cooperative Programme for Forests. Data on the soil solution concentration of DOC were used for the assessment of the content of DOC in all considered localities. Relationships of DOC and soil C/N ratios, pH, altitudes, average annual temperatures and content of organic C in soils were investigated.

Conclusion
The data incorporated in the elaboration were processed with the use of the both measurement and modelled data in 957 forest localities. The main aim was to update critical loads of sulphur and nitrogen. The

results cover the forest area of 6396.25 km^2 altogether. Maximum critical loads of sulphur range from 122.68 eq $ha^{-1}a^{-1}$ to 2680.7 eq $ha^{-1}a^{-1}$. Minimum critical loads of nitrogen are in the range of 35.71–893.21 eq $ha^{-1}a^{-1}$. Results of maximum critical loads of nitrogen fall in the range of 420.77–4064.87 eq $ha^{-1}a^{-1}$. The lower values reached out in the case of critical loads of nutrient nitrogen CLeutN. Their values range from 357.14 to 714.29 eq $ha^{-1}a^{-1}$. This range corresponds to the values of empirical critical loads of nitrogen.

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Summary
This document gives an overview of the response by Finland to the Call for Data 2015–17, dated October 12th 2016 by the CCE. The Finnish NFC submitted critical loads of acidity for lakes, and critical loads of eutrophication, for terrestrial and aquatic Natura 2000 sites. Altogether critical loads for 32,311 sites were submitted, covering a total ecosystem area of 41,427 km^2.

Critical loads of acidity
For Finland, critical loads of acidity were updated only for lakes (EUNIS class C1 Surface standing waters). Critical loads of acidity for Finnish lakes were calculated by Posch et al. (2012). The steady-state First-order Acidity Balance (FAB) model was set up with information from comprehensive national surveys of headwater lakes (N=1066) and soils. A variable ANC limit was used to take into account the total organic carbon concentration of the lakes (Posch et al., 2012). The resulting values of $CL_{max}S$, $CL_{min}N$ and $CL_{max}N$ that define the critical load function of S and N are summarized in Table FI.01. These values were submitted in January 2017 to the CCE for 1066 lakes, covering a total ecosystem area of 287 km^2.

Table FI-1. Summary of critical loads of acidity for a subset of Finnish lakes (N=1066, total area 287 km^2) (Posch et al., 2012).

CL acidity	5%tile	Median	95%tile
$CL_{max}S$ (eq ha^{-1}yr^{-1})	86	603	1 626
$CL_{min}N$ (eq ha^{-1}yr^{-1})	37	72	125
$CL_{max}N$ (eq ha^{-1}yr^{-1})	319	1 554	5 290
$[ANC]_{crit}$ (eq m^{-3})	0.01	0.05	0.10
EcoArea (km^2)	0.02	0.08	1.13

Critical loads of eutrophication
Empirical critical loads of nutrient nitrogen were first assigned for Finnish Natura 2000 sites in response to the CCE Call for Data 2010–2011 (Holmberg et al., 2011), and updated in response to the CCE Call

for Data 2014-2015 (Holmberg et al., 2015). These values were used for the current submission of critical loads of eutrophication ($CL_{eut}N$) (Table FI-2).

Table FI-2. Critical loads of eutrophication ($CL_{eut}N$) for Finnish Natura 2000 sites and total area per protection type.

EUNIS code		CLeutN (kg ha^{-1} yr^{-1})	Natura sites (km^2)	SPA (km^2)	SCI (km^2)	SCI/SPA (km^2)
A2	Littoral sediments	20	125	12	6.3	107
B1	Coastal dune and sand habitats	8	1.3	0	0.4	1.0
B1.3	Shifting coastal dunes	10	1.3	0	0.6	0.7
B1.4	Coastal stable dune grassland	8	1.6	0	0.7	0.9
B1.5	Coastal dune heaths	10	1.0	0	0.7	0.4
B1.7	Coastal dune woods	10	5.7	0	2.7	2.9
B1.8	Moist and wet dune slacks	10	0.6	0	0.03	0.6
C1	Surface standing waters	3	1,508	24	865	619
C1.1	Permanent oligotrophic lakes	3	3,546	10	2,375	1,161
C1.3	Permanent euthrophic lakes	3	29	13	5.5	11
C1.4	Permanent dystrophic lakes	3	1,562	98	1,209	255
D1	Raised and blanket bogs	5	1,729	19	575	1,134
D1.1	Raised bogs	5	1,077	0.5	548	529
D3.1	Palsa mires	5	376	0	105	271
D3.2	Aapa mires	5	6,519	11	1,954	4,554
D4.1	Rich fens	15	460	0.5	110	350
E2.2	Low and medium altitude hay meadows	10	0.2	0	0.1	0.1
E2.3	Mountain hay meadows	10	0.1	0	0.1	0.01
F2	Arctic, alpine and subalpine scrub habitats	5	6 ,859	0.1	1,930	4,929
G1	Broadleaved deciduous woodland	10	542	3.4	146	393
G1.9	Non-riverine woodland with *Betula*	5	3,900	0	1,533	2,367
G1.A	Meso- and eutrophic *Quercus* woodland	15	0.6	0.02	0.3	0.3
G3	Coniferous woodland	5	10,952	26	5,453	5,473
G4.1	Mixed swamp woodland	5	145	2	72	71
G4.2	Mixed taiga woodland with *Betula*	5	1,800	11	540	1,249
Total area			41,141	231	17,431	23,479

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Introduction
The 2017 Call for Data aimed to update and compute maps of so-called “classical Critical Loads”, calculate critical loads for biodiversity and compute habitat suitability indices. Clacid and CleutN were updated by using the SMB model for French forest ecosystems at the territory scale and CLbdiv calculations were in progress, tentatively established at the site scale and compared to classical CL.

To reach these objectives, some important steps have to be completed: i) first, a new ecosystem grid has to be set up by combining the ecosystems already defined, the protection status areas and the corresponding EUNIS habitat with the new EMEP grid (0.1° x 0.05°); ii) to elaborate a new scale of CL (7.5 x 5.5 km *vs*. 50 x 50 km) with new updates of temperature, precipitation and drainage; (iii) to tentatively apply PROPS model to calculate CLBdiv for these new ecosystems and compute HSi (iv) to continue improving the development of the combined model ForSAFE-EcoPlant to calibrate and validate the main parameters driving vegetation occurrence for French forest ecosystems, and finally v) to progress in modelling on long-term periods the influence of nitrogen deposition and climate change scenarios on biodiversity by using accurate HSi and CLbdiv.

For that purpose, we used input data from: (i) very well documented forest sites belonging to the French ICP forest network (RENECOFOR, National network of forest health survey from the National Forest Office), which is part of the European network for forest health survey since 1992 (ONF, 2015); (ii) the National Centre of Meteorological Research through its predictive model SAFRAN (CNRM - Meteo-France, CNRM, 2017); and the National Institute for Geographical and Forest information (IGN) through lists of statistically selected representative vegetation species. The lists were established for the main French ecological regions, and provide percentages of species occurrence. Updating ecosystems database

Updating ecosystems database

Updates of Ecosystems grid using EMEP higher resolution grid

As explained in the last call for data (see ICPMM report, Slootweg et al., 2015), the first step was to update the French Critical Loads database by computing and using the new 0.10° x 0.05° EMEP grid. Differences in resolution between the old and new EMEP grids were presented during the 32nd ICP-M&M Task Force meeting in Dessau (Haunold et al., 2016).

For the present call, we updated the ecosystem database to this grid, and took into account protected and non-protected areas (Figure FR-1a) to update classical CL and to run the coupled biogeochemical-ecological models in order to predict biodiversity evolution. The model simulations should let us know how ecosystems will change at a long time scale, depending on their protection status. Compared to the previous database of the last CL update for nitrogen (Figure FR-1b; Probst et al., 2008), this lead to multiply by 10 the number of French forests ecosystems (> 1ha) considered in the calculations (Figure FR-1c).

Precipitations, Drainage and Temperature updates

Another important step was to update at the territory scale, precipitation (Pmm) and temperature (T°C) data to upgrade the data at the new grid scale. Data from CNRM-SAFRAN (8 km^2 grid cells) was related to data from the ICP forest sites (RENECOFOR Network) and to EcoPlant field data survey, also considering different periods of time. Robust relationships could be set up. To update the drainage at the territory scale (Qle), different methods of calculation were tested (Turc method, Thornthwaite method) and using a large set of different data, (SAFRAN database from Meteo-France, ECOPLANT database observations) and

ICP forest sites measurements for calibration and upgrading. Finally, Qle=P-ETR (with ETR the real evapotranspiration), Pmm and T°C could be calculated for each ecosystem by using average annual values at the grid scale for the period 1959-2013 (Haunold et al., 2016). Using the SAFRAN grid, the average values were spatialized at the territory scale (using Areal Average Estimation method; Sen, 2016).

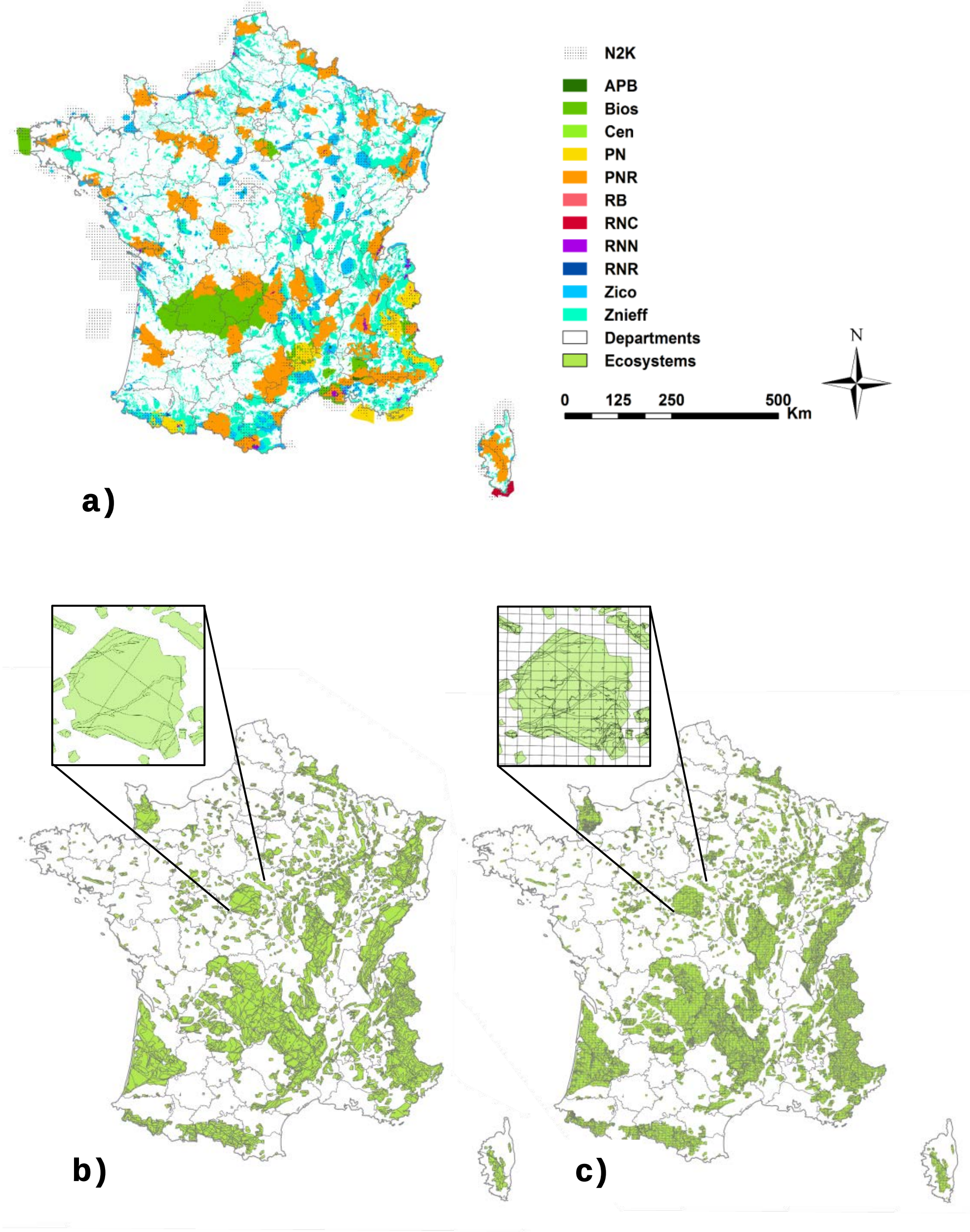

Figure FR-1. a) N2K and National Protection status (Source: https://inpn.mnhn.fr/, 2016); b) Previous ecosystems database (Probst et al., 2008); c) New ecosystems database (call for data 2017). (Zooming in on Sologne's ecosystems).

Updating Classical Critical Loads SMB: CLmaxS; CLnutN; CLeutN

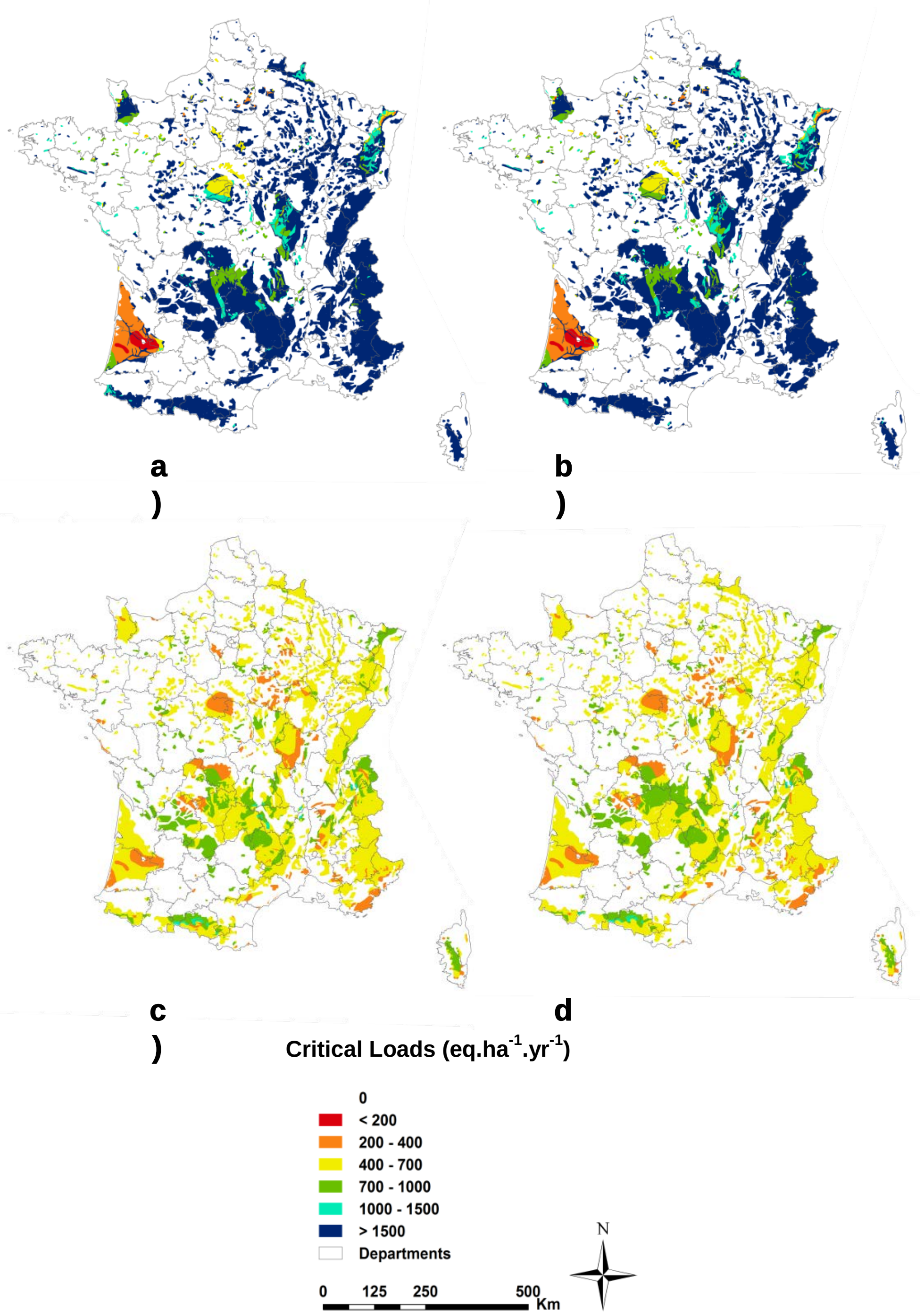

Figure FR-2: Critical Loads maps for France: a) Sulphur CLmaxS 2017; b) Sulphur CLmaxS 2015; c) Eutrophying Nitrogen CLeutN 2017; d) Nutrient Nitrogen CLnutN 2015. Only forested areas are concerned. Note: Critical Loads for the coastal ecosystems are not considered due to a lack of input data.

The above improvements allowed updating new French CL maps. The new map for CLmaxS (Figure FR-2a) is presented in comparison with 2015 map (Figure FR-2b), as well as the new 2017 CLeutN (Figure FR-2c) compared to the CLnutN map 2015 (Figure FR-2d). Few changes were observed at the territory scale for S and N SMB CL. Similar conclusions as those reported in the 2015 report can be drawn (Probst et al., 2015). For acidity, most of the French ecosystems indicate high CLmaxS, but some regions like the Landes, Sologne, Centre and North of the Paris Basin, Northern Vosges, are very sensitive to acid sulphur deposition. For Nitrogen, the whole territory is much more sensitive: the most sensible ecosystems are localized in the Landes region (SW), in the eastern-southern part of the Paris basin, in the very northern part of the Massif Central, in the eastern and southern Alps, and in the Mediterranean region.

At the territory scale, no significant obvious trends could be observed in sensitivity classes in 2017 (Figures FR-2a,c) compared with 2015 (Figures FR-2b,d). However, detailed investigations on CLmaxS indicated that changes in CL classes are linked to the EMEP resolution grid scale.
At the regional scale, one can see some changes:
- ClmaxS (Figures FR-2a,b): a more sensitive area for the Sologne (southern Paris Basin) and the western Pyrénées massif; less sensitive sites in the eastern-southern Vosges massif and in the central Pyrénées massif.
- CleutN (Figure FR-2c) was assessed using the most sensitive value between CLnutN (computed with SMB) and CLemp (empirical CL) as estimated earlier (see Probst and Leguédois, 2008). Since the SMB model gives the more sensitive CL, the CLeutN map (Figure FR-2c) is very similar to the CLnutN map from 2015 (Figure FR-2d, the 2017 map is not shown). Nevertheless, the 2017 CLeutN Map (Figure FR-2c) indicated more sensitive areas located in the eastern Paris Basin, in the Southern and Northern Massif Central, the Centre of the Pyrénées Mountains, in Western Jura. On the opposite, less sensitive areas are in the central Vosges Massif as well as in the Northern and Southern Alps and in Corsica.

At the site scale, maximal critical loads were estimated using two methods: i) by extracting CLmaxS values from the corresponding spatialized ecosystem; ii) by recalculating CLmaxS at site scale using measured values as input data. CLmaxS calculated with observed data at the site scale are more sensitive, indicating that for some sensitive areas, CL maps presented optimistic values for acidification risk.

From 2015 to 2017 calculations, the percentage of total ecosystems that have moved up or down from a given CL class to another, could be evaluated (CLmaxS classes in blue and CLeutN classes in yellow, Figure FR-3). Positive and negative bars indicated a gain or a loss of ecosystems into the considered class of ecosystems, respectively. For each CL class, only net balance of ecosystems is presented, it does not report if the ecosystems have moved from one class to the adjacent one, or if they change jumping into more distant classes.

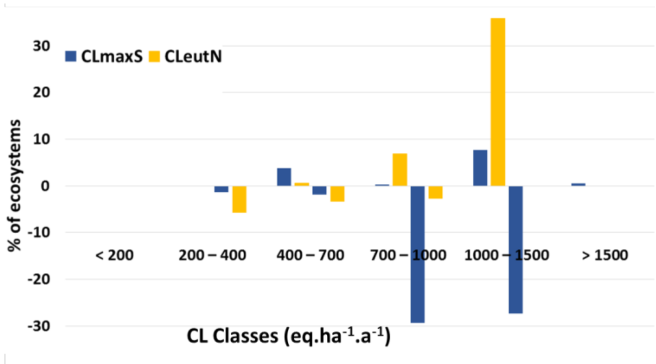

Figure FR-3. Percentage of ecosystems changes in the different CL classes with data update (blue bars: sulphur; yellow bars: eutrophying nitrogen).

As mentioned before, few differences were observed between former and new critical loads. This is particularly true for the most sensitive ecosystems (CL < 700 $eq.ha^{-1}.yr^{-1}$), whereas the main differences concerned elevated critical loads (Figure FR-3). With the updates, an important increase of ecosystems was observed for elevated classes of CLeutN, meaning that non sensitive ecosystems were categorized as even lesser sensitive to nitrogen impacts. On the opposite, a major decrease (up to 30%) of ecosystems is observed for elevated classes of CLmaxS, lowering the sensitivity to acidification of the less sensitive ecosystems belonging to the CL upper classes. Because the main differences are observed in elevated classes of critical loads for both nitrogen and sulphur (i.e. resilient ecosystems to acid inputs), new CL computations using updated data do not call into questions the former results for sensitive ecosystems. Consequently, since the most sensible ecosystems were not significantly impacted by the data update, and because the limit class effect might be influent, the updated CL estimation does not challenge the initial CL results but can be considered as more accurate and precise.

Critical Loads of Biodiversity: CLBdiv

PROPS CLBdiv: HSi -Results and limits

Critical loads for biodiversity were calculated using the PROPS model (Reinds et al., 2012) provided by the CCE and Alterra.

The two main objectives of PROPS are to compute critical loads for biodiversity on the latest updated ecosystems, as well as values of Habitat Suitability indices. The use of HSi for common European biodiversity modelling was agreed in 2014 during the CCE Workshop and ICP Modelling & Mapping Task Force meeting in Rome. Details concerning principles and formulas to compute HSi were presented in various CCE publications (Posch et al., 2014, 2015). This index is defined as the arithmetic mean of the "normalized" probabilities of the species of interest. For a given vegetation unit or ecosystem, the HSi is computed according to eq.FR-1, based on normalized probabilities of representative species.

$$\boldsymbol{HSi} = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{p_i}{p_{i,max}} \qquad \text{eq. FR-1}$$

with n the number of species, $\boldsymbol{p_i}$ the occurrence probability of species i, and $\boldsymbol{p_{i,max}}$ the maximum occurrence probability of species i.

We used the updated data for temperature, precipitation and drainage as inputs, as well as soil geochemical characteristics from the French NFC CLs database, and lists of representative vegetation species. Those lists of typical species were established through the PROPS-Select database and software, but also using the EUNIS classification on French ecosystems, experts' judgement analyses and statistical studies done on observed data on each ecological region of the territory.
PROPS model was first applied on ecosystems groups (in order to reduce the volume of data and time treatment). Groups were constituted on the basis of same values of soil geochemical characteristics and EUNIS habitat. In this first step, the groups of ecosystems belonging to a given EUNIS habitat, were parameterized with the same lists of representative species, even if the ecosystems in a given group were located in different contrasted regions in France. The PROPS model can be parameterized using 2, 3 or 5 dimensions of maxima used in order to compute HSi and critical loads values. If input data on one or two parameters (pH, N deposition, C/N ratio, precipitations and temperature) are missing, it is possible to use default values. We tested two versions of the PROPS model: i) the first one parameterized with 3 dimensions (i.e. using accurate modelled data for P and T, produced by the SAFRAN model at local scale); ii) the second one using default values for P and T. Few differences in terms of CLSmax and HSi values were observed. Nevertheless, because all the input variables were available for the major part of the 38992 ecosystems, the 3 dimensions parameterized PROPS model was used to compute the CL for biodiversity.

In a second step, the PROPS model was applied on each of the 38,992 ecosystems, characterized by their own soil geochemical, climatic and environmental characteristics. The critical loads for biodiversity were more accurate using this second method. However, the list of representative species remains the most influent factor explaining the only differences between the CLs and HSi results of the two methods (groups of ecosystems and all the 38,992 ecosystems) because: (i) within a given group of ecosystems that belong to a same EUNIS habitat, few changes into the list of species lead to different values of critical loads and HSi, which mirrors the ecosystem characteristics; (ii) for a same EUNIS habitat the representative species were selected in relation to the ecosystem proper pedo-climatic conditions.

Consequently, the CLbdiv and HSi results for France were obtained with the PROPS model applied to all the updated ecosystems (Figure FR-4). Typical species of the ecosystem habitat, as well as the ecosystem environment and especially pedo-climatic characteristics, are thus needed to compute accurately critical loads with PROPS.

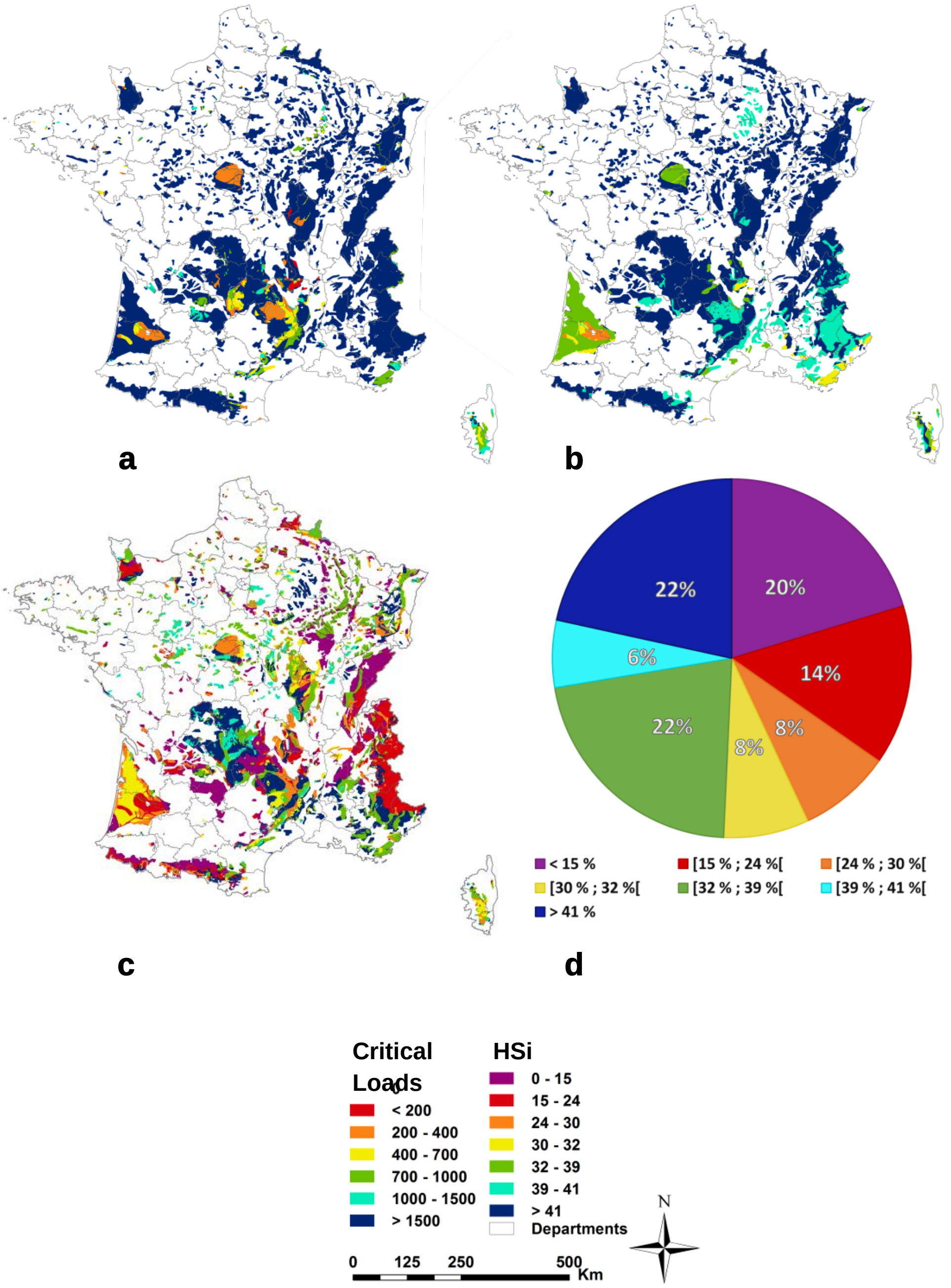

Figure FR-4. Biodiversity critical loads and HSi maps for France: a) Sulphur CLSmax 2017; b) Nitrogen CLNmax 2017; c) HSi 2017. Only forested areas are concerned. (Note: Critical loads for the coastal ecosystems are not considered due to a lack of input data); d) % of ecosystems in each HSi class (expressed as the ratio between the cumulative area of forest ecosystems in each class of HSi and the total area of forests in France). Limits of classes correspond to quantiles.

Differences between the two types of critical loads (classical and biodiversity) are more important for sulphur (Figures FR2a and FR-4a) than for nitrogen (CLmaxN data not shown and Figure FR4b) with a range of one to three critical loads classes. The most sensitive ecosystems according to classical critical loads model (Figure FR2a) are also those presenting the highest differences with the CLbdiv results (Figure FR4a).

The main differences between classical CLSmax and CL for biodiversity (Figures FR2a and FR4a) are observed for the EUNIS D2 and D4 sensitive ecosystems located in the Landes and in the central part of France (Sologne). While D2 habitat ecosystems in the Landes became less sensitive when computing critical loads for biodiversity, it was the reverse for the D4 habitat ecosystems of Sologne (each time jumping from one class to the adjacent one). On the contrary, some ecosystems located in the southern part of the Massif Central, not sensitive at all with classical critical loads, became sensitive to very sensitive when considering critical loads for biodiversity. Indeed, once again, these contrasting results can be explained by the list of representative species that has been established to compute CLbdiv with PROPS. For nitrogen the only differences (CLmaxN, not shown and CLNmax, Figure FR-4b) concerned less sensitive ecosystems and were often due to artificial limit class effects (always occurring between adjacent classes).

Results on HSi indicated a median HSi value of 32% (Figure FR-4d) and a major proportion of forest ecosystems areas distributed into the 5th and 7th classes of HSi (green to blue). The lowest HSi values are generally encountered for the more sensitive ecosystems (i.e. the Landes, the Sologne). Nevertheless, mountain ecosystems (the Pyrenees, the Alps, the Jura and the Central Massif) also exhibit very low HSi values (Figure FR-4c), whereas they were considered as not sensitive according to classical and biodiversity critical loads (Figures FR-2a,c and FR-4a,b). These results could be explained by the more important difficulty to well assign a precise EUNIS habitat to mountain ecosystems and thus the representative species that have to be considered. In the rest of France, all the other HSi values for forest ecosystems located in the plains, pretty well correspond to the sensitivity level determined by classical and biodiversity critical loads (Figures FR-2a,c and FR-4a,b,c).

In order to compare those results with others obtained with a coupled dynamic biogeochemical-ecological model calibrated for French ecosystems and French forest species, the next part of this report will present the EcoPlant model and the HSi results obtained on the same forest ecosystems.

ECOPLANT CLBdiv: HSi -Results and limits

The EcoPlant model (Gegout et al., 2005) and the link with ForSAFE (Wallman et al., 2005; Belyazid, 2006) has been detailed in the 2015 CCE report (Probst et al., 2015). As a reminder, the EcoPlant model calibration was done for a list of more than 800 common and representative plants species of French ecosystems. This coupling between the biogeochemical model ForSAFE calibrated for French ecosystems (Gaudio et al., 2015) and the ecological model EcoPlant has been done at the territory scale (Rizzetto et al., in progress), and let to compute HS indices for the ICP forest sites. Three logistic regression models (binding with and without Growth Degree Days models, ecological model) were computed by selecting the eight more explicative and robust variables for each of them. This selection process necessitated seven main steps, going from 37 at the beginning to 8 selected variables at the end. Results of this work consist in calibrated and validated parameterized logistic equations for each of the 800 species that lead to compute presence probability, depending on soil, climate and geochemistry characteristics of their living sites. Afterwards, Habitat Suitability indices can be calculated with these results.

A description of the variables that composed the binding and ecological models, as well as a summary of their respective weights into the models and the occurrences of concerned species, is presented in Table FR-1 and Figure FR-5, respectively.
Methods used to calibrate and select the variables for the ecological model were exactly the same as for the binding models. The only differences between the two concerned the duration of the cold and the dry periods. Results were also analysed following the same processes. Observed trends for variables weights are nearly the same between the models. For this reason, only the results for the binding model are presented in this report on Figure FR-5.

Table FR-1. Summary table of final ecological variables used to establish the logistic regression models.

Binding model		**Ecological model**	
pHwater		**pHwater**	
CNrat	C/N ratio	**CNrat**	C/N ratio
Hydromorphy	3 qualitatives classes	**Hydromorphy**	3 qualitatives classes
Log(AWC)	Climatic Water Balance of July	**Log(AWC)**	Climatic Water Balance of dry season (one day accuracy duration)
Tree_cover	trees cover % (H > 8 m)	**Tree_cover**	trees cover % (H > 8 m)
Total_radiation	Cumul of annual radiations (in $J.cm^{-2}$)	**Total_radiation**	Cumul of annual radiations (in $J.cm^{-2}$)
Tmin_January	min. Temp. of January	**Tmin_winter**	min. Temp. of winter season (one day accuracy duration)
GDD_5°	Growing Degree Days (5°C)	**GDD_5°**	Growing Degree Days (5°C)

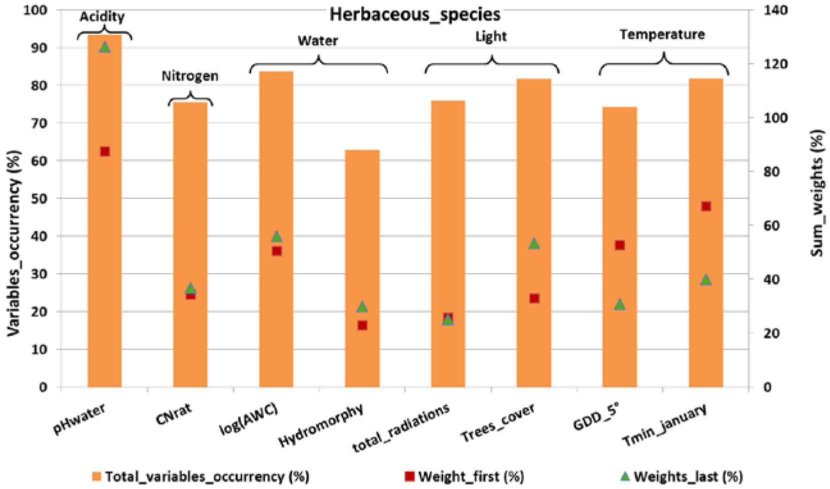

Figure FR-5. Summary of variables representativeness for the binding model integrating Growth Degree Days. The cumulative percentages of each variables when integrating in first or in last position into the model, are scaled on the right Y-axis (red and green points), and species occurrence in % are scaled on the left Y-axis (orange bars). Only results for herbaceous species are shown. The same type of analysis has been done for all species without distinction of vegetation layers.

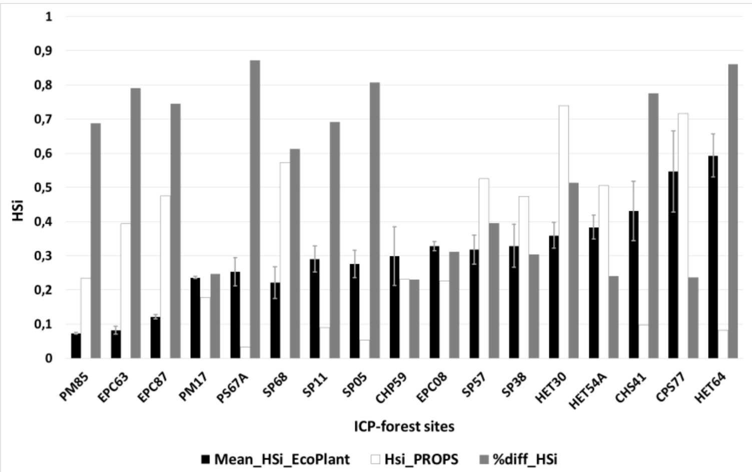

Figure FR-6. Comparison of HSi values obtained with the EcoPlant and PROPS models. Chosen ICP-forest sites PM85 to HET64) correspond to well-known and well instrumented forest sites with various tree species (Rizzetto et al., 2016). The mean and STD of the EcoPlant HSi values were from the results of the 3 EcoPlant models (see text). Sites are ranked according to increasing EcoPlant HSi values. The %diff HSi was calculated as the error rate between the two models (i.e.: lowest HSi / highest HSi).

Once calibrated, the EcoPlant model lets to compute species probability of occurrence for the concerned sites/ecosystems. Because the most important environmental characteristics were measured on the sites/ecosystems on which the model was applied, HS indices were computed according to Eq. FR-1. The lists of representative vegetation species were established using the same criterions and data sources as the ones used into the PROPS model. Thus, a comparison of HSi values from EcoPlant (mean and STD of the mean for the three models) and PROPS models was performed on 17 well-known and instrumented ICP-forest sites on which inputs data were available (Figure FR-6).

The EcoPlant models indicated the best HSi values for sites dominated by deciduous species. This observation has to be taken with caution since this addresses a limited number of sites. However, this is consistent because of the larger list of representative common species under deciduous trees cover, and of non-specific species composition that has to be adapted site by site in the case of coniferous dominant tree species. Whereas the three EcoPlant models behave in a same way, HSi determined by PROPS model follow a more erratic pattern.

More or less important gaps do exist between HSi values computed with EcoPlant and PROPS, depending on the considered sites and their dominant tree species. Gaps are either positive or negative, and even if 9 sites among 17 have higher HSi values using PROPS, no clear trends can be extracted from these results. Significant relative differences might concern the lowest HSi values (Figure FR-6).
Some inherent differences between the EcoPlant and PROPS models can explain these results. First, the logistic regression equations are not similar in the two models, as well as the number and type of explicative variables. Moreover, the EcoPlant model has been calibrated for species really representative of French forest ecosystems (Gégout, 2001), by selecting climate, soil and ecological variables that better explain those species response to environmental conditions (Rizzetto et al., in progress). As a consequence, the EcoPlant model allows computing species presence probability on ecosystems with good accuracy due to an initial calibration at local scale using in situ observed data. PROPS model (Reinds et al., 2012) uses species parameterization and regression equations that are calibrated at a larger scale, considering European areas. This scale difference between the two models, and also the calibration of EcoPlant performed at the site scale, should explain part of the observed differences.

Because the EcoPlant model has been calibrated with representative French vegetation species on more than 6000 sites, it allows to compute HSi values at forest sites scale. The French NFC will go further into that way in order to extend HSi and critical loads for biodiversity calculation at the whole territory scale. Although those calculations were available for many sites, the main goal of this work is to apply this model at ecosystems scale. Moreover, the coupling between the EcoPlant and the biogeochemical ForSAFE models has been performed since the final objective of these in-progress investigations, are to simulate the influence of atmospheric deposition and climate change scenarios on ecosystem response at a century scale (Rizzetto et al., 2016). As a consequence, dynamic modelling of critical loads for biodiversity and HS indices will be soon performed, using consistent measurements on French forest ecosystems as input data.

Conclusion

The French NFC has successfully update the classical CL for CLmaxS, CLnutN and CLeutN, using the new high resolution EMEP grid. Update values for precipitation, temperature and drainage were performed. The number of ecosystems with an area exceeding 1 ha, was multiplied by 10. This led to more precise CL estimations. The results are consistent with those proposed in the 2015 report, with few changes by comparing CL2015 and CL2017 maps. However, in a limited number of regions, the more precise values indicated more or less sensitive ecosystems, but with no obvious general trends. For CLmaxS, the changes can be also due to a very tenuous change of class. CLeutN was found to be consistent with the values given by CLnutN. The CL calculated using measured data at the site scale appeared always more sensitive than the corresponding data given by the model extrapolation at the territory scale, which can thus be considered as maximum values.

The French NFC has also computed biodiversity critical loads and Habitat Suitability indices using the two models EcoPlant (of which three different versions) and PROPS at regional and site scales. The classical CL and biodiversity CL from PROPS at the region/ecosystem scale, were more in agreement for nitrogen than for sulphur. For CLbdiv, the results of the three EcoPlant models are consistent and indicate higher HSi in deciduous forest ecosystems for the considered sites. However, some major gaps were evidenced between EcoPlant and PROPS HSi, due to the models conception relative to selected variables and the equations types, even with similar list of representative species. According to our investigations and verifications, the list of representative species selected to compute HSi and CL values, was found to be the main sensitive driver that control models results, and has to be parameterized case-by-case to the ecosystems conditions, at the local scale.

In the near future, critical loads for biodiversity and HSi values computed by the French NFC will integrate global changes impacts on forest ecosystems. The new coupled ForSAFE – EcoPlant model calibrated with thousands of observed data, will take into account atmospheric deposition and climate change scenarios into the modelling process. This dynamic modelling method, applied at local scale on the whole French forested area, is the next step in progress.

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The response of the German NFC to the Call for Data 2015-17 (CCE, 2016) focuses on the newly developed critical loads based on biodiversity. Despite this, the "classical" critical loads that protect ecosystems against acidification and/or eutrophication were also submitted. The dataset was completed by information on the protection status of the ecosystems (e.g. SPA or SAC under the NATURA 2000 framework) and an overview of EUNIS classes relevant for Germany. The German dataset consists of 1.26 million records representing about 30% percent of the territory. For the first time the new CORINE 2012 land use data formed the basis for the derivation of ecological receptors. A high-resolution data set with a spatial resolution of one hectare was used (UBA, 2015). Further data sources include the long-term annual means of precipitation surplus (1981–2010) provided by the German Weather Service (DWD, 2014), the land use dependent German soil map (BÜK1000N; BGR, 2014a) and precipitation surplus (SWR1000, BGR 2014b). Deposition for sulphur, nitrogen and base cations was taken from the PINETI project (Schaap et al., 2017). Critical loads were computed for each of the resultant polygons, which was then overlaid with the grid used by the CCE. Areas smaller 0.5 ha are neglected, unless a nature protection program applies at this site.

SMB-Critical loads for acidification and eutrophication

Critical loads (CL) to protect ecosystems against acidification and eutrophication were calculated following the simple mass balance method (SMB) as described in the Mapping Manual (CLRTAP, 2016). These data, often referred as "classical critical loads", are used in Germany as indicators for the identification of the environmental condition. The exceedance of critical load for eutrophication at a national level is an indicator in the German Biodiversity Strategy[11] and in the German Sustainability Strategy[12].

Critical loads of acidity, CL_{acid}

The calculation of critical load of acidifying sulphur and nitrogen deposition for forest soils and other (semi-)natural vegetation was made by using the critical load function (CLF). The CLF is quantified by $CL_{max}S$ (eq.V.22 of the Mapping Manual), $CL_{min}N$ (eq.V.25) and $CL_{max}N$ (eq.V.26).

For $CL_{max}S$ the critical load calculation for each polygon of the dataset was done by using 5 different chemical criteria: the critical base cation to aluminium ratio (eq.V.31 of the Mapping Manual, marked as crittype = 7 in the dataset), the critical aluminium mobilisation rate (eq.V.34, crittype = -1), the critical pH-value (eq.V.35, crittype = 4), the critical base cation to proton ratio (eq.V.36, crittype = 6) and the critical base saturation (eq.V.38, crittype = 3). The minimum value determines the $CL_{max}S$ for the specific ecosystem.

For base cation deposition the 3-year means (2009–11) was included in order to smooth large variations of this parameter due to meteorological influences (Schaap et al., 2017). As a result of the sea salt correction the deposition of sodium and chloride ions were not considered.

Approximately 76% of the critical loads were calculated using the critical base saturation, 23% using the critical pH-value and less than 1% using the critical base cation to aluminium ration.

The regional distribution of critical loads for acidifying compounds in Germany is given for sulphur in Figure DE-1 ($CL_{max}S$) and for nitrogen in Figure DE-2 ($CL_{max}N$).

Critical loads of eutrophication, $CL_{eut}N$

There are several ways to determine this value. One is to estimate the empirical critical load $CL_{emp}N$ (Bobbink and Hettelingh, 2011), another is the calculation with the mass balance method (SMB). It was also offered to use the minimum of both. The German NFC decided to apply the mass balance based calculation for the critical load of eutrophication. The method used to calculate SMB values, formerly known as $CL_{nut}N$, is described in detail in the Mapping Manual (eq.V.5).

Different criteria and consequently, different protection targets were used for acceptable N concentrations in soil solution for the critical load computation. According to the Mapping Manual (Chapter V.3.1.2 and Table V.5) the limit can be set between 0.2 mg N per litre (lowest range for vegetation change from lichens to cranberry in forested ecosystems) and 6.5 mg N per litre (upper range for ground vegetation change in deciduous forest). For the calculation the range of values given in the Mapping Manual were specified to single numbers as in previous years (CCE Status Report 2015). The acceptable N concentrations applied in the German dataset for SMB-CL are listed in Table DE-1.

The long-term natural nitrogen immobilization was estimated as in previous years to be in a range between 0.5 kg N $ha^{-1}yr^{-1}$ (background value) and 5 kg N $ha^{-1}yr^{-1}$ (CCE, 2001). Lower values are assigned to

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

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

higher annual temperatures (increased mineralization) and higher immobilization values are assumed in temperate climates. A statistical distribution of immobilization values of the German dataset is given in Table DE-2. When taking the results of a scientific workshop on immobilization in Olten (Switzerland, February 2017) into account, our median values are equal to the maximum values discussed at the workshop. Furthermore beside climate (temperature) the N-immobilization depends as well from vegetation and soil properties (e.g. carbon pool). Unfortunately these most recent results could not be fed into our calculations yet. In the future an approach to calculate the average rate of N immobilization as the ratio of the N stock divided by soil age will be tested and may be regarded as the maximal acceptable value for a sustainable long-term net N immobilization.
The nitrogen uptake equals the long-term removal of nitrogen from the ecosystem was computed for forests taking into account the growth rates and the element content in stems and branches (Table V.6 of the Mapping Manual). A similar approach was applied for grass land and other non-forested ecosystems. The distribution of computed values in the German dataset is shown in Table DE-3.
In accordance with the Mapping Manual the denitrification was assessed with a denitrification fraction (values from 0.1 to 0.8) as a function of the soil drainage and clay content in the rooted horizons. The distribution of computed values in the German dataset is shown in Table DE-4.
The regional distribution of critical loads for eutrophication ($CL_{eut}N$) in Germany is shown in Figure DE-3.

Table DE-1. Applied acceptable N concentrations in soil solution in the German dataset in adaption of values given in the Mapping Manual Table V.5 (as applied in previous years; CCE-Status Report 2015).

Sensitive species of the vegetation type	**N_{crit} [mg N l^{-1}]**
Lichens	0.3
Cranberry	0.5
Blueberry	1.0
Trees with risk on fine root biomass or sensitivity to frost and fungal diseases	3.0
Less sensitively coniferous trees	4.0
Less sensitively deciduous trees	5.0
Rich fens and bogs	2.0
Flood swards	5.0
Grass lands	3.0
Heath lands	4.0
Herbs	5.0

Table DE-2. Statistical distribution of immobilization values of the German dataset.

Percentile	**Nitrogen immobilization [kg N $ha^{-1}yr^{-1}$]**
5	0.65
25	0.85
Median	1.05
75	1.34

Percentile	Nitrogen immobilization [kg N $ha^{-1}yr^{-1}$]
95	2.27
Average	1.20

Table DE-3. Statistical distribution of nitrogen uptake of the German dataset.

Percentile	Nitrogen uptake [kg N $ha^{-1}yr^{-1}$]
5	1.86
25	2.99
Median	3.33
75	4.92
95	5.92
Average	4.03

Table DE-4. Statistical distribution of denitrification of the German dataset.

Percentile	Computed denitrification [kg N $ha^{-1}yr^{-1}$]
5	0.08
25	0.38
Median	1.08
75	2.94
95	10.92
Average	2.57

Critical loads to protect biodiversity

Description of the model approach

The model BERN (Bioindication for Ecosystem Regeneration towards Natural conditions) was designed to integrate ecological cause-effect relationships into environmental assessment studies including the derivation of critical load (Schlutow et al., 2015). The BERN model was applied in the version BERN4 (Schlutow et al., 2017).

Natural plant communities that were observed on reference sites in a reference year, e.g. before major air pollution impact, can be defined as reference communities. They represent the current solution of long-term interaction between their species to each other (competition, coexistence, cooperation) and to the environment. In order to model reactions of plant communities to changes in the environment, the reference realized niches of plant species (currently 1970) and of plant communities (692 communities) with their fuzzy (blurred) thresholds of the suitable site parameters are derived from the BERN database. It is assumed that the combinations of site parameters represent a dynamic nutrient balance. The plant communities are therefore classified as reference site types.

The BERN model derives the niches of those plant species, which mainly constitute the community, i.e. the constant plant species, which are by definition, the characteristic species and all attendant species that can be found with a similar abundance in more than 70% of all vegetation relevés representing the plant community at the same ranges of the site parameters. The assemblage of constant plant species of a community does not vary significantly within a climatic region or at a short time scale, if the factors do not vary significantly in space or time.

The possibility for a plant community should be defined in a way that it reaches the highest values at the point where most constant species have their maximum values to.

The following site parameters are used in the BERN database to characterize reference site types (in the shape of trapezoidal functions). From this the minimum, the maximum and an optimum plateau (range of optimal conditions for species and/or plant communities) can be defined:

- Soil water content at field capacity [m^3 m^{-3}];
- Base saturation [%];
- pH value (in H_2O);
- C/N ratio [g/g];
- Climatic water balance [mm per vegetation period]: precipitation minus potential evaporation;
- De Martonne-Index of continentality [precipitation in vegetation period per mean temperature in vegetation period + 10];
- Length of vegetation period [d yr^{-1}]: number of days of the year with an average daily temperature above 10°C;
- Available energy from solar radiation during the vegetation period [kWh m^{-2} yr^{-1}]: depends on latitude, slope, aspect, cloudiness, and the shading caused by overlapping vegetation layers and their coverage in the plant communities;
- Temperature [°C]: The trapezoid function was defined by the following indicators: minimum (frost hardiness), minimum and maximum of optimum (beginning and ending of photosynthesis) and maximum (heath hardiness).

Critical load for biodiversity, CL_{bdiv}

The parameters in the BERN database for which critical thresholds for the preservation of plant communities can be estimated are similar to the parameters used in the SMB method for critical load computations, e.g. C/N ratio, base saturation, pH value. A reasonable threshold value is the degree of possibility at the intersection point of the optimum plateau border line with the site gradient for nutrient imbalance with decreasing C/N-ratio and decreasing base saturation caused by eutrophication and acidification (see Figure DE-4). Complying with these values, the natural reference plant community just can exist at the maximum possibility of its occurrence. These values were set for critical limits.

Comparable to the “classical” critical loads also the CL for biodiversity can be derived with soil-chemical models (in the German dataset the SMB model) and associated data (application of the BERN model). Following this the critical load function for biodiversity can be characterized by CLS_{max}, CLN_{max}, CLS_{min} and CLN_{min} (CCE 2016).

For CLS_{max} and CLN_{max} the equations of the Mapping Manual can be used as well. The substitution of critical limits suggested in the Mapping Manual for the “classical” critical load calculation with threshold determined by plant communities allows the application of the SMB approach to protect biodiversity. For the threshold of acid deposition (CLS_{max}) the critical base saturation ($BS_{crit(bdiv)}$) was used in eq.V.38.

Biodiversity related critical load of nitrogen (CLN_{max}) are based on the fact that the C/N ratio is a rather solid parameter which changes with nitrogen deposition continuously and reflects the site conditions very well. The critical C/N ratio needs a transformation to a critical nitrogen concentration $[N]_{crit(bdiv)}$ in order to fit into the simple mass balance equations according to the manual (eq.V.6). The following approach is proposed:

$$[N]_{crit(bdiv)} = \frac{N_{\min(crit)}}{\theta \cdot z}$$

with:

$[N]_{crit(bdiv)}$ = critical nitrogen concentration in soil water of the rooting zone as long-term annual mean [kg N m^{-3}]
$N_{min(crit)}$ = critical amount of mineral nitrogen as long-term annual mean [kg N m^{-2}]
θ = average content of water in the rooting zone [m³ m^{-3}]
z = depth of the rooting zone [m] (as minimum of the potential depth determined by the rooting potential of the soil and the potential rooting depth of the dominant plant species of the occurring plant community)

and:

$$N_{\min(crit)} = N_{t(crit)} - N_u - N_{de} - N_{org}$$

with:

$N_{t(crit)}$ = critical amount of total nitrogen in soil and soil water as long-term annual mean [kg N m^{-2}]
N_{org} = amount of organic nitrogen as long-term annual mean [kg N m^{-2}]
N_u = annual nitrogen uptake of biomass as long-term annual mean [kg N m^{-2}]
N_{de} = annual nitrogen loss by denitrification as long-term annual mean [kg N m^{-2}]

Under critical load conditions, a harmless N input from the atmosphere is also permitted. However it should only be allowed to add to the accumulated N in the ecosystem until a state of equilibrium between the rate of N-mineralization and the N-output rate has been reached over a prolonged period of time. From this it is clear that over the long-term average the following conditions apply to semi-natural ecosystems:

$$N_{dep} - N_u - N_{de} \rightarrow 0$$

Therefore the previous equation can be simplified to

$$N_{\min(crit)} = N_{t(crit)} - N_{org}$$

And

$$N_{t(crit)} = \frac{C_{org}}{C/N_{crit(bdiv)}}$$

with:

C_{org} = amount of organically fixed carbon as long-term annual mean [kg C m^{-2}]
$C/N_{crit(bdiv)}$ = critical C/N ratio derived from the ecological niche of the occurred plant community (BERN4 database)

and:

$$N_{org} = N_{t(crit)} \cdot (1 - f_{min})$$

with:

f_{min} = factor (0-1) describing the share of N_{min} to N_t (linked to the clay content in the soil)

The data for C_{org}, θ and z was derived by the horizon specific data of reference soil types in Germany. The f_{min} was derived by the clay content, but is an indicator for soil moisture and pH in soil water as well. These land use specific datasets are provided by the BGR (2014a). The plant communities described in the BERN database were linked to their typical reference soil profiles and the deduced data.
Regularly a plant community can be typical for various reference soil types leading to different $[N]_{crit(bdiv)}$ for the same community; therefore the values for the $[N]_{crit(bdiv)}$ needed aggregation to one value. The 90th percentile was chosen as threshold representing a rather conservative approach since the maximum values still contain vital plant communities.
The $[N]_{crit(bdiv)}$ for natural and semi-natural plant communities range between 0.07 mg l^{-1} (5th percentile) and 5.0 mg l^{-1} (95th percentile) with a median of 1.2 mg l^{-1}. Compared with the values of the “classical” SMB approach it results in more sensitive critical loads.

Results
The regional distribution of resulting critical load to protect biodiversity is shown for Sulphur, CLS_{max} in Figure DE-5 and nitrogen, CLN_{max} in Figure DE-6.

Compared to the “classical” critical load computed with critical limits according to the Chapter V.3 of the Mapping Manual, the application of new critical limits to protect biodiversity derived from the BERN database result in a higher sensitivity especially for nitrogen deposition. Ecosystems with a risk for acidification are nearly similar. But nearly 45 % were identified for a high risk of eutrophication using the biodiversity critical load with a critical nitrogen deposition below 500 eq N ha^{-1}yr^{-1} (see Table DE-5). Figure DE-7 shows the overall distribution of the resulting datasets and underpins the trends described above.

Table DE-5. Comparison of “classical” critical load in accordance to Chapter V.3 of the Mapping Manual and critical load for biodiversity resulting from the BERN4 model.

Range eq N $ha^{-1}yr^{-1}$	$CL_{max}S$ (1) % of receptors	CLS_{max} (2) % of receptors	$CL_{max}N$ (1) % of receptors	$CL_{eut}N$ (1) % of receptors	CLN_{max} (2) % of receptors
< 500	7,93%	8,69%	1,61%	32,53%	44,44%
500 – 1000	41,15%	41,02%	10,04%	33,53%	31,02%
1000 – 1500	18,49%	19,03%	29,22%	15,75%	15,33%
1500 – 2000	14,23%	14,02%	7,29%	9,17%	2,7%
2000 - 3000	10,2%	9,64%	31,21%	6,29%	3,44%
3000 - 5000	7,99%	7,6%	20,64%	2,74%	3,07%

(1) “Classical” critical load applying the SMB method as described in Chapter V.3 of the Mapping Manual (data included in the 2017 submission)

(2) Resulting critical load of biodiversity from the BERN4 model (data included in the 2017 submission)

Habitat Suitability Index (HSI)

Since the critical limits to calculate critical loads for biodiversity were derived from the optimal range of plant communities, the value for HSI is equal to one in the German data set. This means that all habitats have good ecological conditions when the critical load for biodiversity will be not exceeded.

Summary

Significant changes in the critical load dataset have taken place due to the introduction of the new land use information based on CORINE 2012. The high resolution of this base layer has the effect that smaller, more sensitive habitats in need of protection have been recorded. In addition due to the broadened scope focusing on biodiversity, the precautionary environmental protection could be expanded. Overall, the new German critical load dataset provides a good scientific tool for policy advice and supports the tasks associated with the German national sustainability strategy as well as the implementation of the Convention for the Protection of Biodiversity.

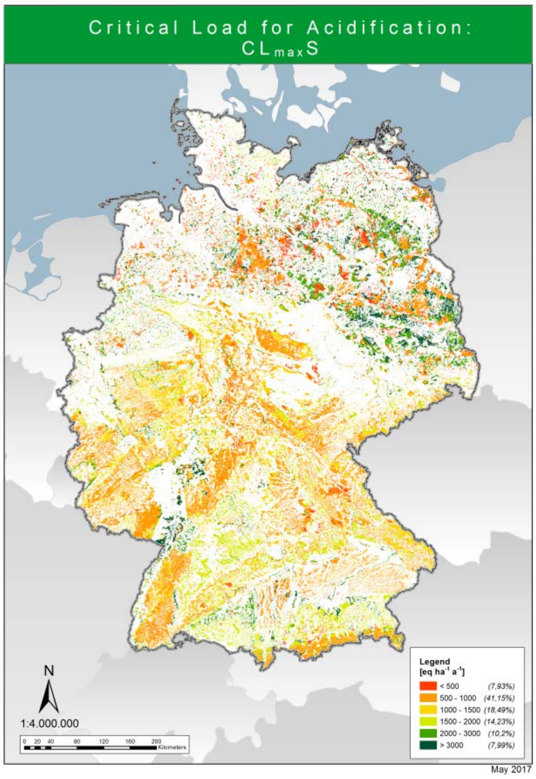

Figure DE-1. Critical loads for acidifying compounds in Germany in terms of Sulphur, $CL_{max}S$.

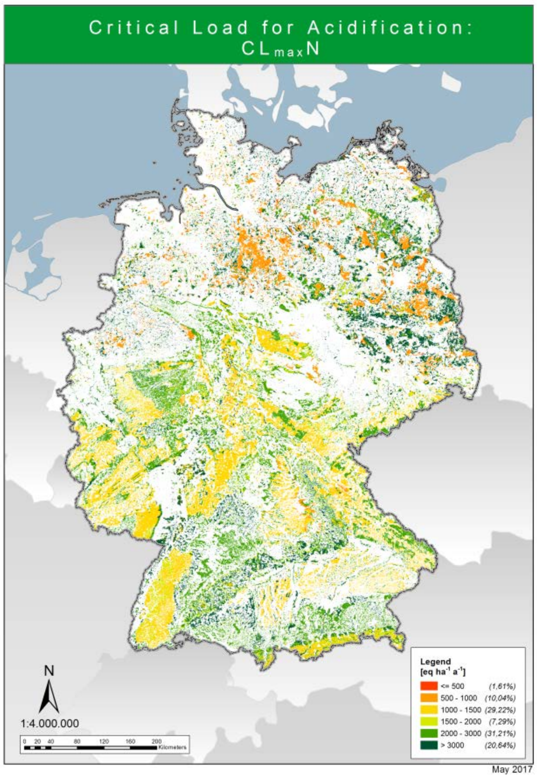

Figure DE-2. Critical loads for acidifying compounds in Germany in terms of Nitrogen, $CL_{max}N$.

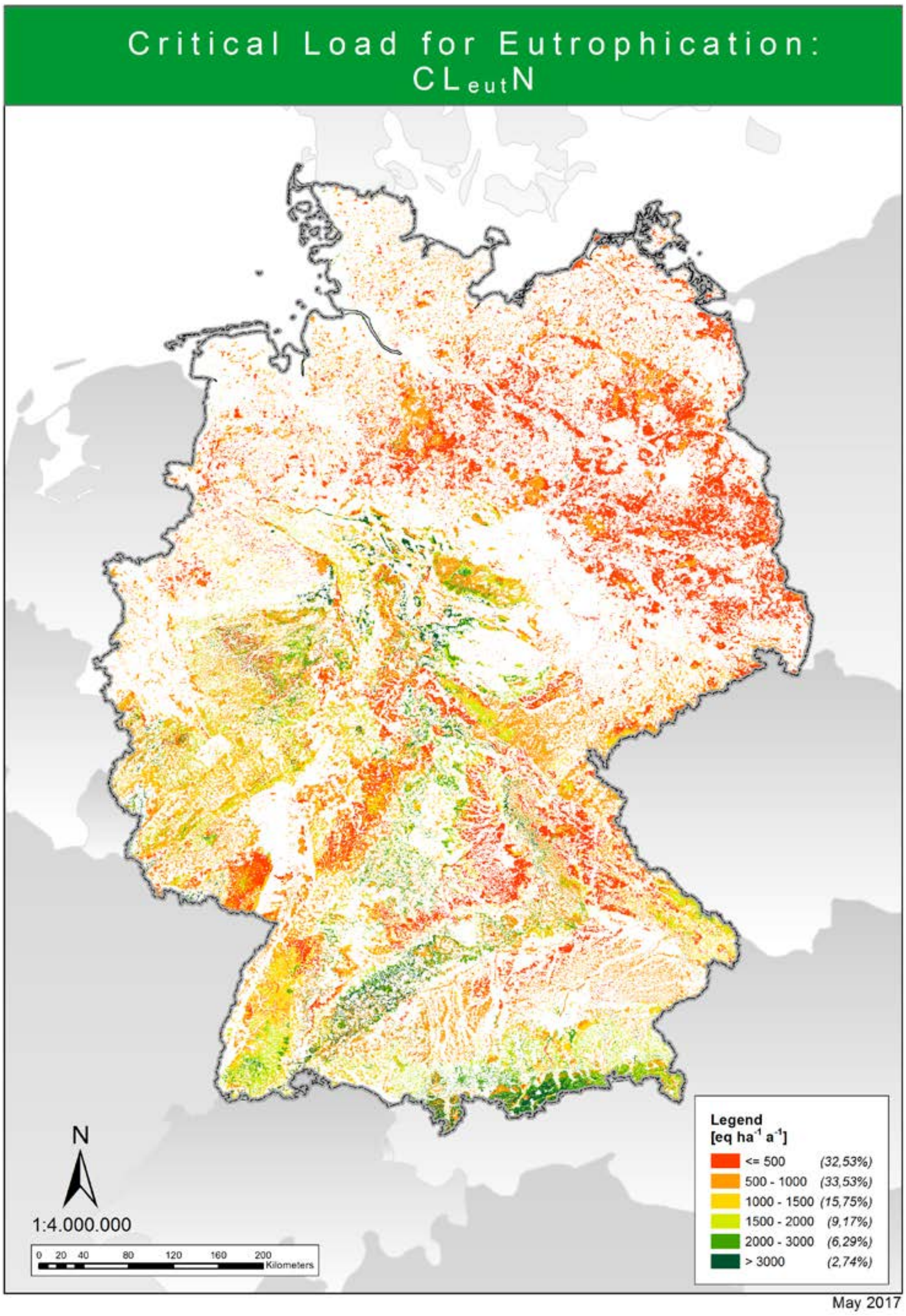

Figure DE-3. Critical loads for eutrophication in Germany, $CL_{eut}N$.

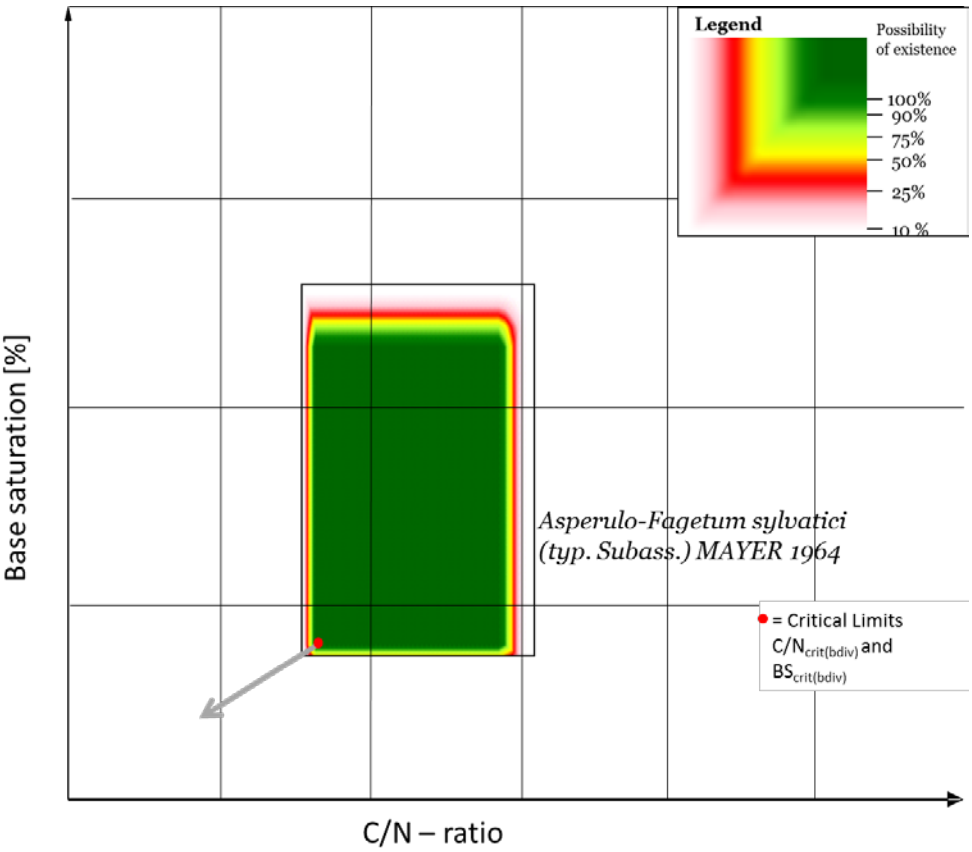

Figure DE-4. Principle for the calculation of critical limits from the possibility function of the plant society, using the example of Asperulo-Fagetum sylvatici. The grey arrow indicates the trend of nutrient imbalance after acidification and eutrophication, the red point define the critical limits of the community.

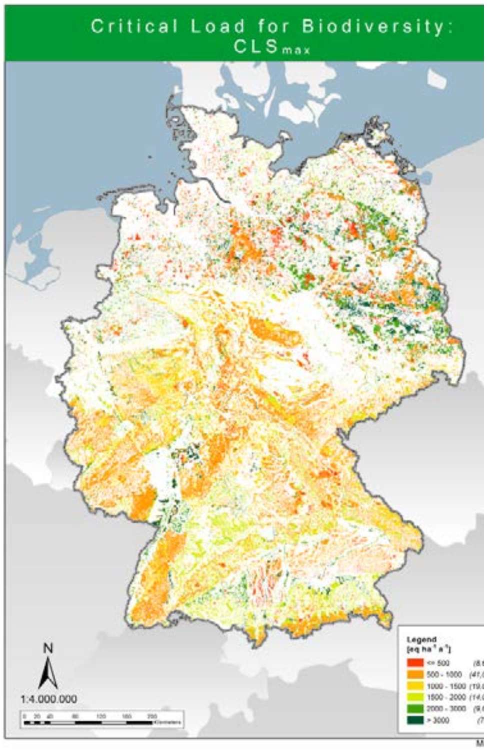

Figure DE-5. Critical load to protect biodiversity in terms of sulphur, CLS_{max}.

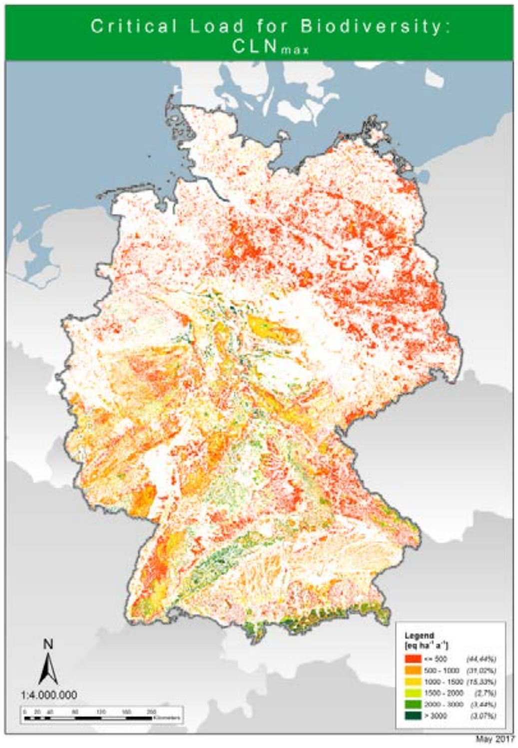

Figure DE-6. Critical load to protect biodiversity in terms of nitrogen, CLN_{max}.

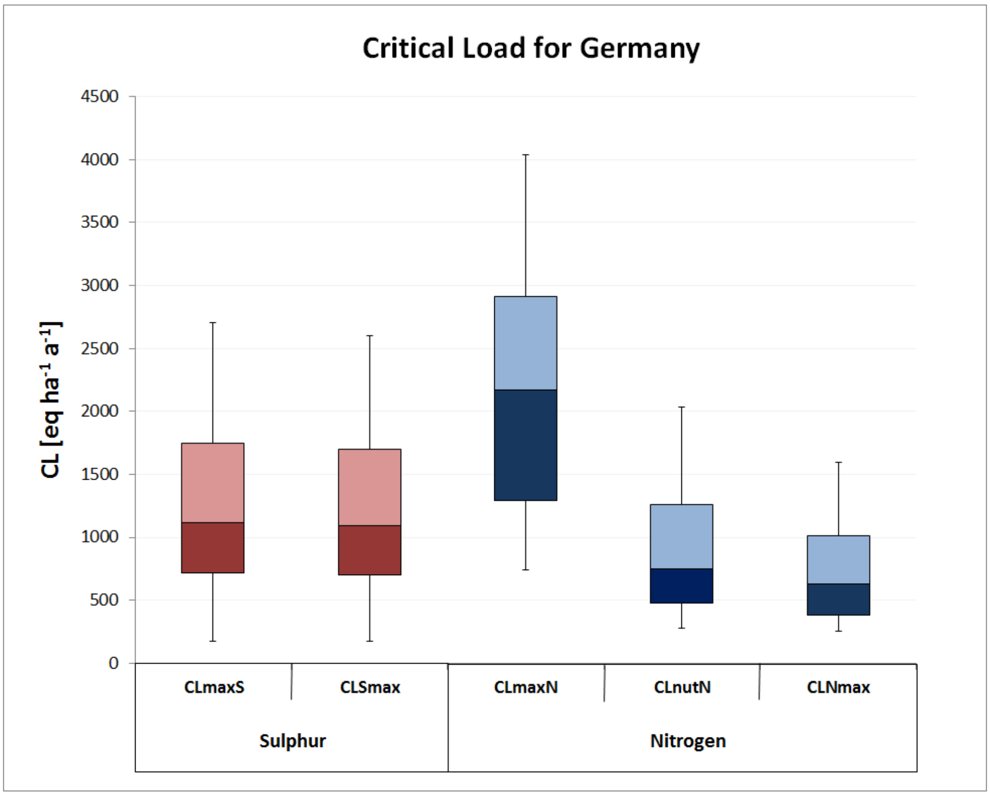

Figure DE-7. Distributions of the submitted critical load datasets.

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UBA, 2015. CORINE Land Cover (CLC) 2012, LBM-DE2012 © BKG/Geobasis-DE

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The 2015–2017 'call for data' issued by the International Cooperative Programme on Modelling and Mapping was focused on biodiversity critical loads. The call contained two primary tasks: (a) to derive nitrogen and sulphur critical load functions taking into account their impact on biodiversity, and (b) to update national critical load data on acidity and eutrophication. The Irish National Focal Centre (NFC) submitted a response as outlined below.

Critical loads for biodiversity: In response to the 2015–2017 'call for data', PROPS-CLF was applied to ~420 plant relevé plots representing eight EUNIS habitats (D1 [n = 8], E1.26 [66], E1.7 [63], E2.2 [30], E3.51 [216], F2 [8], F4.11 [12], and F4.2 [18]). The habitat types was determined by the National Parks and Wildlife Service (NPWS) during field surveys conducted between 2007–2013; a top soil sample was also collected from each plot for the determination of carbon and nitrogen. Plant species selected for the Habitat Suitability Index (HSI) were based on habitat-specific 'positive indicator species' provided by the NPWS; critical loads for biodiversity were determined at HSI = 0.667.

In general, the maximum (biodiversity) critical loads for nitrogen (CLN_{max}) were broadly consistent with empirical critical loads for nutrient nitrogen, with grasslands showing higher CLN_{max} (see Figure IE-1). The

Habitat Suitability Index (HSI) ranged from 0.119 (E2.2) to 0.912 (E3.51), with a median of 0.492 (Figure IE-1). The maximum (biodiversity) critical load for sulphur (CLS_{max}) had a wider range, with grasslands showing lower values compared with heathlands and peatlands (Figure IE-2). The relevé plots were mapped onto 337 unique habitat polygons (with 1–8 relevés per habitat polygon) covering a total ecosystem area of 345 km^2.

Updates to national critical load database: Minor updates were applied to the national critical loads database since the 2011 ‘call for contributions’; the national terrestrial receptor ecosystem habitat map was refined following discussion with national habitat experts (NPWS). The protection status for each ecosystem was derived from national maps of Nature Reserves, Natural Heritage Areas (NHA), Special Areas of Conservation (SAC) and Special Protection Areas (SPA). Empirical critical loads of nutrient nitrogen were assigned to all receptor ecosystems under the critical load habitat map based on output from the ‘Workshop on the Review and Revision of Empirical Critical Loads and Dose-response Relationships’, Noordwijkerhout (The Netherlands), June 2010. Modelled nutrient nitrogen ($CL_{nut}N$) was only estimated for managed forest habitats (G1, G3.1 and G4.6).

Future activities: The NFC will continue to support activities under the LRTAP Convention, with a greater focus on determination of critical loads for biodiversity.

Acknowledgements: Financial support for the development of critical loads for Ireland was provided by the Irish Environmental Protection Agency under the STRIVE Programme 2007–2013.

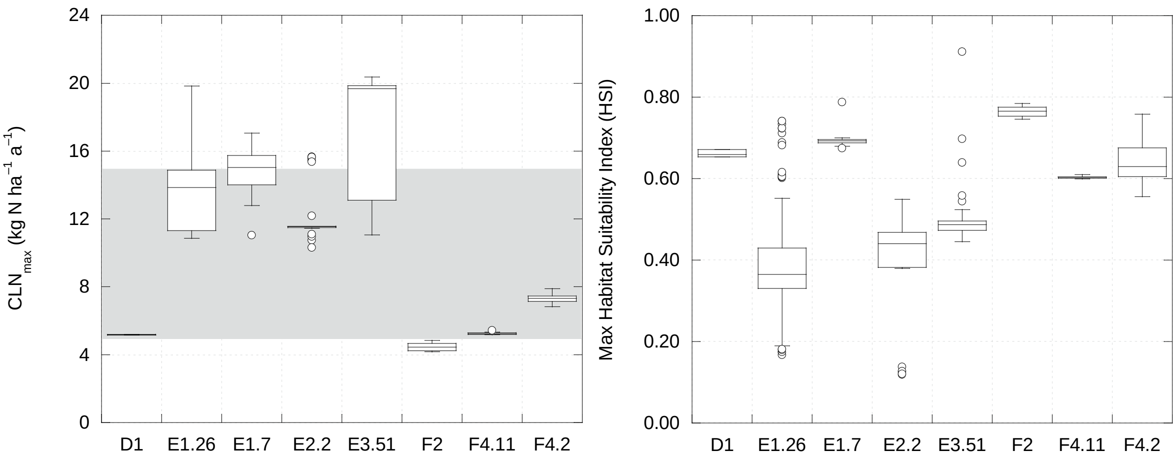

Figure IE-1. Box-plot showing the maximum critical load of nitrogen (CLN_{max} [kg N ha^{-1} a^{-1}]) and maximum Habitat Suitability Index (HSI) for each habitat type. The grey band represents a range of 5–15 kg N ha^{-1} a^{-1}.

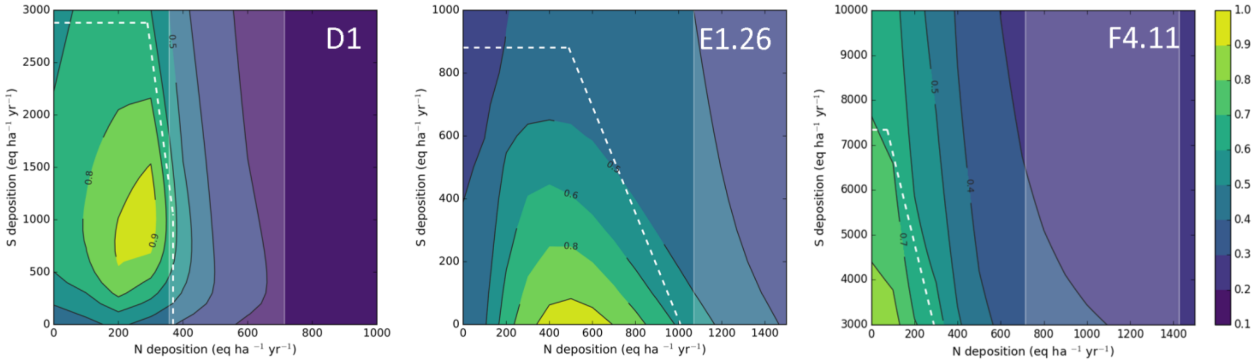

Figure IE-2. Average Habitat Suitability Index (HSI) isoline plots for three EUNIS habitats (D1, E1.26 and F4.11). The white dashed line indicates the average N-S critical load function; the number of vegetation plots for each habitat ranged from 8 (D1) to 66 (E1.26). The vertical shading indicates the recommended empirical nutrient nitrogen range.

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Introduction

For the call for data 2015-2017, the Italian NFC, supported by ENEA and University of Rome "La Sapienza", applied the modelling chain VSD+, MetHyd and GrowUp in five ICP-forest level II plots belonging to the EUNIS class G1.6 (IT05,IT08), G1.7 (IT07, IT09) and G4.6 (IT10), respectively. The results obtained from the model's chain and the PROPS vegetation module, were used to calculate site specific Habitat Suitability Index and biodiversity Critical Loads (CLN_{max}).
The vegetation module PROPS was applied using three different lists of vegetation: the first one made of observed plant species in the field during 10 years relieves in the frame of the ICP forests network; a second one containing plant species characteristic for the specific Habitat derived from Annex I of Habitat Directive as indicated by vegetation specialist; the third one was obtained by the PROPS indicated list on the basis of selected EUNIS category.
The results obtained indicate a generic correlation from the three different plant species lists, with the consideration that vegetation list obtained by the Habitat Directive is more sensitive in quite all sites and indicate a more conservative values of critical loads.
It is clear that all the sites under review showed conditions far to have impacts due to N depositions. Indeed the N depositions derived from CLE scenarios for both 2010 and 2030 are below the CLN_{max} obtained by the all plant species lists used in this comparison.

Method

Meteo-data to run the model were given by CREA (Centro di Ricerca per l'Agricoltura ed l'Economia Agraria), whereas soil chemistry data, vegetation relieves and pollutants deposition were obtained from ICP Forest; Habitat Directive specific species were individuated by ISPRA vegetation specialists.

The model's chain was applied on five forest sites representing three different kinds of forest and four Habitat types. More information about the sites is shown in Table IT-1.

Inputs data needed to run Methyd (evapotranspiration, soil moisture, runoff and parameters related to denitrification and mineralization) were obtained from ICP Forest network; also forest management data were obtained from ICP Forest network.

Table IT-1. Site information.

Site_ID	IT05/ABR1	IT07/EMI1	IT08/EMI2	IT09/LAZ1	IT10/LOM1
Locality name	Selvapiana	Carrega	Brasimone	Monte Rufeno	Val Masino
Latitude	41.8475	44.7183	44.1086	42.8306	46.2378
Longitude	13.5975	10.2017	11.1253	11.9139	93.5211
Elevation (m)	1500	200	975	690	1190
Species N°	24	30	34	60	60
Main specie	beech forest	oak forest	beech forest	oak forest	spruce (and fir) forest
Forest Age	124	59	54	49	94
Protection class	3	2	2	0	3
Eunis class	G1.6	G1.7	G1.6	G1.7	G4.6
Props Veg	North and middle appenninian beech	Ligurian-middle Apennine downy oak	Fir-beech forests	Middle Apennine mixed hop-	Central European Galium odoratum-
Props veg class	F146	G44	F142	G52	F115

Table IT-2. Protection class description.

Protection category	Description
0	No specific nature protection applies
1	Special Protection Area (SPA), Birds Directive applies
2	Special Area of Conservation (SAC), Habitats Directive applies
3	SPA and SAC (1 and 2)
4	SPA or SAC (1 or 2, don't know which one)
9	National nature protection program applies (but not 1 or 2)

Concerning VSD+ model input, data characteristics and data sources see Table IT-3.

Between the different options available to study the vegetation dynamic we selected PROPS module because more appropriated for Mediterranean environment.

Table IT-3. Data source and processing for VSD in.

VARIABLE	UNIT	IT05	IT07	IT08	IT09	IT10	SOURCES AND PROCESSING
Thick	m	0.200	0.600	0.423	0.531	0.527	European soil database
Bulkdens	g/cm^3	0.700	1.06299	0.871	1.183	0.905	European soil database
Theta	m^3/m^3	**File**	**File**	**File**	**File**	**File**	MetHyd output
pCO2fac	atm	19.547	24.348	22.684	24.016	20.202	European soil database
Clay_ct	%	26	21	30	25	15	Daffinà et al. (2003)
CEC	meq/kg	166.526	125.175	123.796	178.814	197.535	M&M eq5.2
Cpool_0	g/m^2	449.86	14791.48	14983.95	2515.464	3033.45	By VSD calibration
CNrat0		0.632	10.0091	15.10	12.77778	38.0181	By VSD calibration
lgKAlBC	depending on exchange model	0.511	0.098003	11.434	0.8378	1.5988	By VSD calibration
lgKHBC	depending on exchange model	3.676	6.148333	7.7984	3.9702	1.8791	By VSD calibration
expAl		3	3	3	3	3	Constant
lgKAlox		8	8	8	8	8	Constant
TempC	C°	**File**	**File**	**File**	**File**	**File**	MetHyd output
percol	m/yr	**File**	**File**	**File**	**File**	**File**	MetHyd output
Nadep	$eq/m^2/yr$	**File**	**File**	**File**	**File**	**File**	By ICP Forest measured
Cadep	$eq/m^2/yr$	**File**	**File**	**File**	**File**	**File**	By ICP Forest measured
Mgdep	$eq/m^2/yr$	File	File	File	File	File	By ICP Forest measured
Kdep	$eq/m^2/yr$	File	File	File	File	File	By ICP Forest measured
Cldep	$eq/m^2/yr$	File	File	File	File	File	By ICP Forest measured
NH3_dep	$eq/m^2/yr$	File	File	File	File	File	By ICP Forest scaled on GP scenery
NOx_dep	$eq/m^2/yr$	File	File	File	File	File	By ICP Forest scaled on GP scenery
SO2_dep	$eq/m^2/yr$	File	File	File	File	File	By ICP Forest scaled on GP scenery
EAlobs		1.57	8.5	4.81	4.12	4.9	By ICP Forest measured
EHobs		1.82	8.3	4.59	4.5	5	By ICP Forest measured
cAlobs	eq/m^3	-	-	-	0.248556	0.33	By ICP Forest measured
cBcobs	eq/m^3	0.014	-	0.0017	0.36	0.0023	By ICP Forest measured
cHobs	eq/m^3	-	-	-	0.000624	-	By ICP Forest

VARIABLE	UNIT	IT05	IT07	IT08	IT09	IT10	SOURCES AND PROCESSING
							measured
pHobs		6.38	4.03	6.2	6.053	5.75	By ICP Forest measured
bsatobs	eq/m3/yr	0.85	0.34	0.32	0.36	0.34	By ICP Forest measured
CNratobs	g/g	17.65	17.65	17.65	11.4838	17.08	By ICP Forest measured
Cpoolobs	g/m^2	3176	3176	3176	2773	5250	By ICP Forest measured
Nawe	$eq/m^3/yr$	0.0241049	0.0241049	0.0241049	0.014048	0.0100498	Mapping Manual eq 5.39
Kwe	$eq/m^3/yr$	0.0144629	0.0144629	0.0144629	0.008429	0.0060299	Mapping Manual eq 5.40
Cawe	$eq/m^3/yr$	0.0554410	0.0554410	0.0554410	0.03231	0.0231144	Mapping Manual eq 5.41
Mgwe	$eq/m^3/yr$	0.0216943	0.0216943	0.0216943	0.012643	0.0090448	Mapping Manual eq 5.42
Ca_upt	$g/m^2/yr$	**File**	**File**	**File**	**File**	**File**	GrowUp output
Mg_upt	$g/m^2/yr$	**File**	**File**	**File**	**File**	**File**	GrowUp output
K_upt	$g/m^2/yr$	File	File	File	File	File	GrowUp output
N_gupt	$g/m^2/yr$	File	File	File	File	File	GrowUp output
Ni	eq/ha/yr	**File**	**File**	**File**	**File**	**File**	GrowUp output
Nfire	eq/ha/yr	**File**	**File**	**File**	**File**	**File**	GrowUp output
Nvol	eq/ha/yr	File	File	File	File	File	GrowUp output
Nfix	eq/ha/yr	File	File	File	File	File	GrowUp output
Clf	$g/m^2/yr$	**File**	**File**	**File**	**File**	**File**	GrowUp output
Nlf	$g/m^2/yr$	**File**	**File**	**File**	**File**	**File**	GrowUp output
Nimobs	$eq/m^2/yr$	File	File	File	File	File	GrowUp output
Ndeobs	$eq/m^2/yr$	File	File	File	File	File	GrowUp output

Results

In Figures IT-1 to IT-5 the list of plant species and Habitat Suitability Index graphics are showed for each site of VSD model application. For the site IT08 no relevés are available so just two lists of species are shown.

Observed Sp.

Acer_platanoides	Homalothecium_sericeum
Acer_pseudoplatanus	Moehringia_trinervia
Agrostis_capillaris	Monotropa_hypopitys
Anemone_nemorosa	Mycelis_muralis
Atropa_bella-donna	Myosotis_sylvatica
Bromus_ramosus	Neottia_nidus-avis
Cardamine_bulbifera	Potentilla_micrantha
Cardamine_enneaphyllos	Prenanthes_purpurea
Clinopodium_vulgare	Prunus_spinosa
Digitalis_lutea	Ranunculus_lanuginosus
Epilobium_montanum	Rubus_caesius
Epipactis_microphylla	Sanicula_europaea
Fagus_sylvatica	Sorbus_aucuparia
Fragaria_vesca	Stachys_sylvatica
Galeopsis_speciosa	Stellaria_media
Galium_aparine	Stellaria_nemorum
Galium_odoratum	Veronica_montana
Galium_rotundifolium	Veronica_officinalis
Geum_urbanum	Viola_riviniana

HABITAT type 9210 appennine beech forest with Taxus and Ilex

Abies alba
Anemone apennina
Aremonia agrimonioides
Cardamine bulbifera
Cephalanthera spp.
Corydalis spp.
Daphne laureola
Doronicum columnae
Doronicum orientale
Epipactis spp.
Fagus sylvatica
Galium odoratum
Geranium versicolor
Ilex aquifolium
Lathyrus venetus
Melica uniflora
Neottia nidus-avis
Pulmonaria apennina
Ranunculus lanuginosus
Taxus baccata

Eunis G1.6 Props F146

Acer pseudoplatanus
Allium triquetrum
Allium ursinum
Aruncus dioicus
Cardamine bulbifera
Cardamine enneaphyllos
Daphne laureola
Euphorbia amygdaloides
Galanthus nivalis
Galium odoratum
Geranium nodosum
Hepatica nobilis
Hieracium murorum
Hypnum cupressiforme
Laburnum alpinum
Lathyrus venetus
Lilium martagon
Luzula nivea
Melica uniflora
Mercurialis perennis
Polystichum aculeatum
Prenanthes purpurea
Ranunculus lanuginosus
Rubus hirtus
Salvia glutinosa
Sanicula europaea
Saxifraga rotundifolia
Scilla bifolia
Sorbus aucuparia
Trochiscanthes nodiflora
Valeriana tripteris
Veronica montana
Viola reichenbachiana

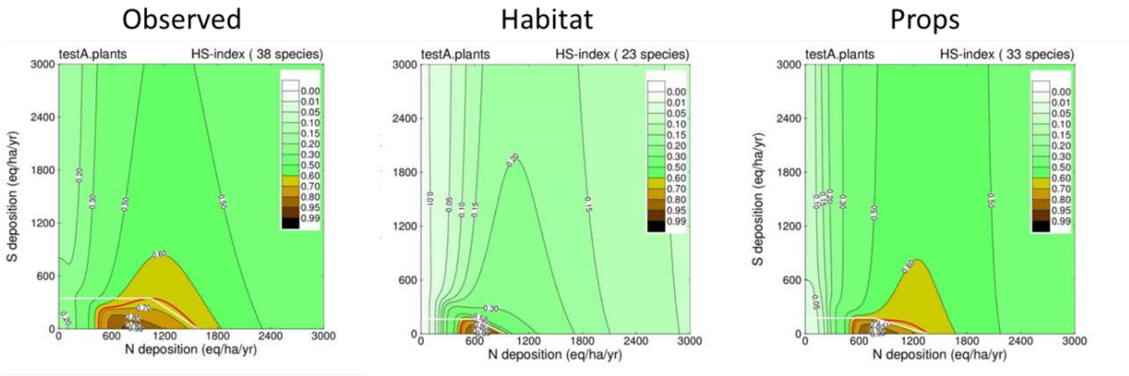

Figure IT-1. Site IT05.

Observed Sp.

Acer_pseudoplatanus	Hypericum_montanum
Alliaria_petiolata	Hypnum_cupressiforme
Aremonia_agrimonoides	Juglans_regia
Brachypodium_pinnatum	Lathyrus_niger
Calluna_vulgaris	Lilium_bulbiferum
Carex_flacca	Lonicera_caprifolium
Carpinus_betulus	Luzula_forsteri
Castanea_sativa	Mespilus_germanica
Corylus_avellana	Molinia_caerulea
Cruciata_laevipes	Platanthera_bifolia
Dicranella_heteromalla	Polygonatum_odoratum
Erica_arborea	Prunus_avium
Festuca_heterophylla	Pteridium_aquilinum
Fraxinus_excelsior	Quercus_cerris
Fraxinus_ornus	Quercus_petraea
Genista_germanica	Rubus_caesius
Genista_tinctoria	Sorbus_domestica
Hedera_helix	Sorbus_torminalis
Hieracium_racemosum	Vinca_minor
Holcus_lanatus	

HABITAT type 91L0
Illyrian oak-hornbeam forest
(Erythronio-Carpinion)

Anemone nemorosa
Anemone ranunculoides
Anemone trifolia
Arisarum proboscideum
Asarum europaeum
Carex alba
Carex digitata
Carex umbrosa
Carpinus betulus
Crataegus laevigata
Erythronium dens-canis
Euonymus verrucosus
Euphorbia carniolica
Gagea lutea
Galanthus nivalis
Isopyrum thalictroides
Lamiastrum galeobdolon
Ornithogalum pyrenaicum
Quercus petraea
Quercus robur

Eunis G1.7
Props G44

Acer_campestre
Arum_italicum
Buphthalmum_salicifolium
Campanula_medium
Cercis_siliquastrum
Cornus_mas
Cornus_sanguinea
Crataegus_monogyna
Cyclamen_repandum
Fraxinus_ornus
Hedera_helix
Helleborus_foetidus
Knautia_drymeia
Ligustrum_vulgare
Melittis_melissophyllum
Ostrya_carpinifolia
Peucedanum_cervaria
Quercus_pubescens
Rosa_sempervirens
Sorbus_domestica
Sorbus_torminalis
Teucrium_chamaedrys
Viburnum_lantana

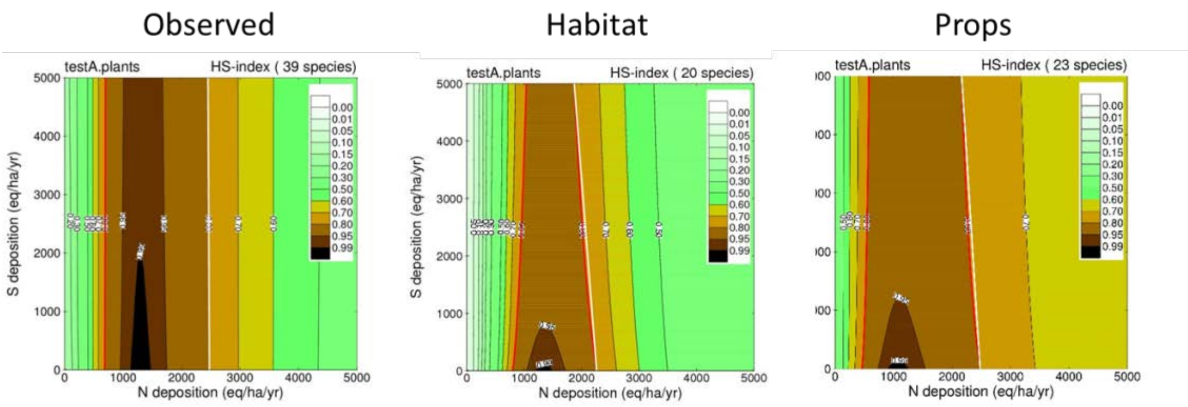

Figure IT-2. Site IT07.

HABITAT type 9110
Luzulo-Fagetum beech forests

Abies alba
Calamagrostis villosa
Castanea sativa
Deschampsia flexuosa
Dryopteris carthusiana
Dryopteris dilatata
Fagus sylvatica
Luzula luzuloides
Luzula nivea
Luzula pedemontana
Picea abies
Quercus cerris
Teucrium scorodonia
Vaccinium myrtillus
Veronica urticifolia

Eunis G1.6
Props F142

Abies_alba	Festuca_drymeja
Acer_obtusatum	Fissidens_dubius
Acer_platanoides	Galium_aristatum
Acer_pseudoplatanus	Hacquetia_epipactis
Anemone_trifolia	Hedera_helix
Aposeris_foetida	Helleborus_niger
Aremonia_agrimonoides	Hepatica_nobilis
Aruncus_dioicus	Homogyne_sylvestris
Calamagrostis_varia	Lamium_orvala
Calamintha_grandiflora	Lathyrus_vernus
Cardamine_bulbifera	Lonicera_alpigena
Cardamine_enneaphyllos	Lonicera_xylosteum
Cardamine_pentaphyllos	Mercurialis_perennis
Cardamine_trifolia	Neottia_nidus-avis
Carex_alba	Omphalodes_verna
Cephalanthera_damasonium	Oxalis_acetosella
Cephalanthera_longifolia	Plagiochila_porelloides
Clematis_alpina	Plagiomnium_undulatum
Clematis_vitalba	Polygonatum_verticillatum
Corylus_avellana	Polystichum_aculeatum
Ctenidium_molluscum	Prenanthes_purpurea
Cyclamen_purpurascens	Rosa_pendulina
Daphne_laureola	Rubus_hirtus
Daphne_mezereum	Salvia_glutinosa
Epimedium_alpinum	Sanicula_europaea
Euphorbia_amygdaloides	Ulmus_glabra
Euphorbia_carniolica	Veronica_urticifolia
Fagus_sylvatica	

Habitat Props

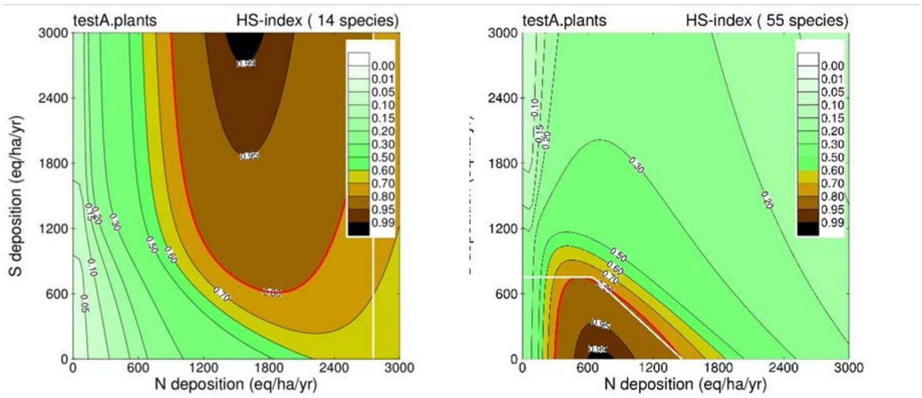

Figure IT-3. Site IT08.

Observed sp.

Acer_campestre	Lonicera_caprifolium
Agrimonia_eupatoria	Luzula_campestris
Agrostis_capillaris	Luzula_forsteri
Ajuga_reptans	Luzula_sylvatica
Anemone_nemorosa	Malus_sylvestris
Anthericum_liliago	Melica_uniflora
Anthoxanthum_odoratum	Mespilus_germanica
Brachypodium_sylvaticum	Mycelis_muralis
Buglossoides_purpurocaerulea	Neottia_nidus-avis
Carex_flacca	Oenanthe_pimpinelloides
Carpinus_betulus	Pinus_pinaster
Cephalanthera_longifolia	Pinus_strobus
Clematis_vitalba	Platanthera_chlorantha
Clinopodium_vulgare	Polytrichum_commune
Cornus_mas	Potentilla_micrantha
Crataegus_laevigata	Primula_vulgaris
Crataegus_monogyna	Prunus_spinosa
Crocus_vernus	Pyrus_pyraster
Cruciata_glabra	Quercus_cerris
Cytisus_scoparius	Quercus_ilex
Dactylis_glomerata	Quercus_petraea
Dicranum_scoparium	Quercus_pubescens
Digitalis_lutea	Ranunculus_lanuginosus
Erica_arborea	Rhinanthus_minor
Euphorbia_dulcis	Rosa_arvensis
Eurhynchium_praelongum	Rubus_hirtus
Festuca_heterophylla	Rubus_ulmifolius
Fragaria_vesca	Ruscus_aculeatus
Fraxinus_ornus	Solidago_virgaurea
Genista_germanica	Sorbus_domestica
Hedera_helix	Sorbus_torminalis
Hieracium_racemosum	Stachys_officinalis
Holcus_mollis	Symphytum_tuberosum
Hypericum_perforatum	Tamus_communis
Hypnum_cupressiforme	Teucrium_scorodonia
Isothecium_alopecuroides	Torilis_arvensis
Juniperus_communis	Viola_alba
Lathyrus_montanus	Viola_reichenbachiana

HABITAT type 91AA
Eastern white oak woods

Anthericum ramosum
Asparagus acutifolius
Carpinus betulus
Carpinus orientalis
Cornus sanguinea
Coronilla emerus
Crataegus monogyna
Dictamnus albus
Epipactis helleborinae
Fraxinus ornus
Geranium sanguineum
Hedera helix
Ligustrum vulgare
Ostrya carpinifolia
Quercus virgiliana
Quercus pubescens
Rosa sempervirens
Rubia peregrina
Smilax aspera
Viola alba subsp. Dehnhardtii

Eunis G1.7
Props G52

Acer_campestre
Acer_monspessulanum
Acer_obtusatum
Buxus_sempervirens
Campanula_trachelium
Clematis_vitalba
Cornus_mas
Crataegus_monogyna
Daphne_laureola
Euphorbia_amygdaloides
Euphorbia_dulcis
Fraxinus_ornus
Helleborus_foetidus
Hepatica_nobilis
Knautia_drymeia
Laburnum_anagyroides
Lathyrus_venetus
Ligustrum_vulgare
Lonicera_etrusca
Melica_uniflora
Melittis_melissophyllum
Ostrya_carpinifolia
Prunus_mahaleb
Quercus_cerris
Quercus_pubescens
Scutellaria_columnae
Viola_reichenbachiana

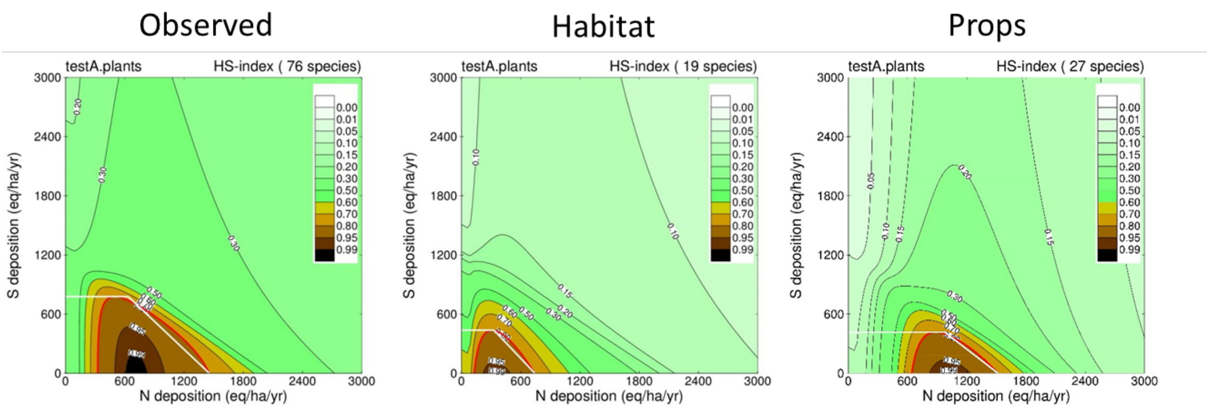

Figure IT-4. Site IT09.

Observed sp.

Abies_alba	Homogyne_alpina
Acer_pseudoplatanus	Laburnum_alpinum
Ajuga_reptans	Lonicera_nigra
Anemone_nemorosa	Luzula_luzulina
Asplenium_trichomanes	Luzula_nivea
Athyrium_filix-femina	Luzula_pilosa
Betula_pendula	Maianthemum_bifolium
Carex_caryophyllea	Melampyrum_sylvaticum
Carex_digitata	Milium_effusum
Carex_pallescens	Oxalis_acetosella
Corylus_avellana	Phegopteris_connectilis
Dactylorhiza_majalis	Picea_abies
Dryopteris_affinis	Polypodium_vulgare
Dryopteris_dilatata	Potentilla_erecta
Dryopteris_filix-mas	Prenanthes_purpurea
Epipactis_helleborine	Pulsatilla_montana
Euphorbia_dulcis	Ranunculus_montanus
Fagus_sylvatica	Rubus_idaeus
Festuca_altissima	Saxifraga_cuneifolia
Festuca_heterophylla	Solidago_virgaurea
Fragaria_vesca	Sorbus_aria
Fraxinus_excelsior	Sorbus_aucuparia
Geranium_phaeum	Viola_biflora
Gymnocarpium_dryopteris	Viola_reichenbachiana

HABITAT type 9110
Luzulo-Fagetum beech forests

Abies alba
Athyrium filix-femina
Calamagrostis arundinacea
Deschampsia flexuosa
Dryopteris carthusiana
Dryopteris dilatata
Fagus sylvatica
Lathyrus niger
Luzula luzuloides
Luzula nivea
Picea abies
Polytrichum formosum
Quercus petraea
Vaccinium myrtillus

Eunis G4.6
Props F115

Abies alba
Acer pseudoplatanus
Aposeris foetida
Athyrium filix femina
Atrichum undulatum
Brachypodium sylvaticum
Cardamine bulbifera
Cardamine enneaphyllos
Cardamine trifolia
Carex sylvatica
Carpinus betulus
Corylus avellana
Crataegus monogyna
Daphne mezereum
Dryopteris filix mas
Fagus sylvatica
Festuca gigantea
Fraxinus excelsior
Galium odoratum
Lonicera xylosteum
Mercurialis perennis
Milium effusum
Oxalis acetosella
Prenanthes purpurea
Quercus petraea
Quercus robur
Quercus x rosacea
Symphytum tuberosum
Tilia cordata
Tilia platyphyllos
Ulmus glabra
Viburnum lantana

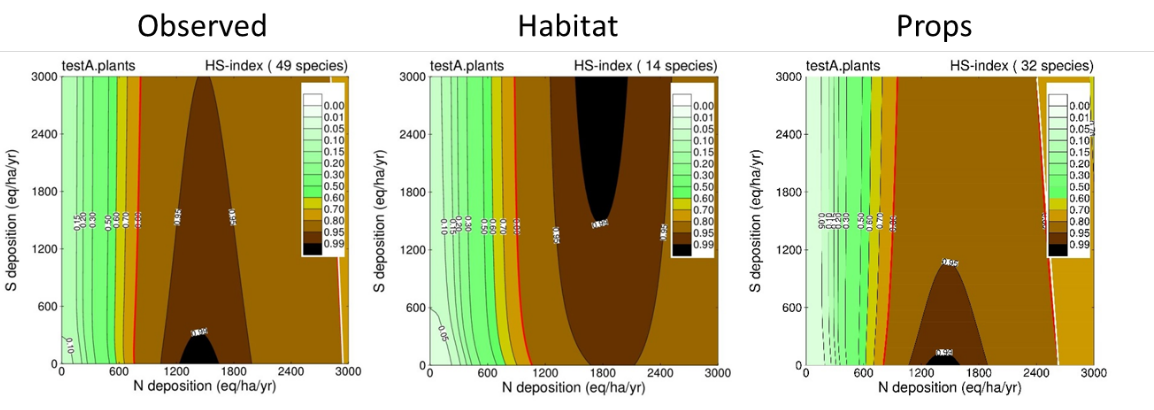

Figure IT-5. Site IT10.

By comparing CLN_{max} derived from observed species and PROPS ones (see Table IT-4), similar results were observed. Observed vegetation was similar to expected. On the other hand, the CLN_{max} derived from the Habitat Directive plant species list, showed lower level probably because of the reduces number of the species included. If we compare the CLN_{max} determined from the three kind of list used in this work, with the $CL_{nut}N$ derived from SMB (Simple Mass Balance) model, it turns out that in all five analysed sites the CLN_{max} is much higher, or ecosystems express a much lower sensitivity, than that calculated with SMB (Table IT-4). Further comparison between CLN_{max} derived by observation and PROPS vegetation lists is showed in Figure IT-6.

Table IT-4. Deposition from scenario CLE 2010 and 2030 (kg/ha/yr) compared with CLN_{max} (kg/ha/yr) calculate using three different kind of vegetation.

SITE_ID	N_{dep} CLE 2010	N_{dep} CLE 2030	CL_{nut}	CLN_{max} Props	CLN_{max} Habitat	CLN_{max} Observed
IT05	321,87	244,986	1300,361	1363,19	937,15	1580,61
IT07	807,15	691,59	691,442	2480,31	2260,59	2476,48
IT08	374,16	284,407	792,918	1464,84	2758,28	-
IT09	286,71	230,811	867,723	1515,95	742,85	1455,82
IT10	501,92	416,526	745,624	2629,32	3000	2942,67

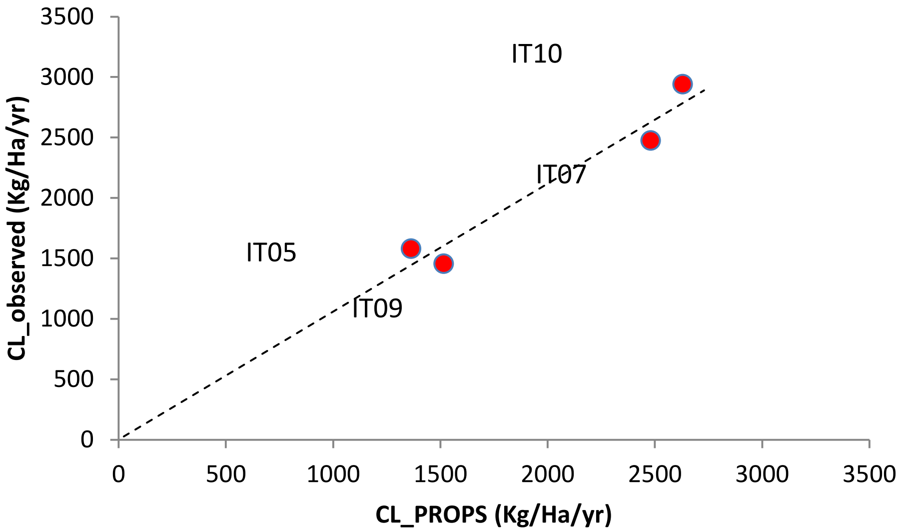

Figure IT-6. Critical loads based on observed plant lists living in the test sites are closely similar to Critical loads predicted by PROPS that, pointing thus a high naturality of these sites being also able to tolerate actual N deposition.

Conclusions

The five sites under consideration are located in low N deposition zones (Figure IT-7). CLN_{max} calculated using observed species or Props derived species is always higher than CL_{nut}N and N deposition even looking to scenario CLE 2030. This condition highlights that N depositions are not a threat for forest sites in Italy now and in the near future.

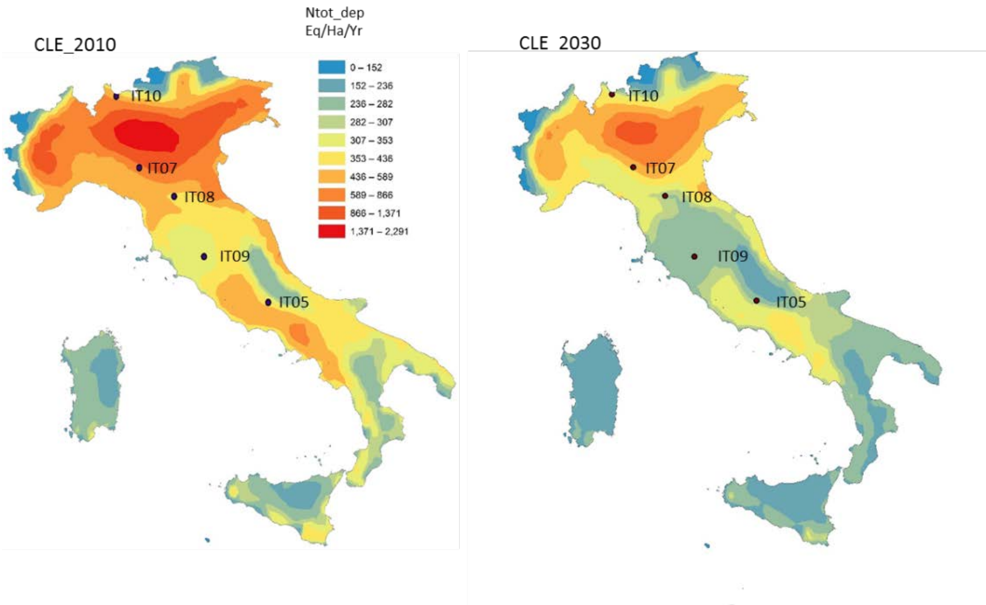

Figure IT-7. The five sites for which biodiversity critical loads have been derived.

Acknowledgment
Thanks to Laura Casella and Pierangela Angelini for their contribution in suggesting typical species for each Habitat type used in this work.

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Introduction

Nitrogen deposition in the Netherland is recognized for being a large threat to protected habitats and species. Various policy measures are taken to reduce this threat. On the one hand, there is the international policy to reduce emissions on an international level, as stated in the LRTAP Convention. On the other hand, there is a Dutch Integrated Approach to Nitrogen (PAS; Ministry of Economic Affairs & Ministry of Infrastructure and the Environment, 2015) which was set-up to reduce emissions on national, sub-regional and local levels, and take restoration measures in sensitive Natura 2000 areas.

Both type of policies make use of information on critical loads for nitrogen (Van Dobben et al., 2006; Van Dobben et al., 2014). In the Call for Data 2015□2017, CCE asked for data and updates on critical loads of acidification (SMB model), eutrophication (CLnutN from SMB or CLempN), and critical loads of Nitrogen and Sulphur, for protecting plant species diversity. This report describes the methods used to generate this information about the Dutch ecosystems.

General methodology

In the Netherlands, there is a long history of using dynamic soil-vegetation models in environmental assessments (Kros et al., 1998). The backbone of this modelling has long been the SMART2-MOVE model. Within this modelling framework, the SMART2 model has been used to simulate abiotic soil conditions under certain deposition scenarios, while MOVE was used to assess how changes in soil conditions could influence plant species occurrences. These same models have been used to derive critical loads for Dutch plant associations (Van Dobben et al., 2006), nature targets types (Van Hinsberg and Kros, 2001) and the habitat types included in the European Habitats Directive (Van Dobben et al., 2014). For recent calls for data, PROPS-NL has been used instead of MOVE and VSD+ (Bonten et al., 2009) instead of SMART2 (see CCE, 2011; CCE, 2014; CCE, 2015).

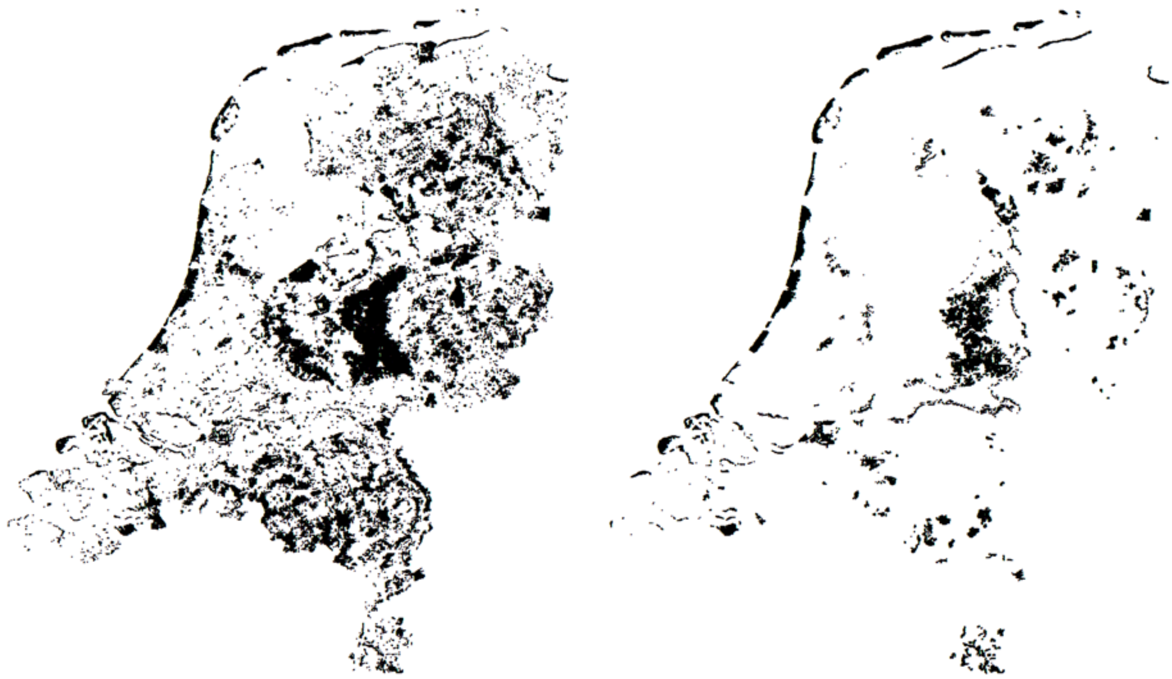

Figure NL-1. 250x250m grids in the Critical Load database with terrestrial Dutch nature target types in the National Ecological Network (left) and terrestrial habitat types in the Natura 2000 areas (right).

Mapping critical loads for nature policy targets

In the Dutch critical load database, critical loads were calculated for both Natura 2000 areas and other terrestrial natural areas in the National Ecological Network (NEN; Figure NL-1, left). In earlier studies, the critical loads in both areas were based on maps of the Dutch nature target types. Now, within the Natura 2000 areas, CLbio and CLnutN were mapped for protected habitat types (Figure NL-1, right). This map of habitat types was provided by the Ministry of Economic Affairs.

In order to derive a consistent set of input parameters for VSD+, information on habitat type (i.e. species list and suitable pH and nitrogen availability) had to be linked with information on corresponding soil types and vegetation types. Within each 250x250-metre grid, we determined the dominant habitat type and the most likely type of vegetation that would occur in that habitat (i.e. deciduous forest, dark coniferous forest, light coniferous forest, heathland and grassland). The same was done for the seven soil types for which VSD+ has been parametrized. This linkage was not only based on vegetation and soil types present within the grids, but also on information about the type of vegetation and soil that could occur within a particular habitat type (http://www.synbiosys.alterra.nl/natura2000).

Information on parametrization of vegetation and soil types in VSD+ was similar to earlier calls for data, except for the amount of litterfall and the N content in litterfall. In previous calculations of critical loads, these inputs were assigned to combinations of nature target types and soil types. In the calculations for habitat types, we now derived this information based on plant associations, following the same procedure as reported in the CCE report of 2014. We calculated the values per plant association by taking the average value of all nature target types in which that associations could occur. Then we calculated the average of all plant associations within a habitat type. The calculated amounts and contents of litterfall was checked with information from the SUMO model (Wamelink et al., 2009) and adjusted where needed. Any N content below 1% was set to 1%.

Ranges of suitable pH and nitrogen availability were derived for each nature target and habitat type. This was done by calculating conditions suitable for 80% of the desired species that could occur under optimal abiotic conditions (f = 0.8). The desired species were obtained from the lists of typical species of habitat types and target species for Dutch nature targets (Bal et al., 2001). These species can be considered as the species that are present when biological quality of habitats and targets is high (see CCE, 2015). Invasive or undesired species (i.e. the species that are more abundant in less-developed forms of the given plant associations) were not included, because modelling these species produced unrealistic results (Kros et al., 2016).

Critical load function

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

$$CL(N) = N_{avail,crit} - N_{upt} - N_{lf} - N_{fix} - N_{seep} \qquad \text{(NL-1)}$$

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

Since we used nitrogen availability as the criterion to compute N critical loads related to both eutrophication and biodiversity, both CLeutN and CLNmax were computed with eq. NL-1. However, for each 250x250m grid, we compared the calculated CLeutN with the empirical critical range (see CCE, 2011). When CLeutN was within this range, the calculated value was used, otherwise we took the empirical value given by Van Dobben et al. (2012). For CLNmax we always used the value computed with eq. NL-1. For the acidification critical loads, a critical pH was used as the criterion which means that CLmaxN is based on pH and thus differs from CLNmax which is based on N availability. Critical loads for sulphur are always based on a critical pH, so CLSmax and CLmaxS are identical.

From the calculated CLNmax we calculated CLSmin by finding the Sdep at CLNmax (see also Figure NL-2) according to:

CLSmin = CLSmax(pH) - (CLNmax-CLNmin)*slope (NL-2)

In which the 'slope' was calculated as:

$$slope = f_{ni}*(2-f_{de})-1 \qquad \text{(NL-3)}$$

where f_{ni} is the nitrification fraction and f_{de} is the denitrification fraction.

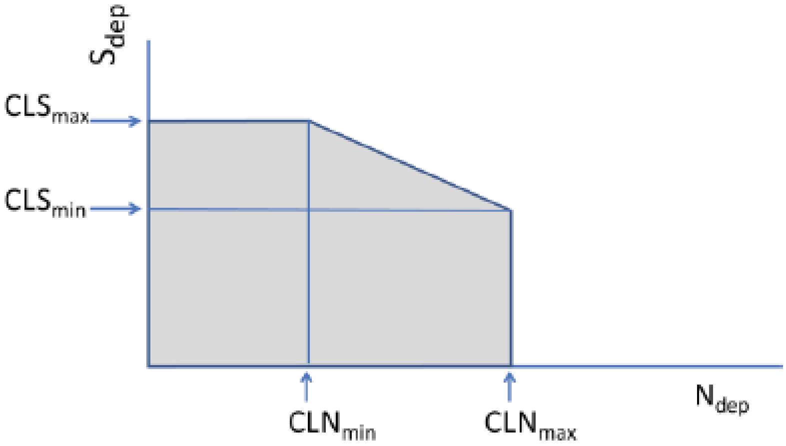

Figure NL-2.The biodiversity critical load function.

Results and discussion

Cumulative frequencies (Figure NL-3) show that CLeutN has a smaller range than CLNmax, which is caused by forcing the values of CLeutN to be within the empirical range. Tables NL-1 to NL-3 summarise the results per vegetation type. Table NL-1 depicts the results for all grid cells, whereas Table NL-2 shows the results for the cells within Natura 2000 areas with habitat types, and Table NL-3 shows the results for the cells outside Natura 2000 with nature target types. Results show that the largest differences between CLeutN and CLNmax can be found in locations with deciduous forests. High CL(N) values are calculated in these forests with relatively low N input from litterfall. This often causes critical loads that exceed the empirical ranges. For CLeutN, these high values were corrected so that they meet the empirical ranges (see Van Dobben et al. (2014) for habitat types or Bal et al. (2007) for nature target types) causing CLeutN to be lower than CLNmax.

We were not always able to calculate the full critical load functions (see Tables NL-1 to NL-3). Reasons for this vary between sites and types of parameters. For example, for various sites, CLNmin could not be calculated, because used N input by litterfall and/or seepage already exceeded the desired N availability leaving no room for any additional deposition of N. CLSmax could not be calculated when the critical pH cannot be obtained without acid deposition, and CLSmin cannot not be calculated in cases where CLSmax or CLNmax or CLminN were absent (cf eq. NL-2).

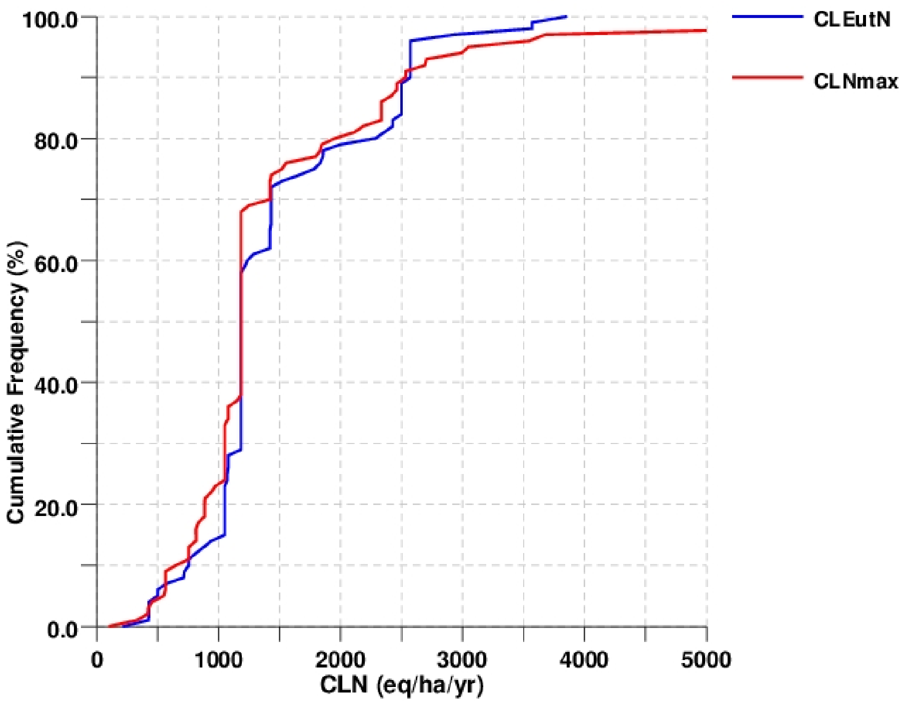

Figure NL-3. Cumulative frequency distributions of CLeutN and CLNmax, based on the N-availability criterion.

Discussion on choice for dominant habitat types

For the habitat type calculations, the original habitat type map was gridded to a map with 250 x 250 m^2 grid cells. For each grid cell, the dominant habitat type within a grid cell was assigned to that particular grid cell. By assigning a habitat type to a 250x250-m^2 cell, the habitat map increased in size from about 88000 ha to more than 141,000 ha. Moreover, the relative contribution of the various habitat types did not change because of this procedure, as the regression line between the relative contribution of each habitat type within the original map and the derived map was close to the y=x line (y=1.071x – 0.001; r^2=76%). However, the area of, for example, dry heath increased by 12%.

By focusing on the dominant habitat type, we could calculate critical load values that have the highest relevance for the grid cell. Moreover, the focus on dominant habitat improved the link with soil and vegetation maps. By focusing on the critical load for the dominant habitat type, significant negative effects of deposition levels equal to the critical load for the dominant habitat on other more sensitive habitats in the grid cell cannot be ruled out, which is not in accordance with the Habitat Directive. This problem can be resolved by calculating critical loads for the most sensitive habitat type in each 250x250 grid cell. However, such an approach would need more precise soil and vegetation data and more site-specific model parameterization. Given the shortcomings of our procedure, it is clear that the current maps on CLeutN should not be used on a local scale.

Discussion on calculated critical load values

Results show that calculated critical loads for nitrogen for habitat types are often outside the empirical critical load ranges for the EUNIS type to which the habitats belong. For example, calculated CLNmax for bogs, fens, open sand and various forest types are higher than the empirical critical loads. This is a shortcoming in the modelling, as the empirical critical loads often are based on information on species loss or vegetation changes which also should be the basis of the modelling. A similar problem was identified when using critical loads calculated with the SMART model (Dobben et al., 2014). As empirical values are broadly accepted, and the model results are considered as a further specification, Dobben et al. (2014) used modelled critical loads only when ranges overlapped. In that process, model output was critically screened in view of the shortcomings and uncertainties that exist when modelling certain habitat types. For the submitted CLeutN a similar check with CLempN was made. However, for the CLNmax, this check has not yet been performed as delivering this unchecked raw data enables a better comparison with data from other countries. In addition, shortcomings in VSD+ modelling or parametrization can easier be identified.

Results show that the model is very sensitive to N input by litter production (N_{lf}). In various cases, no possible CL(N) could be calculated, because input by litter was already higher than the maximum N availability (CLeutN < 0). In such cases, N_{lf} is probably overestimated. At the same time, for forests, litter production might be underestimated, since calculated critical loads are often higher than empirical critical loads. This might partly be due to not including the nutrient cycle of the ground vegetation. Another important source of uncertainty might be the ratio between above-ground and below-ground litter production.

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Table NL-1. CLNmin, CLSmax, CLeutN and CLNmax for all grid cells (mol/ha). The standard deviation is provided between brackets. Number of results per category is also given.

Vegetation		CLNmin		CLSmax		CLeutN		CLNmax	
	Count	Value (stdev)	Count	Value (stdev)	Count	Value (stdev)	Count	Value (stdev)	Count
Deciduous forest	24460	507 (124)	23229	6070 (20510)	19791	1749 (704)	24436	2313 (1749)	23997
Grassland	25935	471 (82)	24319	16594 (31387)	7419	1590 (875)	25907	1192 (1029)	22266
Heathland	12231	44 (3)	11284	1802 (7421)	12136	968 (218)	12160	923 (378)	11959
Pine forest	20975	265 (27)	20576	1746 (8410)	20912	1261 (381)	20973	1229 (295)	20894
Spruce forest	3557	385 (52)	3470	1960 (8134)	3489	1388 (602)	3557	1295 (394)	3536
TOTAL	87158	368 (179)	82878	4839 (17448)	63747	1460 (704)	87033	1493 (1228)	82652

Table NL-2. CLNmin, CLSmax,CLeutN and CLNmax for grids within Natura 2000 areas with habitat types (mol/ha). The standard deviation is provided between brackets. Number of results per category is also given.

Vegetation		CLNmin		CLSmax		CLeutN		CLNmax	
	Count	Value (stdev)	Count	Value (stdev)	Count	Value (stdev)	Count	Value (stdev)	Count
Deciduous forest	8643	524 (123)	8483	1866 (5876)	6613	1647 (434)	8643	2991 (1128)	8516
Grassland	4804	488 (52)	4679	10480 (19021)	427	1499 (460)	4804	2128 (1371)	3597
Heathland	9201	44 (3)	8550	1374 (4228)	9106	1014 (149)	9200	956 (393)	9076
Pine forest	147	206 (74)	127	4469 (7726)	132	1482 (489)	147	2489 (1949)	137
Spruce forest	2	387 (0)	2	251 (0)	2	1857 (0)	2	5953 (0)	2
TOTAL	22797	327 (242)	21841	1837 (6009)	16280	1359 (458)	22796	1977 (1333)	21328

Table NL-3. CLNmin, CLSmax, CLeutN and CLNmax for grids outside Natura 2000 areas with nature target types (mol/ha). The standard deviation is provided between brackets. Number of results per category is also given.

Vegetation		CLNmin		CLSmax		CLeutN		CLNmax	
	Count	Value (stdev)	Count	Value (stdev)	Count	Value (stdev)	Count	Value (stdev)	Count
Deciduous forest	15817	497 (124)	14746	8180 (24518)	13178	1805 (809)	15793	1940 (1910)	15481
Grassland	21131	466 (88)	19640	16973 (31954)	6990	1611 (943)	21103	1012 (836)	18669
Heathland	3030	44 (3)	2734	3087 (12834)	3030	825 (315)	2960	819 (307)	2883
Pine forest	20828	266 (26)	20449	1728 (8411)	20780	1259 (380)	20826	1221 (228)	20757
Spruce forest	3555	385 (52)	3468	1961 (8136)	3487	1388 (602)	3555	1293 (378)	3534
TOTAL	64361	383 (147)	61037	5868 (19808)	47465	1496 (769)	64237	1324 (1143)	61324

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Methods and data

Norway has updated the empirical critical loads for nutrient nitrogen, based on a new vegetation map. No changes have been made to the critical loads of acidity for surface waters. The MAGIC modelling of the 990 lakes form the national lake survey has been recalibrated. Critical loads for biodiversity have been estimated for four sites.

Critical loads for surface waters

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

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

Nitrogen removal in harvested biomass was estimated by Frogner et al. (1994) and mapped for the entire Norway according to forest cover and productivity. Nitrogen immobilisation was kept constant at 0.5 kg N yr^{-1} (CLRTAP, 2015). The de-nitrification factor (f_{de}) was kept constant at 0.1 and the fraction of peat in the catchments ignored in the national scale applications. Mass transfer coefficients were kept constant at 5 m yr^{-1} and 0.5 m yr^{-1} for N and S, respectively, and chosen as the mid-value of the ranges proposed by Dillon and Molot (1990) and Baker and Brezonik (1988), respectively. Mean annual runoff data were taken from runoff maps prepared by the Norwegian Water Resources and Energy Directorate (NVE). The lake to catchment area was set constant to 5%.

Dynamic modelling of surface water acidification

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

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

Atmospheric deposition data were provided by the CCE. In 2008 data were supplied on the 50×50km^2 EMEP grid, whereas in 2016 they were on the 0.25°×0.5° latitude-longitude grid. In addition to the changed grid, the whole deposition sequence was changed, taking into account both changes to the 1990-2010 deposition and effects of the revised Gothenburg Protocol on future deposition. In 2008 14 scenarios of future deposition were compared, while in 2016 only one scenario was applied. The 990 lakes were assigned the deposition of the grid cell in which they were located. The model was calibrated to the year 1995 and run for the time-period 1880-2100 (the deposition was set constant after 2030).

The calibrated lakes were used to assign MAGIC output to all grid cells in the Norwegian 0.25°×0.125° longitude-latitude critical loads grid (2304 cells) using a matching routine called “MAGIC library” (IVL, 2016). The 2304 grid cells were matched to the 990 lakes according to a Eucledian distance routine based on water chemistry and location. Each of the 2304 grid cells was thus assigned a MAGIC modelled lake. Past and future ANC is shown in Figure NO-1.

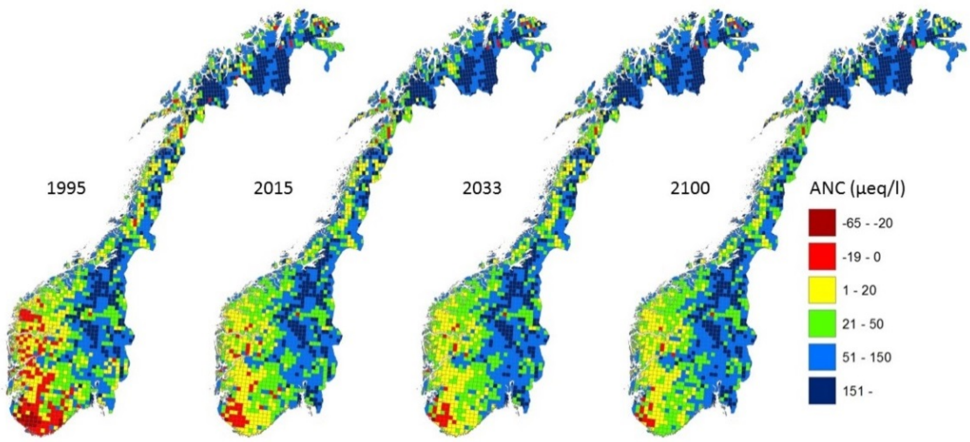

Figure NO-1. Modelled ANC per grid cell for 1995-2100.

Empirical critical loads for nutrient nitrogen

The empirical critical loads for nutrient nitrogen were last updated following the “Workshop on the review and revision of empirical critical loads and dose-response relationships” (Bobbink and Hettelingh, 2011) in 2011 (see CCE Status Report 2011 (Posch et al., 2011)). For the 2014/15 call empirical critical loads were provided in the new 0.10°×0.05° longitude-latitude grid. Moreover, critical loads were reported per ‘ecord’, defined as an area within a grid cell with homogenous vegetation.

In 2017 the vegetation map used as basis for assigning empirical critical loads was replaced. Previously the satellite based map produced by the *Stockholm Environment Institute*, SEI, in cooperation with the CCE, was used. The new map, produced by the *Northern Research Institute* (Norut) (Johansen, 2009), is also satellite based, but it is more detailed and better reflects Norwegian vegetation. The vegetation types used in the original map were translated into the relevant EUNIS classes. Some of the vegetation types in the original map were grouped. The EUNIS classes were assigned the same critical loads as used before, or if a specific EUNIS class was not used in the previous map, critical loads were set in accordance with Bobbink and Hettelingh (2011). The resulting critical loads map (Figure NO-2) was overlaid by the 0.10°×0.05° longitude-latitude grid. Given the high detail of the map, the 'ecords' were defined as the total area of a specific EUNIS class within a grid cell, with coordinates given as the mid-point of the grid cell.

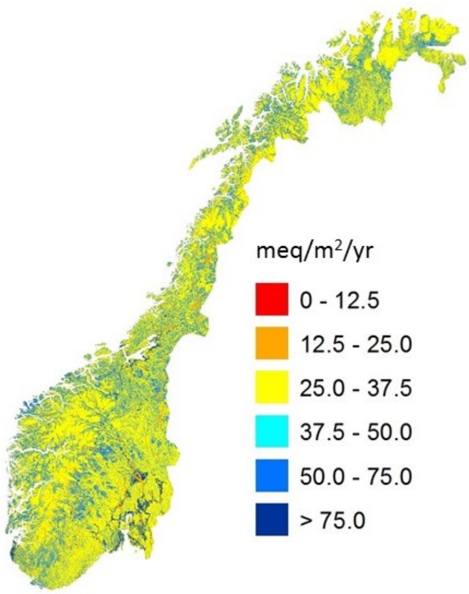

Figure NO-2. Map of empirical critical loads for nutrient nitrogen (dark blue areas agricultural/urban land, not submitted).

Critical loads for biodiversity

In 2016 critical loads for biodiversity were estimated for four sites, using the PROPS-CLF tool provided by the CCE (Posch, 2016). The tool is based on the PROPS and SMB models (see Chapter 3 in the CCE Status Report 2015 (Slootweg et al., 2015)). The selected sites were nutrient poor birch forest sites (empirical critical load for nitrogen 357 eq/ha/yr) with vegetation monitoring since the early 1990s (Framstad, 2014), differing with respect to climate and nitrogen deposition. Species selection was made by expert judgement, selecting characteristic species for the different sites. Climate and soil data were available from the monitoring programme. Other input parameters were taken from MAGIC model applications for nearby lakes (Austnes et al., 2016), from the Mapping Manual (CLRTAP, 2015), and from default values for CLF-PROPS (Posch, 2016). A 2D model approach was applied (setting temperature, precipitation, and soil C/N constant), and the habitat suitability index (HSI) threshold was set to 0.8. This was a first attempt to estimate critical loads for biodiversity in Norway using this type of approach, and the main purpose was to investigate whether it produced reasonable results. A more detailed note is available from the NFC.

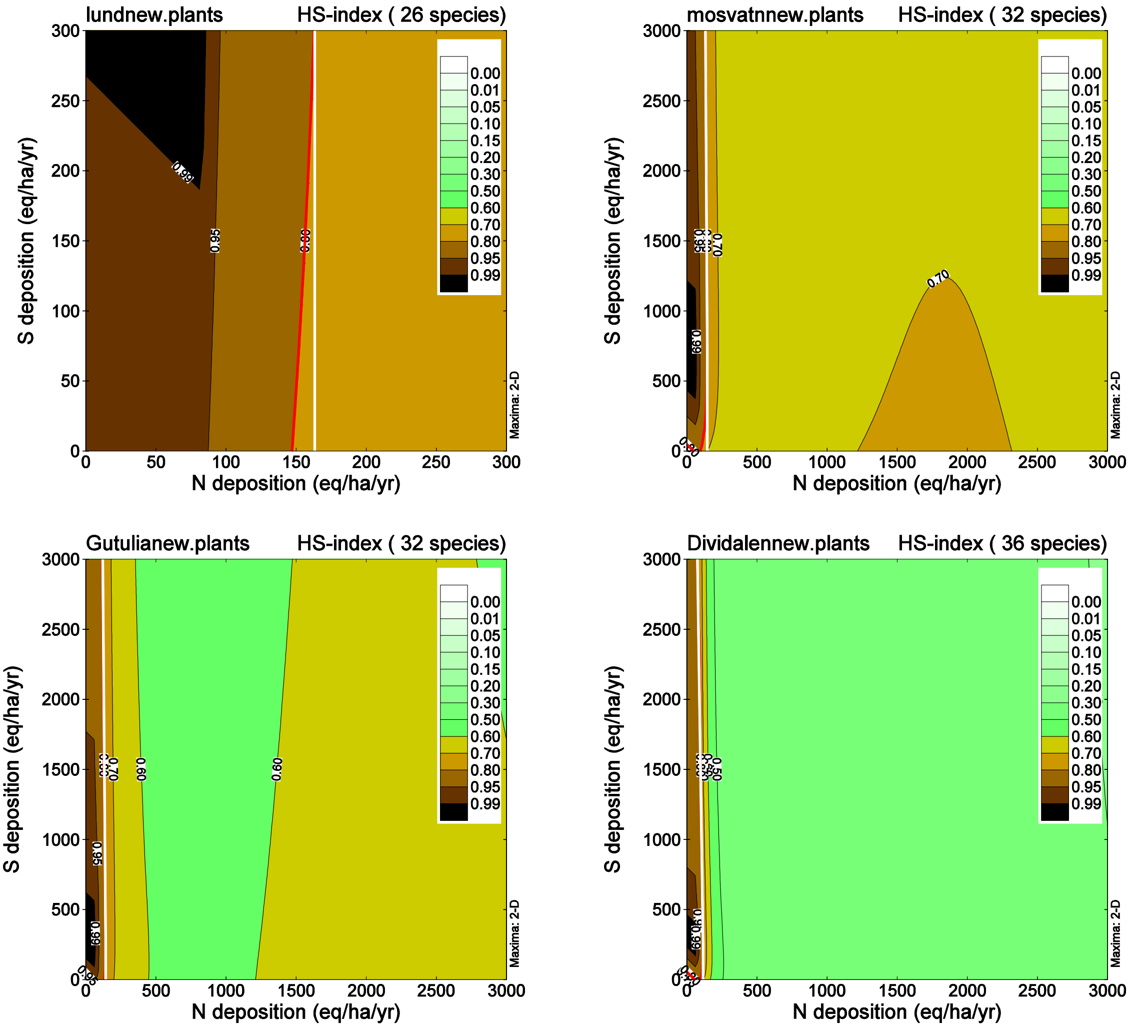

Figure NO-3. Critical loads plots for the four different sites. Upper left: Lund. Upper right: Møsvatn. Lower left: Gutulia. Lower right: Dividalen. Note: The Lund plot was double peaked, making it necessary to reduce the range of the axes to be able to calculate the CLNmax.

The critical loads plots (Figure NO-3) show that the calculated CLSmax was very high for all sites. This indicates that the model or the concept does not represent sensitivity to acidification very well. However, the critical load for acidification, based on response in surface waters, is probably sufficiently low to protect also the ground vegetation from acidification effects. The calculated CLNmax values were generally lower than the empirical critical load (32-46% of the empirical critical load). This meant that two of the sites (Møsvatn and Gutulia), where critical loads for nitrogen are currently not exceeded if using the empirical critical loads, become exceeded if using the critical loads for biodiversity. Especially for Gutulia, but partly also Møsvatn, exceedance of critical loads is not in line with what is observed in the field. In general, the experts find the current empirical critical load level suitable for these kind of systems.

The chosen HSI threshold of 0.8 seemed reasonable: For three of the sites the horizontal distance between the isolines above 0.7 was relatively small, so changing the threshold either way would not affect the CLNmax to a large degree. For the Lund site setting the threshold to 0.7 would give an unreasonably high CLNmax. The CLSmax would be high irrespective of where the threshold was set.

The method was evaluated in various ways. Observed probability of single species was compared with PROPS probability at two of the sites (Lund and Møsvatn). This gave somewhat contradictory results, where there were several species with large discrepancy between observed and estimated probability at Lund, while the deviation was small for most species at Møsvatn, with two notable exceptions. Development over time was reasonably well modelled, in that the direction of change was the same as for the observations at both sites. However, for the Lund site there was some discrepancy with respect to the size of the changes.

For the Lund site critical load plots for single species were made using the same model input as for the whole species set, but using only one species at a time. The plots were evaluated with respect to the general knowledge of sensitivities of these species. E.g. *Barbilophozia lycopodioide*s like many liverworts are expected to be sensitive to N deposition, which was reflected in a low CLNmax. However, the closely related *Barbilophozia barbata* had a very high HSI optimum along the x-axis giving a CLNmax outside the range of the axis. *Anemone nemorosa* is regarded as having an intermediate nutrient demand, and a somewhat higher CLNmax was predicted for this species. On the other hand, it is suggested that *Vaccinium myrtillus* in birch forests in Norway is sensitive to high N deposition, but the plot for this species indicated very high N tolerance. The only species showing any sensitivity to S deposition were two *Cladonia* species.

Together these results indicate uncertainty in the use of the PROPS model in these kind of systems. This may be due to the far lower amount of data from Fennoscandia in the PROPS database. Even though the species can be found in the database, the responses to the explanatory variables may not be representative for our systems if they are mainly based on data from other climate zones and/or habitats.

The sensitivity to the choice of species was also investigated. It showed that CLNmax was clearly affected by the species selection, but minor adjustments did not have dramatic effects. Ideally the selected species should be distinctive, i.e. particular to that type of habitat. However, when biodiversity is generally low, as in the boreal/alpine region, distinctive species are harder to find. And certain species may be regarded as essential in a certain habitat, even if they can be found elsewhere as well. One would also seek to select desired or positive indicator species, but there is a question how these should be defined and to which extent the prior knowledge on N sensitivity should be part of the reasoning. If the HSI is to describe the overall biodiversity value, one should select the species one wants to see present and exclude species that one does not want to see increasing in cover. On the other hand, if the HSI is to be regarded solely as an N indicator, one would want to choose N sensitive species only. In practice the two concepts often coincide, as the positive indicator species are frequently N sensitive while the negative indicators are often nitrophilous. However, in this application the plots of individual species showed that species that, according to the model, were N tolerant or nitrophilous species were included even when focusing on positive indicator species in the selection. One could have chosen to adjust the selection by excluding some of these species, but this would be circular arguing. When using expert judgement to select the species this should be done independently from the modelling. Moreover, if these species are truly desired and one wants the HSI to be a general biodiversity metric, they should probably be included.

The ultimate question is whether the critical loads for biodiversity better protects Norwegian ground vegetation habitats from harmful effects than the empirical nutrient nitrogen critical loads. Both types of critical loads aim to protect the biodiversity. In this application the CLNmax was lower than the empirical critical loads, so giving better protection. The empirical critical loads as they are currently applied have the disadvantage that they are the same for a certain habitat, irrespective of climate and soil conditions. They are also based on a limited number of studies. Moreover, they do not take into account the accumulated effect of previous N deposition, which is to some degree covered by the critical loads for biodiversity, as the soil C/N for the site is taken into account. However, as has been shown there are several uncertainties related to the critical loads for biodiversity applied at the Norwegian sites. A major concern is whether species responses in our systems are sufficiently well represented in the PROPS database. There are also uncertainties and conceptual issues related to species selection and the HSI threshold. Also, the method requires more data, which are not always available or they are uncertain. Any improvement provided by the method could thus be counteracted by these uncertainties. There are also reasons to believe that the CLNmax values calculated here are too low.

Norway has not submitted the results from this exercise. However, further investigation of the methodology is considered. A next step could be to calculate biodiversity critical loads for other vegetation types. Another way forward could be to work towards a Fennoscandian version of the PROPS model.

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Introduction

In response to the CCE "Call for Data 2015-17", the Polish NFC has submitted an updated critical loads data (CL_{acid}, CL_{eut}) to be used by CIAM as environmental receptors for integrated assessment modelling with GAINS-Europe.

Calculation grid and ecosystems database

The CLs calculation grid for Polish ecosystems was prepared according to new CCE grid, based on 0.10° x 0.05° longitude-latitude spatial reference. The spatial resolution for Polish ecosystems was set at 0.02° x 0.01° resulting in grid dimensions from (lon x lat) 1.1 x 1.3 km^2 in Northern Poland to 1.1 x 1.6 km^2 in Southern Poland.
Terrestrial ecosystem database, was based on CLC2012 (GIOS, 2016) and linked with spatial database of wetland and non-forest ecosystems (IMUZ, 2012) with EUNIS codes derived from Corine LC codes. Thus ecosystems D, E and F were extended to 2nd level of EUNIS

classification. The SPAs and SACs from Natura 2000 database for Poland were used (EEA, 2016) to obtain area conservation status and indicate areas of special concern due to atmospheric deposition.
The final database covered 96 858.3 km^2 of ecosystems area, with one or more habitats in each grid cell and contains 239,066 records (for "EcoArea" larger than 0.5 ha). Forest habitats cover 98.5% of total calculation area.

Table PL-1. Ecosystem database for Poland.

EUNIS code	EUNIS habitat name	Ecosystem Area			CL database records > 0.5 ha
		Total	Covered by Natura 2000		
		[km^2]	[km^2]	% of Total	
D1	Raised and blanket bogs	47.13	39.68	84	381
D2	Valley mires, poor fens and transition mires	105.56	59.09	56	818
D4	Base-rich fens	1 040.73	765.52	74	3782
E2	Mesic grasslands	245.72	211.35	86	617
E4	Alpine and subalpine grasslands	78.66	76.37	97	319
F2	Arctic, alpine and subalpine scrub	36.39	36.39	100	105
F4	Temperate shrub heathland	4.76	4.50	95	18
G1	Broad-leaved forests	14 866.91	7 760.21	52	51 853
G3	Coniferous forests	56 049.04	38 485.43	69	106 570
G4	Mixed forests	24 383.35	11 419.74	47	74 603
	TOTAL	**96 858.26**	**58 858.28**	**61**	**239 066**

Critical Loads of Acidity

Critical loads of acidity calculations were based on the SMB model as described in the Mapping Manual (UBA, 2004).
The spatial distribution of soils and their properties were obtained from European Soils Database (ESDB, 2016), with additional data taken from Polish ICP Forest II-level monitoring system (Wawrzoniak et al., 2005; IBL, 2011) and other published data (Brożek and Zwydak, 2003. Base cation weathering were calculated from weathering rates classes (WRc) obtained from soil texture (eq. 5.39 in Mapping Manual). Long-term precipitation and temperature dataset was derived from latest database described in New et al. (2002). The base cation depositions were obtained from national monitoring stations (5 year average) and spatially distributed. Chemical criterion used was molar [Bc]/[Al]. CLacid average calculated values for EUNIS ecosystem classes are shown in Table PL-2. Spatial distribution of $CL_{max}S$ is presented in Figure PL-1.

Table PL-2, CL_{acid} values for terrestrial ecosystems in Poland.

EUNIS code	**CLacid –** Critical Load Function **[eq/ha/year]**		
	CLmaxS	**CLminN**	**CLmaxN**
D1	1842.96	120.75	3343.19
D2	1457.83	113.52	2576.31
D4	1885.28	108.07	3442.11
E2	1856.95	106.21	2863.64
E4	1969.76	207.75	3090.86
F2	2403.59	328.42	3997.16
F4	2053.00	107.00	3186.13
G1	985.52	580.06	2136.25
G3	1301.79	375.87	2375.95
G4	1215.02	476.58	2348.93
Average	**1219.61**	**445.08**	**2337.61**

Critical Loads of Eutrophication

Critical loads of eutrophication ($CL_{eut}N$) for forests were derived from $CL_{nut}N$ calculation methods based on SMB model (UBA, 2004) and for non-forest ecosystems as combinations of $CL_{nut}N$ and $CL_{emp}N$.
Nitrogen uptake (N_u) was obtained from State Forest Inventory (GDLP, 2011) as forest biomass (stems and branches) removed from forest ecosystems.
Calculation of precipitation surplus (Q) was based on long-term climatic data (New et al., 2002) and derived with Penman-Monteith evapotranspiration equations.
The acceptable nitrogen leaching (N_{acc}) was calculated with data establish both in Sweden and the Netherlands (Table 5.7 from Mapping Manual, updated 2007). For the lower threshold value of the growing season N_{acc} empirically determined in Scandinavia were used while for the upper threshold N_{acc} reported for the Netherlands were taken. The values of N_{acc} between the both threshold values of growing season were calculated for considered ecosystems using simple linear functions.
Additionally $CL_{emp}N$ were calculated for all ecosystems types as an average of their min and max values (Bobbink et al., 2011) and recalculated to eq/ha/yr for further $CL_{emp}N$ and $CL_{nut}N$ comparisons to the derive final $CL_{eut}N$.
Comparison of modelled and empirical CLs revealed large split of values for non-forest ecosystems. Only for forests both $CL_{emp}N$ and $CL_{nut}N$ values didn't differ more than 4% for G1 and 13% for G3 up to 20% for G4. $CL_{nut}N$ for mire bog and fen habitats (D) don't reflect their different trophic status (D1: poor raised bogs, D4: rich fens). For E and F habitats $CL_{nut}N$ show higher values for mountain habitats (E4, F2) than for lowland ecosystems located on richer soils (E2, F4) and it also doesn't correspond to result of field studies and $CL_{emp}N$ data.
Based on above the final $CL_{eut}N$ were derived for following conditions:

- D class: as an average $CL_{emp}N$ values, calculated from min and max for each class respectively,

- E and F classes: as minimum from $CL_{nut}N$ and average $CL_{emp}N$ values calculated from min and max for each class respectively,
- G class: as $CL_{nut}N$.

Calculation procedure and final $CL_{eut}N$ results for each EUNIS class are shown in Table PL-3; the spatial distribution of $CL_{eut}N$ is presented in Figure PL-2.

Table PL-3. $CL_{eut}N$ calculation method and values derived for terrestrial ecosystems in Poland

EUNIS code	$CL_{nut}N$	$CL_{emp}N$			$CL_{eut}N$		
	eq/ha/a	kg/ha/a		eq/ha/a	eq/ha/a	kg/ha/a	derivation method
		Min*	Max*	mean**			
D1	1135.3	5	10	535.7	**535.7**	**7.5**	CLempN {AVE (min;max)}
D2	769.6	10	15	892.8	**892.8**	**12.5**	CLempN {AVE (min;max)}
D4	631.7	15	30	1607.1	**1607.1**	**22.5**	CLempN {AVE (min;max)}
E2	1101.0	5	15	714.2	**620.6**	**8.7**	Min {CLnutN or AVE CLempN}
E4	1969.4	5	10	535.7	**535.7**	**7.5**	Min {CLnutN or AVE CLempN}
F2	2624.5	5	15	714.2	**702.7**	**9.8**	Min {CLnutN or AVE CLempN}
F4	1200.5	10	20	1071.4	**786.0**	**11.0**	Min {CLnutN or AVE CLempN}
G1	1120.8	10	20	1071.4	**1120.8**	**15.7**	ClnutN
G3	827.2	5	15	714.2	**827.2**	**11.2**	ClnutN
G4	1013.0	7.5	15	803.5	**1013.0**	**14.2**	ClnutN
Avarage	**950.3**				**950.3**	**13.3**	

* $CL_{emp}N$ min and max range from Bobbink et al. 2011;

** $CL_{emp}N$ min/max average value, recalculated to eq/ha/yr

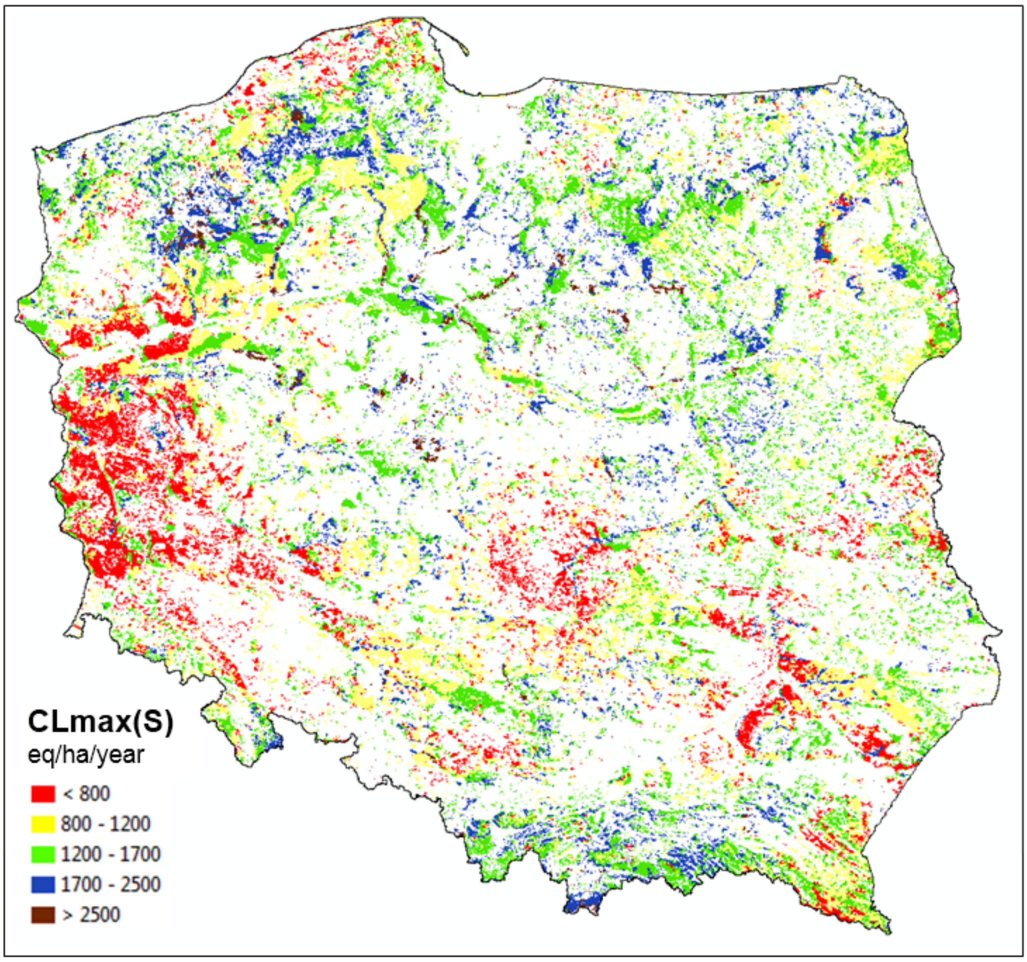

Figure PL-1. Spatial distribution of $CL_{max}S$ values for terrestrial ecosystems in Poland.

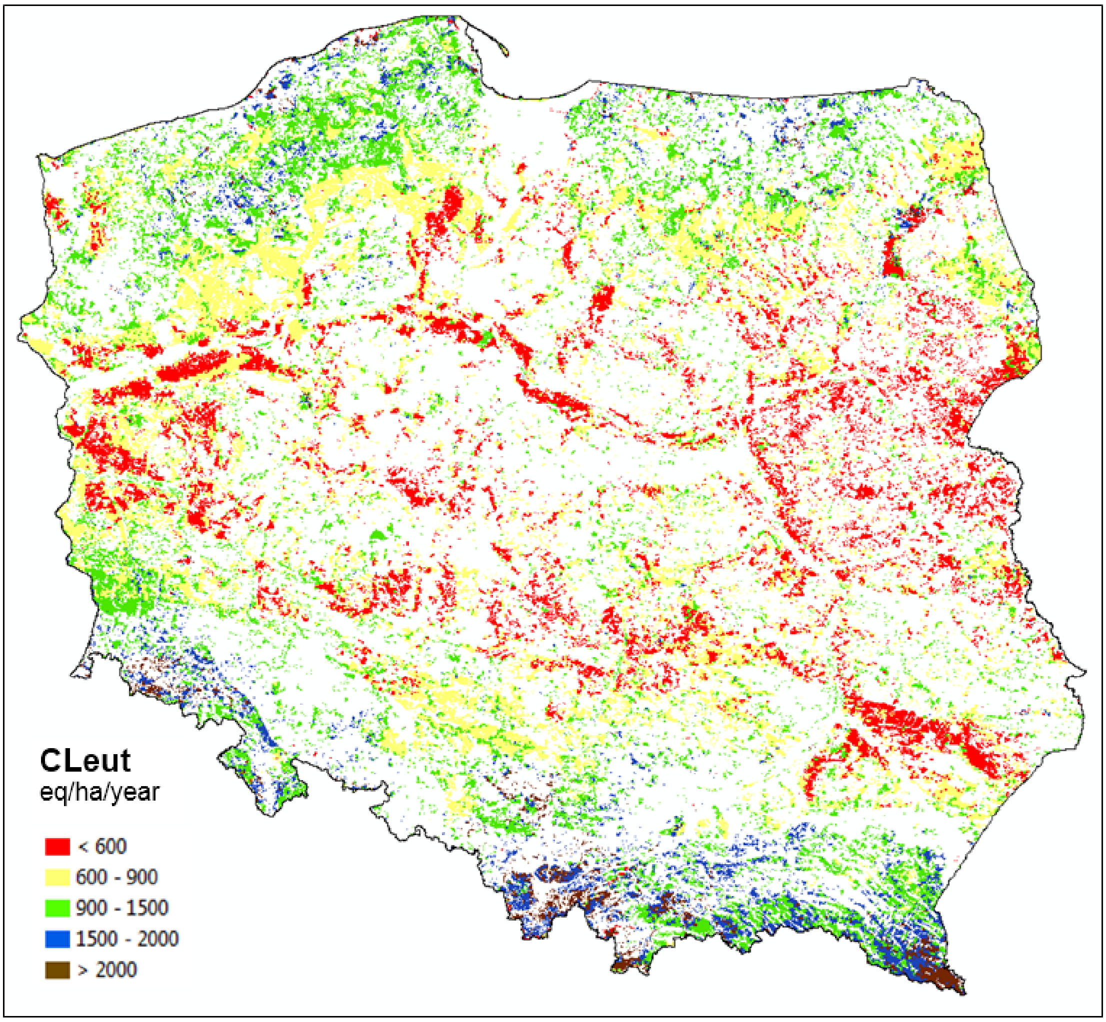

Figure PL-2. Spatial distribution of $CL_{eut}N$ values for terrestrial ecosystems in Poland.

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Summary
At the 1st joint session of the Steering Body to the EMEP and the Working Group on Effects (Geneva, 14-18 September 2015) the Coordination Centre for Effects was requested to issue a Call for Data in the autumn of 2015 with a deadline in 2017.

The aims of the Call for Data were to; (1) Derive nitrogen and sulphur critical load functions taking into account their impact on biodiversity (critical loads for biodiversity); (2) Present plans and preliminary results of the assessment of critical loads for biodiversity at the ICP M&M meetings in Dessau (19-22 April 2016) (3) offer the possibility to NFCs to update their national critical load data on acidity and eutrophication, the latter consisting of (the minimum of) the critical load of nutrient nitrogen and the empirical critical load at a site.

The Swedish NFC answers point three of the call. The submission consists of the newly calculated critical loads for acidity and the previously (2015) reported empirical critical loads for nutrient nitrogen established in 2014 by Swedish habitat experts at 3798 Swedish Natura 2000 sites.

For acidity the calculations are based on lakes and apply for both lakes and their catchments, in the same way as in earlier data submissions in 2012, 2014 and in 2015. In this submission an updated methodology regarding the critical load calculations and more recent data has been used. A database with the results of the new calculations is submitted simultaneously.

Introduction

In Sweden the impact of air pollution on ecosystems is of major concern, both with respect to acidification and eutrophication of soils and waters. In response to the Call for data Swedish NFC reports critical loads for acidity calculated on lakes and empirical critical loads at Natura 2000 areas at the $0{,}10^0 \times 0{,}05^0$ degrees longitude and latitude grid. The submitted critical loads reflect our view on acceptable level of air pollution which – if not exceeded – provides sufficient level of protection of Swedish ecosystems from harmful effects of acidification and eutrophication due to N deposition. Due to limited availability of resources, the response does not address the part of the Call concerned with assessment of critical loads for biodiversity.

Critical loads for acidity

In 2016 Sweden revised the calculations of critical loads for acidity in surface waters. The changes in calculations consist of four adjustments: 1) the use of BC^*_0 (1860) as BC^*_0, instead of the earlier used BC^*_0 (2100), which is more in line with the common methodology described in the Mapping Manual, 2) In cases where historical ANC_0 is very low, restrictions (e.g. lowest ANC_{limit} set to 0 µeq/l) is used to avoid setting a negative ANC_{limit}. For ANC_{limit} an upper threshold is set for pH 6.2, which means that for high pH lakes the maximum demanded target pH is 6.2, and 3) The MAGIC library is used in the critical loads calculations to set the ANC_{limit} for individual lakes and to provide the base cations at steady state (BC^*_0). In 2015-2016 there was a major update of the entire MAGIC library catalogue of model runs, including a new forestry scenario. 4) The way N deposition is treated in critical loads calculations was also adjusted compared to previous submissions. N immobilisation was set to 2 kg N/ha/yr in forest soils and non-acidifying leaching of organic nitrogen has also been accounted for in the critical load calculation. Deposition in access of the sum of these two terms is considered acidifying according to the precautionary principle. Changes in the used methodology and the MAGIC library update resulted in adjustments in the calculated critical loads for acidity compared to previous submissions towards slightly less exceedance of critical loads with a given emission scenario (preliminary calculations).

The ecosystem area of each grid is treated in the same way as in the 2015 submission (Slootweg et al., 2015) which means that the submitted ecosystem area (EcoArea) for critical loads for acidity is the area of Sweden reduced by the area of the nine largest Swedish lakes along with densely populated areas and agricultural land. Thus the EcoArea for critical loads of acidification (395 226 km^2) is 88% of the total area of Sweden (449 964 km^2).

Critical loads for acidity are based on updated calculations on the 5084 lakes described in CCE Status Report 2014 (Slootweg et al., eds., 2014). For the grid cells with no assessed lakes in it we have used inverse distance weighting interpolation (IDW). IDW determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. This method assumes that the variable being mapped decreases in influence with distance from its sampled location. Between 3 and 10 lakes within 30 km radius were considered for interpolation for each grid. For the grid cells with several assessed lakes in it we have used the average critical loads at these lakes. The geographical distribution of the areas most sensitive to acidification follows the same pattern as observed in the previous CL submissions.

Critical loads on eutrophication

Empirical critical loads are used for CLeut. The empirical critical loads were established at 82 relevant habitats represented in 3798 Natura 2000 areas covering 58 688 km^2 (Figure SE-1). The calculations are identical to the 2015 submission (Slootweg et al., 2015). EcoArea for CLeut is significantly lower than the EcoArea used for CLacid. In both cases, however, the EcoAreas are relevant to the long term goal of non-exceedance of critical loads for acidity and for eutrophication respectively. If achieved, then the most sensitive Swedish ecosystems will be protected from further damage due to air pollution.

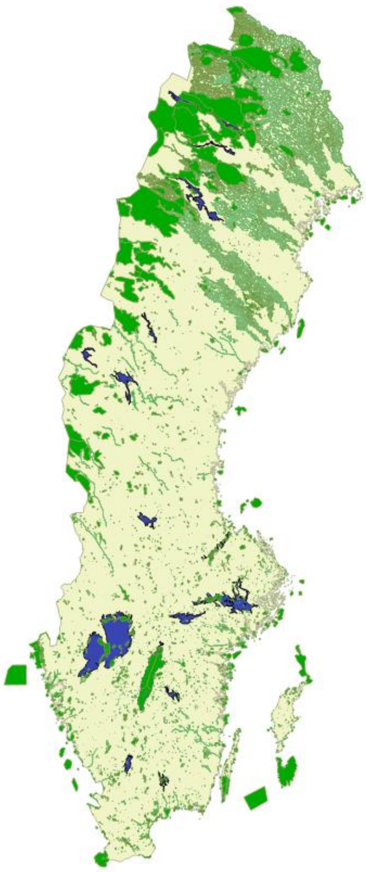

Figure SE-1. Map of Sweden showing geographical location of Natura 2000 areas in green.

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Overview of Critical Load Data

This document gives a summary of data sources and methods used to calculate Swiss critical loads, and highlights changes since the previous data submission (Achermann et al., 2015). As in 2015, the Swiss data set on critical loads of acidity and nutrient nitrogen is compiled from the output of four modelling and mapping approaches (see Figure CH-1). For the CCE data call 2015/17 the empirical critical loads were updated. In addition, critical loads for biodiversity of forest ground flora were calculated and submitted for the first time:

1) The SMB method for calculating critical loads of nutrient nitrogen (CLnutN) was applied on 10,632 forest sites. 10'331 of these sites originate from the National Forest Inventory (NFI 1990/92), which is based on a 1x1 km^2 grid. They are complemented by the 301 DM-sites ('dynamic modelling sites') with full soil profiles.
2) The empirical method for mapping critical loads of nutrient nitrogen (CLempN*)* includes different natural and semi-natural ecosystems, such as raised bogs, fens, species-rich grassland, alpine scrub habitats and poorly managed forest types with rich ground flora. For the first time, CLempN were also set for oligotrophic alpine lakes. The mapping was done on a 1x1 km^2 grid combining several input maps of nature conservation areas and vegetation types. The total sensitive area amounts to 14,600 km^2.
3) A variant of the SMB was used for assessing critical loads of acidity (CLacid) on the 301 DM-sites, where forest soil profiles were available. Net-uptake fluxes were modelled with the model MakeDep.
4) Critical loads of acidity (CLacid) were calculated for 100 sensitive alpine lakes in Southern Switzerland applying a generalized version of the FAB model (first order acidity balance).
5) Biodiversity crtitical loads (CLbdiv) were calculated for 76 forest plots in Switzerland using PROPS-CLF.

The Swiss critical loads database is constructed on the base of sampling points and modelling sites in such a way that ecosystem areas are consistent with the new EMEP longitude-latitude grids (0.50° x 0.25° or

0.1° x 0.1°). Figure CH-1 gives an overview of the ecosystems and methods used for mapping. Details of the mapping of critical loads for nutrient N can be found in a recent report (Rihm and Achermann, 2016).

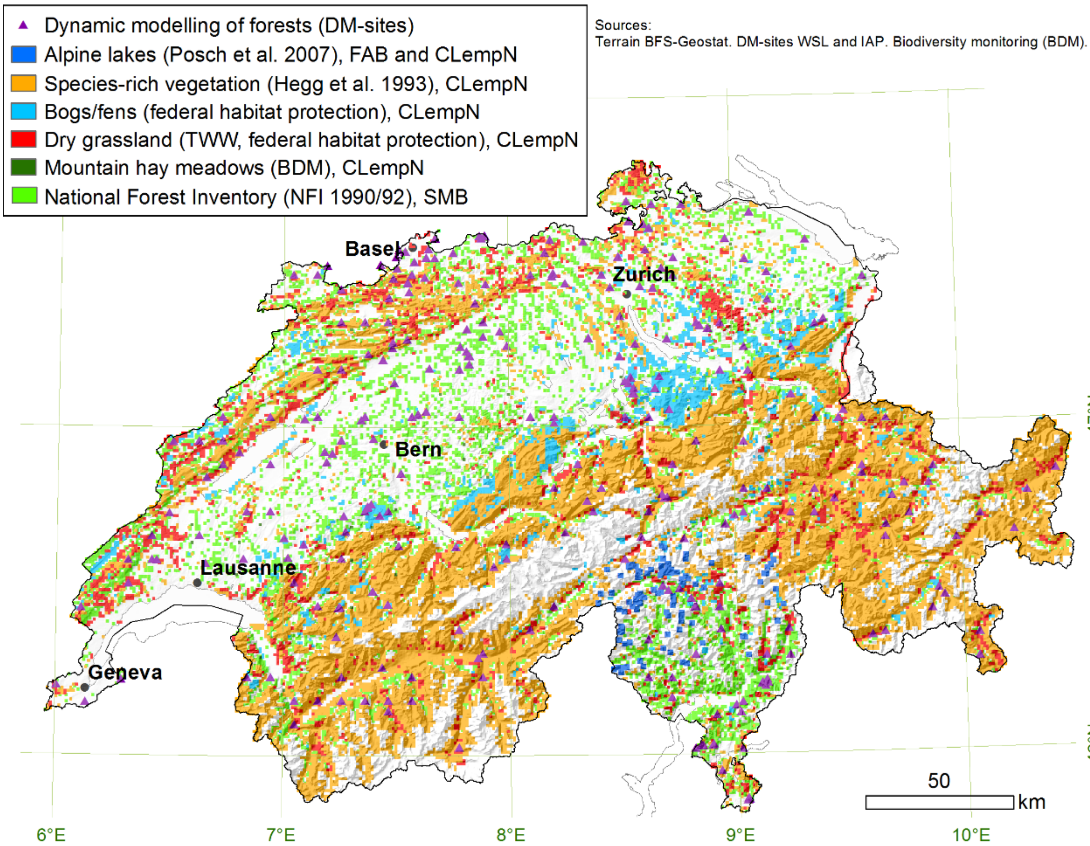

Figure CH-1. Overview of ecosystems: forest monitoring sites used for dynamic modelling (DM-sites), alpine lakes, forest sites from the NFI and semi-natural ecosystems from various data sources (Hegg et al., 2003; national inventories of raised bogs, fens and dry grassland (TWW), biodiversity monitoring network)).

Some essential results of the update are shown in Figure CH-2 as cumulative frequency distributions: CLnutN for forests (SMB method), CLnutN for (semi-)natural ecosystems (empirical method) as well as the maximum critical load of sulphur (CLmaxS) for forests (MakeDep/SMB models) and Alpine lakes (FAB model).

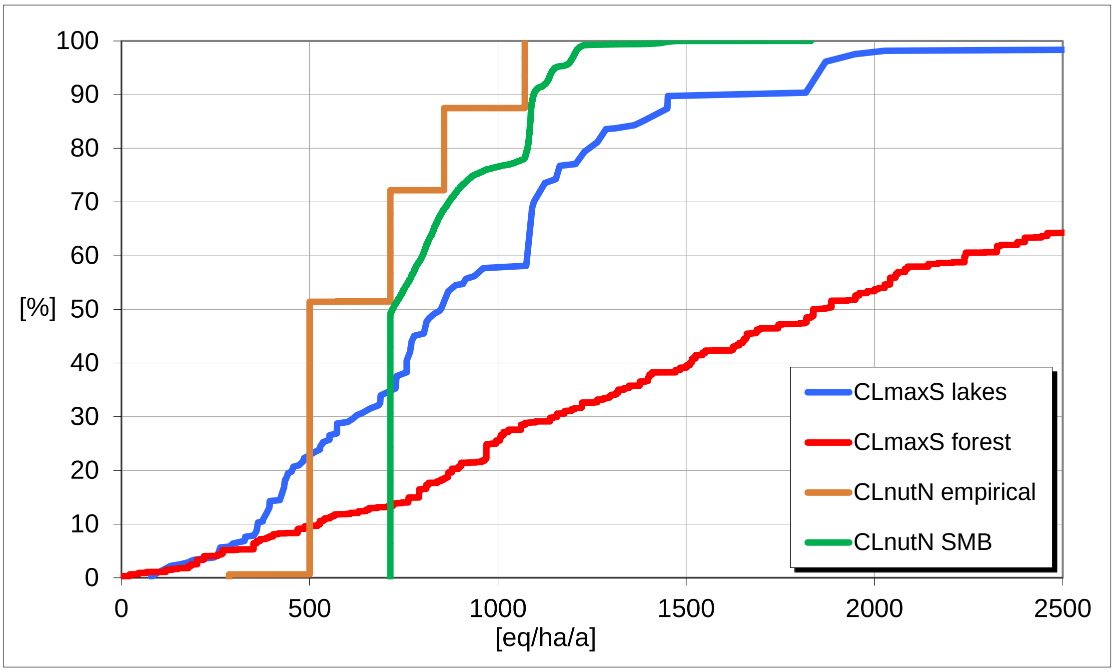

Figure CH-2. Cumulative frequency distributions of CLnutN (SMB and empirical method) and CLmaxS (forests and alpine lakes).

Critical loads of nutrient nitrogen (SMB method)

Procedure

In a first step, CLnutN was calculated by the SMB method for 301 forest sites used in dynamic modelling and for 10'331 sites of the National Forest Inventory (NFI). Table CH-1 gives a summary of the input parameter values. Thereby, only NFI-sites with a defined mixing ratio of deciduous and coniferous trees are included (NFI 1990/92). This corresponds approximately to the productive forest area as brush forests and inaccessible forests are excluded.

In a second step, the lower limit of CLnutN calculated by the SMB was set to 10 kg N ha^{-1} a^{-1} (corresponding to the lower limit of CLempN used for forests). This means, all values of CLnutN below 714 eq ha^{-1} a^{-1} were set to 714. This is done with respect to the fact that so far no empirically observed harmful effects in forest ecosystems were published for depositions lower than 10 kg N ha^{-1} a^{-1} and for latitudes and altitudes typical for Switzerland. Therefore, the critical loads calculated with the SMB method were adjusted to empirically confirmed values.

Table CH-1. Range of input parameters used for calculating CLnutN with the SMB method.

Parameter	Values	Comment
$N_{le(acc)}$	4 kg N ha^{-1} yr^{-1} at 500 m, 2 kg N ha^{-1} yr^{-1} at 2000 m altitude, linear interpolation in-between	Acceptable N leaching. Leaching mainly occurs by management (after cutting), which is more intense at lower altitudes.
N_i	1.5 kg N ha^{-1} yr^{-1} at 500 m, 2.5 kg N ha^{-1} yr^{-1} at 1500 m altitude, linear interpolation in-between	N immobilization in the soil. At low temperature (correlated with high altitude) the decomposition of organic matter slows down and therefore the accumulation rates of N are naturally higher.
N_u	0.5 – 14.7 kg N ha^{-1} yr^{-1}	N uptake calculated on the basis of long-term harvesting rates.
f_{de}	0.2 – 0.7 depending on the wetness of the soil	Denitrification fraction. For NFI-sites, information on wetness originates from soil map 1:200'000. For DM-sites it is a classification according to the depth of the saturated horizon.

Acceptable Nitrogen Leaching

Total acceptable nitrogen leaching was defined based on total annual amounts because limits based on N concentration in soil water are not applicable in high precipitation areas. The rationale for this choice was presented in a former CCE Status Report (Achermann et al., 2007). The leaching rates reflect an average long-term N leaching which is caused by management, mainly after cutting or other disturbances. Forest management is generally more intense at lower altitude than at high altitude (see also Section Nitrogen Uptake). Therefore $N_{le(acc)}$ was calculated as a function of altitude (see Table CH-1).
The submitted values of acceptable N concentration were calculated as: $[N]_{acc} = N_{le(acc)} / Q$.

Nitrogen Immobilization

Nitrogen immobilization rates were set under the assumption that at high altitudes, the decomposition of organic matter slows down due to lower temperatures and therefore the accumulation rates of N in the soil are naturally higher. Findings of the Olten Workshop on nitrogen immobilization (February 2017) were not taken into account. The values shown in Table CH-1 are somewhat higher than the proposal in the Mapping Manual.

Net growth uptake of nitrogen

For the DM-sites, net-uptake fluxes were modelled with MakeDep (Alveteg et al., 2002) using biomass data from the 3rd National Forest Inventory (http://lfi.ch, WSL, 2013), tree genera-specific logistic growth curves, site productivity index, nutrient contents in the various compartments of the tree, and average annual harvesting rates stratified according to the five NFI-regions (Table CH-2).

The uptake for the other forest sites was derived from the DM-sites by a linear regression with altitude (z) within each region (Table CH-2).

Table CH-2. Net nitrogen uptake (N_u) in the five NFI-regions (kg N ha^{-1} a^{-1}).

Region	Average	Function of altitude z (m a.s.l.)
1. Jura	5.3	6.99 - 0.00300 z
2. Central Plateau	8.5	--
3. Pre-Alps	4.3	7.60 - 0.00322 z
4. Alps	2.9	3.58 - 0.00064 z
5. Southern Alps	1.6	2.29 - 0.00056 z
Average CH	4.4	--

Denitrification fraction

For calculating CLnutN, f_{de} was determined according to wetness class information from the digital soil map BEK (SFSO, 2000) as shown in Table CH-3. On the DM-sites, information from the soil profiles was used to determine the depth of the water saturated horizon.

Table CH-3. Values of f_{de} selected for the BEK classes of soil wetness.

Wetness class BEK	Description	Depth of saturated horizon	f_{de}
0	Unknown	--	0.2
1	No groundwater	--	0.2
2	Moist	below 90 cm, but capillary rise	0.3
3	Slightly wet	60-90 cm	0.4
4	Wet	30-60 cm	0.6
5	Very wet (not occurring on the digital map)	<30 cm	0.7

Empirical critical loads of nutrient nitrogen

The application of the empirical method is based on vegetation data compiled from various sources and aggregated to a 1x1 km raster (see Figure CH-1). Overall, 45 sensitive vegetation types were identified and included in the critical load data set:

- 1 type of raised bog; source Federal Inventory of Raised and Transitional Bogs of National Importance (EDI, 1991), CLempN = 7 kg N ha^{-1} a^{-1};
- 3 types of fens; source Federal Inventory of Fenlands of National Importance (WSL, 1993), CLempN = 7 to 15 kg N ha^{-1} a^{-1};
- 21 types with various vegetation worthy of protection (Hegg et al., 1993) including rare and species-rich forest types, grasslands and (sub)alpine scrub habitats, CLempN = 7 to 15 kg N ha^{-1} a^{-1};
- 1 type of mountain hay meadow in montane to sub-alpine altitudinal zones with more than 35 species (10 m^2)$^{-1}$ (Roth et al., 2013), source Biodiversity Monitoring (BDM, http://www.biodiversitymonitoring.ch/en/data/indicators/z/z9.html), CLempN = 12 kg N ha^{-1} a^{-1};

- 18 types of dry grassland; source National Inventory of Dry Grasslands of National Importance (TWW, FOEN, 2007), CLempN = 7 to 15 kg N ha^{-1} a^{-1};
- 1 type of alpine oligotrophic softwater lakes mapped by Posch et al. (2007), CLempN = 4 kg N ha^{-1} a^{-1}.

The values for the empirical critical loads for nitrogen (CLempN) have been based on the outcome of the Workshop in Noordwijkerhout (Bobbink and Hettelingh, 2011). In addition, the relative sensitivity of the ecosystems was reassessed by Burnand (2011).

On the basis of recent results from the assessment of relationships between nitrogen deposition and species diversity in mountain hay meadows (EUNIS class E2.3) and (sub)alpine scrub habitats (EUNIS class F2.2) in Switzerland (Roth et al., 2017) it was concluded that the empirical critical loads for nitrogen proposed by Bobbink andHettelingh (2011) for mountain hay meadows (10–20 kg N ha^{-1} a^{-1}) could be narrowed down to 10–15 kg N ha^{-1} a^{-1}, whilst the empirical critical loads proposed for (sub-)alpine scrub habitats (5–15 kg N ha^{-1} a^{-1}) were confirmed.

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

A new CLempN of 4 kg N ha^{-1} a^{-1} was set for alpine lakes according to the range 3–5 kg N ha^{-1} a^{-1} proposed by ICP Waters (De Wit and Lindholm, 2010).

If more than one sensitive ecosystem type occurs within a 1x1 km^2 grid-cell the lowest value of CLempN was selected for this cell.

Detailed information on the CLempN of selected ecosystems can be found in in Tables 2 and 3 of the report from Rihm & Achermann (2016).

Critical loads of acidity for forests
Critical loads of acidity were assessed by means of a variant of the Simple Mass Balance (SMB) model also considering the extensions listed in the Mapping Manual (Chapter 5.3, UNECE, 2017). To allow weathering rates to be consistently calculated for conditions at critical load, the Sverdrup-Warfvinge Weathering (SWW) algorithm (i.a. Sverdrup and Warfvinge, 1995) was linked to the SMB (version March 23, 2013, M. Posch, CCE, pers. comm.).

Critical Chemical Limits
On the basis of results from the long-term monitoring of forest sites (inter-cantonal long-term forest monitoring network, including i.a. soil profile analysis, soil solution analysis, forest condition assessment, ground vegetation relevés) and on the basis of published results on

relationships between base saturation and storm-induced forest damages as well as fine root conditions (Braun et al., 2003; Braun et al., 2005) we came to the conclusion that a critical limit value of the Bc/Al ratio of 1 allows for too much acidification and weakening of forests stands in Switzerland. Taking the Bc/Al ratios resulting from soil solution monitoring and considering its relation to base saturation (Braun, 2013) we concluded that a critical limit value for Bc/Al of 5-10 would be more appropriate to protect forests from acidification since it would not allow, like for Bc/Al=1, a development of base saturation towards values substantially below 20%. Thus, our revised critical loads of acidity for forests are based on calculations with a critical limit value for Bc/Al ratio of 7.

Input

For the submission in 2015, the SMB was extended with the SWW algorithm and the list of needed input parameters got slightly larger than in earlier assessments (see Table CH-4). A total of 311 forest sites were considered in the modelling and a series of basic data was brought up-to-date in recent years entailing changes in the model input.

Climate input was drawn from revised site-specific monthly climate data (Remund et al., 2014) for a past 1961-1990 and future 2045-2074 period adopting an IPCC A1B scenario. For critical loads calculations the data were annualized for each of the 30 years period (i.e. input is 30 years annual average).

Wet and dry deposition rates for base cations (Bc), Na and Cl were interpolated by spatial regression on the basis of monitoring results from the Long-term Forest Ecosystem Research Programme of WSL (http://www.wsl.ch/info/organisation/fpo/lwf/index_EN). They represent an average of the period 2006-2009 (Rihm et al., 2013). Deposition of base cations is input to MakeDep, which was used to simulate forest growth and management and resulting nutrient cycle. Annual harvest and corresponding nutrient contents were taken from an up-to-date MakeDep run. Net uptake of base cations and nitrogen was calculated as the sum of tree compartment mass removed from the plot (harvest) times the average nutrient contents of the compartments. Since critical loads are being used to set future emission/deposition targets and to remain consistent with the climate input, it was decided to use average annual deposition and nutrient flux output from MakeDep for the period 2045-2074.

In the course of the implementation of the weathering calculation routine, soil input required by the extended SMB was already revised for the previous submission in 2015, including the following modifications (cp. Phelan et al., 2014):

- a modification of the assessment of the major rooting zone, which defines the single soil compartment required by the SMB,
- a modification of the weatherable surface area estimation,
- a modification of the area weighting of the mineralogy,
- the introduction of a stoichiometry correction for base cation depleted clay minerals,
- a harmonisation of the assessment of long-term average soil moisture content and porosity, which determine water saturation

and thereby wetted mineral surface.

As for the submission in 2015, instead of averaging the layered soil input within the rooting zone, transfer functions used to get from soil raw data to the requested soil input were applied to averaged raw data.

Table CH-4. List of input parameters required to run the SWW/SMB.

Key word	Unit	Comment
SiteInfo	-	string with info on the site (max.128 chars)
useSWW	-	flag; 0=weathering rates given; 1=steady-state weathering rates computed with SWW
AciCrit	-	Criterion for acidity CLs; 1=Al:Bc (mol mol^{-1}); 2=[Al] (mol$_c$ m^{-3}); 3=bsat (fraction); 4=pH (mol L^{-1}); 5=[ANC] (mol$_c$ m^{-3})
Vacicrit	-	Critical value for criterion 'AciCrit'; units as given under 'AciCrit'
NutCrit	-	Criterion for CLnutN; 1=[N]acc (mgN L^{-1}); 2=Nle,acc (mol$_c$ m^{-2} a^{-1})
Vnutcrit		Critical/acceptable value for criterion 'NutCrit'; units as given under 'NutCrit'
thick	m	thickness of the soil compartment
porosity	m^3 m^{-3}	porosity of the soil
Theta	m^3 m^{-3}	volumetric water content of the soil
lgKAlox	(mol L^{-1})$^{-2}$	log10 of equilibrium constant in [Al] = KAlox*[H]^3
lgKAlBC	-	log10 of Gapon selectivity constant for Al-Bc exchange
lgKHBC	-	log10 of Gapon selectivity constant for H-Bc exchange
pCO2fac	-	CO_2 pressure in soil solution as multiple of pCO_2(atm) in air
cRCOO	mol m^{-3}	total concentration of organic acids (m*DOC); (0=no organic acids simulated)
TempC	°C	soil temperature
percol	m a^{-1}	percolation (precipitation surplus) (m/a)
f_de	-	denitrification fraction (0<=f_de<=1)
Nim_acc	mol$_c$ m^{-2} a^{-1}	'constant' (acceptable, minimum) N immobilized
Ca_dep	mol$_c$ m^{-2} a^{-1}	deposition of Ca
Mg_dep	mol$_c$ m^{-2} a^{-1}	deposition of Mg
K_dep	mol$_c$ m^{-2} a^{-1}	deposition of K
Na_dep	mol$_c$ m^{-2} a^{-1}	deposition of Na
Cl_dep	mol$_c$ m^{-2} a^{-1}	deposition of Cl
Ca_upt	mol$_c$ m^{-2} a^{-1}	net uptake of Ca
Mg_upt	mol$_c$ m^{-2} a^{-1}	net uptake of Mg
K_upt	mol$_c$ m^{-2} a^{-1}	net uptake of K
N_gupt	mol$_c$ m^{-2} a^{-1}	net uptake of N
!For useSWW=0:		
Ca_we	mol$_c$ m^{-2} a^{-1}	weathering rate for Ca
Mg_we	mol$_c$ m^{-2} a^{-1}	weathering rate for Mg
K_we	mol$_c$ m^{-2} a^{-1}	weathering rate for K
Na_we	mol$_c$ m^{-2} a^{-1}	weathering rate for Na
!For useSWW=1:		
surface	m^2 m^{-3}	soil particle surface area
MinDat	-	Path to PROFILE-style 'mineraldata' file {mineraldata}
M_groups	-	number of mineral groups used (first M_groups of those in MinDat)
M_fracts	m^2 m^{-2}	surface area fractions of minerals in M_groups

Determining the ecosystem area
Critical loads of acidity were successfully calculated for 301 DM-sites. These are not regularly distributed within the country. The NFI-sites (National Forest Inventory), however, are a systematic sample, each representing a forest area of 1 km^2. Therefore, the area of forest represented by one DM-site was determined by those NFI-sites situated within the respective Thiessen-polygon constructed for the DM-sites, and all acidity parameters were copied from a DM-site to the affiliated NFI-sites. In consequence, EcoArea was set to 1.0 km^2 for all resulting sites with critical loads for acidity.

However, if a NFI-site was situated on a 1x1 km grid cell containing also a site with empirical critical loads, EcoArea was set to 0.8 km^2 for the NFI-site and to 0.2 km^2 for the empirical site. Thus, double area counts were excluded.

Critical loads of acidity for alpine lakes
Critical loads of acidity for alpine lakes were left unchanged. They were calculated with a generalised FAB-model (Posch et al., 2007). The model was run for the catchments of 100 lakes in Southern Switzerland (see Figure CH-1) at altitudes between 1650 and 2700 m (average 2200 m). To a large extent the selected catchments consist of crystalline bedrock and are therefore quite sensitive to acidification.

Critical loads for biodiversity
Critical loads for biodiversity were assessed for a subset of forest monitoring plots (DM-sites) considered in the conventional acidity critical loads calculation using the PROPS-CLF model provided by the Coordination Centre for Effects (www.wge-cce.org/Methods_Models/Available_Models). PROPS (Reinds et al., 2012; Reinds et al., 2014; Rowe et al., 2015; Reinds et al., 2015) estimates the occurrence probability of plant species as a function of soil chemical, deposition and climatic variables namely soil pH and carbon to nitrogen (C/N) ratio, annual average total N deposition (N_{dep}), precipitation (P) and temperature (T). Plant species-specific response functions were calibrated by means of presence-absence data of several 100'000 relevés in Europe using a logistic regression technique. To allow the use of the model in the assessment of S and N critical loads, PROPS was linked with the Simple Mass Balance (SMB) model. Details on the calculation of critical loads and the use of PROPS-CLF on the European scale are described in Posch et al. (2014) and Posch et al. (2015).

Input for the Swiss PROPS-CLF runs was drawn from the basic database and from the acidity critical loads calculations with the SMB (cp. Section above, Figure CH-3). Details regarding modelling with this set-up are described in Kurz and Posch (2015). In compliance with the decisions of the Task Force meeting of the ICP Modelling & Mapping in Rome (April 7–10, 2014), the Habitat Suitability Index (HSI) was used to quantify the response of the ground vegetation plant communities to varying S and N deposition:

$$HSI = \frac{1}{n}\sum_{j=1}^{n}\frac{p_j}{p_{j,max}}$$

where n is the number of species, p_j the occurrence probability of species j, and $p_{j,max}$ the maximum occurrence probability of species j. The model was set to make use of $p_{j,max}$ determined in the 2 dimensional (pH-N_{dep}) subspace, implying constant C/N, P and T as given by the site-specific input. Modelling with PROPS-CLF requires to specify the bounding box of deposition, which was limited to 4000 eq ha^{-1} a^{-1}. By common accord, a critical limit of $0.8 \cdot HSI_{max}$ was chosen to derive the critical load function in the N_{dep}-S_{dep} plane (Posch et al., 2015).

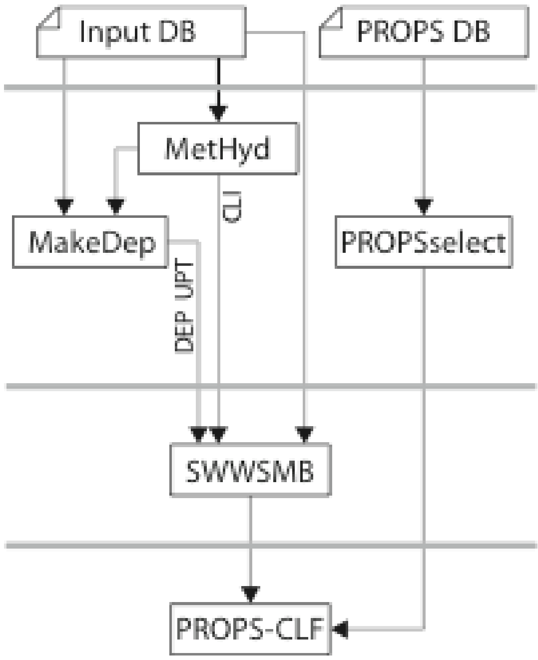

Figure CH-3. Model stacking and data flow set up to run the SMB model and ultimately PROPS-CLF. Note that all models are stand-alone and processed data is passed downstream via temporary files.

To account for the empirical knowledge that a particular habitat is characterised by a limited number of key species, sites were categorised with regard to the prevailing forest type and a characteristic natural ground vegetation community was assigned to each forest type (S. Braun, IAP & T. Burger, Burger & Liechti GmbH, pers. comm., Feb 23, 2015). The plants in a community additionally were labelled according to their importance for the plant community: level 6 (determinant) to 1 (ubiquist). For the modelling, generally plants of level 6 to 3 were used and ubiquists were ignored. The detailed habitat classification was available for 76 sites.

Resulting biodiversity (Figure CH-4A) compared to acidity (Figure CH-4B) critical loads for forests appeared to mostly be less restricting regarding S deposition, but tended to often curtail N deposition between 2000 and 2500 eq ha^{-1} a^{-1}. The impact on the combined conventional critical load function considering also nutrient N critical loads (CLnutN; Figure CH-4C), however, was marginal, since the leaching criterion used in Switzerland to assess CLnutN limited N deposition mostly to <1500 eq ha^{-1} a^{-1}.

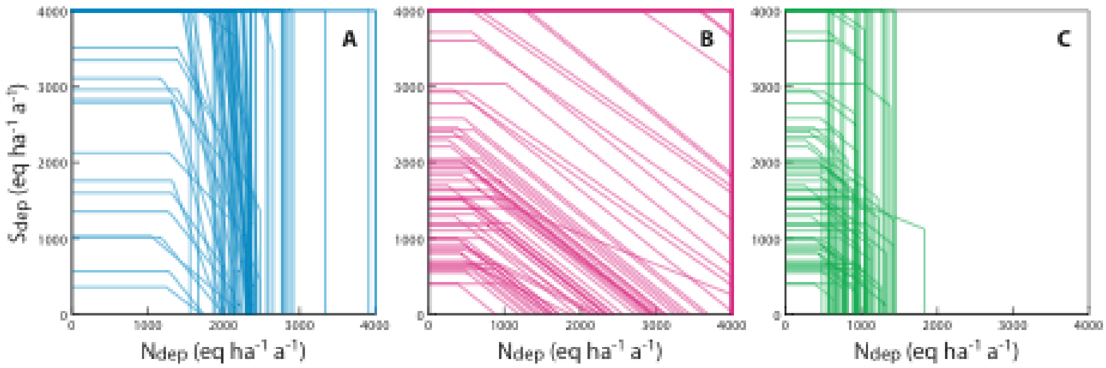

Figure CH-4. Critical loads functions for biodiversity (A), conventional acidity (B) and combined acidity and nutrient N (C) calculated for 76 forest plots in Switzerland.

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Introduction

In response to the "CCE Call for Data 2015-2017" the UK NFC has:

i. The UK critical loads database for sixteen EUNIS terrestrial and freshwater habitat classes was re-submitted to the CCE in the new database format required. The UK database additionally includes empirical nutrient nitrogen critical loads applied to the designated feature habitats of Natura 2000 sites as described in the CCE 2015 Status Report (Hall et al., 2015b). Further details on the methods and data used to derive the national database can be found in Hall et al. (2015a).

ii. Submitted the results of applying the MADOC-MultiMove model to calculate biodiversity-based critical loads based on a habitat quality metric, for 87% (i.e. 16,423) of the UK 1x1 km squares that contain bog habitat (D1 Raised and blanket bogs), and subsets of other acid-sensitive habitats. Methods are summarised below. More detail is provided in recent CCE reports (Hall et al., 2015b; Hall et al., 2014) and in publications describing the models and metrics used (Henrys et al., 2015; Rowe et al., 2016a; Rowe et al., 2014).

Calculating biodiversity-based critical loads

To take account of the combined effects of N and S pollution over time, including delays in recovery, dynamic modelling approaches have been developed that link soil processes to the responses of plant species (De Vries et al., 2010). The UK NFC has applied the MADOC-MultiMOVE model (Rowe et al., 2015) to predict changes to an index of habitat quality, *HQI*: the mean habitat-suitability for locally-occurring positive indicator species for the habitat. A threshold value for this index was obtained by running the model forward with N deposition set to the empirical critical load for nitrogen ($CL_{emp}N$) for the habitat, and used to calculate the combinations of N and S deposition that are likely to cause a decline in *HQI* below this critical threshold. These combinations are then summarised into a simple biodiversity-based critical load (CL_{bdiv}) function (Figure UK-1).

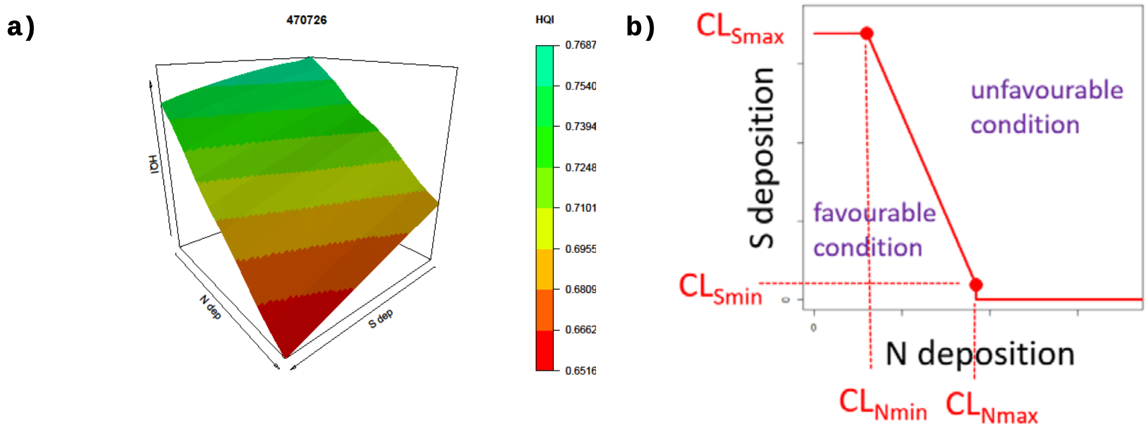
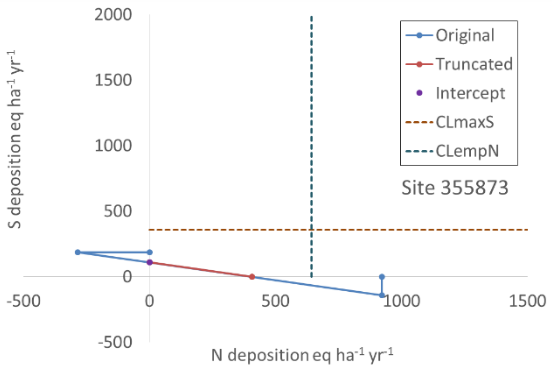


Figure UK-1. a) Response of a habitat quality index, HQI, to variation in nitrogen and sulphur deposition at a bog site in the Scottish Borders, showing high HQI with low values of S and N, a decline in HQI with more S, and a steeper decline with more N. The contour on the left-hand plot that corresponds to a critical threshold for HQI (calculated to be 72.8 % at this site) is approximated (b) using a simple two-node function which describes the biodiversity-based critical load.

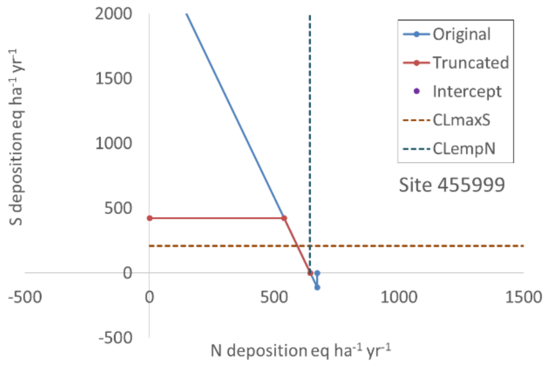
The UK NFC made an interim submission to the CCE in May 2016 of CL_{bdiv} functions calculated for acid-sensitive habitats within selected Natura2000 sites. Work in the last year has focused on parallelising the implementation of MADOC-MultiMOVE to make it feasible to calculate CL_{bdiv} functions for the UK at 1x1 km scale. These functions were calculated for the EUNIS class D1 (raised and blanket bogs) for the majority (87 %) of UK 1 km^2 grid-cells which contain this habitat. Results for other habitats were affected by the inclusion of some dominant species as positive indicators, giving a positive response of the habitat quality metric to increasing N deposition. We excluded these dominant species, recalculated the critical load functions, and submitted data for subsets (*ca*. 1000 randomly-selected sites per habitat) of the UK 1x1 km squares containing E1.7 (Closed non-Mediterranean dry acid and neutral grassland), F4.11 (Northern wet heaths) and F4.2 (Dry heaths). Responses remained problematic for E3.52 (Heath *Juncus* meadows and humid *Nardus stricta* swards) and data were not submitted for this habitat.

The procedure for summarising the critical threshold function (corresponding to a 'contour' in Figure UK-1a) into a simple two-node CL_{bdiv} function (Figure UK-1b) resulted in many cases in the nodes being placed outside the ranges of N and S deposition over which sensitivity was assessed, often giving negative values for CLN_{min} and/or CLS_{min} or extreme values for CLN_{max} and/or CLS_{max}. In such cases, the function was truncated to ensure that CLS_{min} and CLS_{max} are in the range (0 to 2 x $CL_{max}S$) and that CLN_{min} and CLN_{max} are in the range (0 to 2 x $CL_{emp}N$). Examples are illustrated in Figure UK-2.

a)



b)



FigureUK-2. Examples of sites where the values originally fitted for CLSmax, CLSmin, CLNmax and/or CLNmin were outside a reasonable range, which we defined as between zero and 2 x CLmaxS for S, or between zero and 2 x CLempN for N. Where the original function lay within these ranges, its shape was retained. Values less than zero were increased to zero, as in example a). Where original values were greater than 2 x CLmaxS for S, or greater than 2 x CLempN for N, they were decreased to these maximum reasonable values, as shown for CLSmax in example b). The UK data submission consisted of these truncated values.

Results

Biodiversity-based critical load functions

The CL_{bdiv} functions calculated for D1 bogs are illustrated in Figure UK-3. Since the critical threshold for *HQI* is calculated on the basis of the $CL_{emp}N$, the value of CLN_{max} is usually close to the $CL_{emp}N$ (see Figure UK-1b). Variation in value of CLS_{max} is of more interest (Figure UK-3a). Many aspects of the response may be responsible for this variation, such as the selection of locally-occurring indicator species, pollution history, rainfall, and/or temperature. Rainfall has a relatively strong influence, as shown by the often greater values of $CL_{max}S$ in more westerly, wetter areas. The main effects of N and S (i.e. the mean response to N over all levels of S deposition, and the mean response to S over all levels of N deposition) were calculated from *HQI* response surfaces (e.g. Figure UK-1a) to more clearly illustrate the geographic variation in sensitivity. These maps show the decline in *HQI* likely at each site if rates of deposition of S (Figure UK-3b) and N (Figure UK-3c) were to increase. Relatively unpolluted sites were usually more sensitive to S, showing declines of more than 0.2 % *HQI* per kg S ha^{-1} yr^{-1} in areas such as SW England, South Wales W Scotland. By contrast, bog sites in chronically polluted areas such as the South Pennines were relatively insensitive to S. Sites were in general more sensitive to N than to S, with a mean decline of 0.41 % *HQI* per kg N ha^{-1} yr^{-1}, compared with 0.11 % *HQI* per kg S ha^{-1} yr^{-1}. The spatial pattern of sensitivity to N (Figure UK-3c) was similar to the pattern of sensitivity to S, with sites shown to be more sensitive to N in less-polluted areas towards the north and west. The step-changes in sensitivity to N along some 10 x 10 km grid boundaries, notably in the north of Scotland in Figure UK-3c, reflect the influence of particular indicator species, for which occurrence data are at 10 km scale.

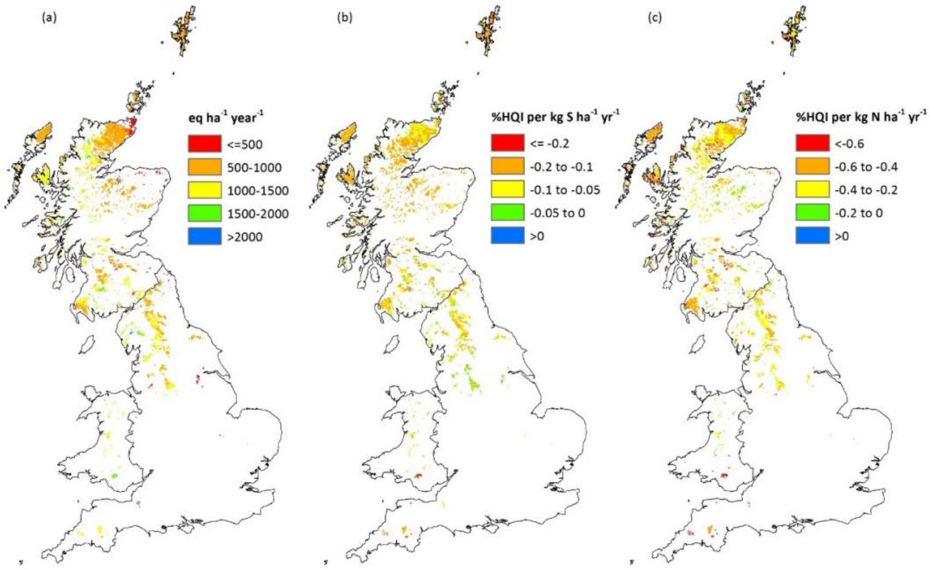


Figure UK-3. Geographical variation in biodiversity-based Critical Load functions for bogs: a) CLSmax; b) slope of main effect of sulphur deposition rate on a habitat quality index, HQI; c) slope of main effect of nitrogen deposition rate on HQI.

Results for other habitats

In the other habitats assessed, for some positive-indicator species there was a decline in habitat suitability with increasing plant productivity, but an overriding increase with greater vegetation height, resulting in increasing habitat-suitability with greater N deposition. We therefore excluded species that we considered likely to become dominant under conditions of N enrichment (even when these species are characteristic of the habitat, such as *Calluna vulgaris* in heathlands) from lists used to calculate *HQI* (Table UK-1). Species that responded positively to N at some sites but that we considered unlikely to become dominant were not excluded. The choice of species to exclude would be better made on the basis of survey evidence, and guidance is also needed from habitat specialists, so the results may be subject to revision.

Table UK-1. Species excluded from lists of positive indicator-species used to calculate a habitat quality metric, HQI, for three habitats.

Habitat	**Species excluded**	
E1.7 Closed non-Mediterranean dry acid and neutral grassland	*Calluna vulgaris*	*Erica cinerea*
F4.11 Northern wet heaths	*Calluna vulgaris* *Erica cinerea* *Ulex gallii*	*Ulex minor* *Vaccinium vitis-idaea*
F4.2 Dry heaths	*Agrostis stolonifera* *Molinia caerulea*	*Calluna vulgaris* *Erica cinerea*

Data were submitted on the basis of the revised indicator-species lists for subsets (*ca*. 1000 randomly-selected sites per habitat) of the UK 1x1 km squares that contain: E1.7 (Closed non-Mediterranean dry acid and neutral grassland), F4.11 (Northern wet heaths) and F4.2 (Dry heaths).

Variation in values of CLS_{max} for these habitats is shown in Figure UK-4. The responses remained problematic for E3.52 (Heath *Juncus* meadows and humid *Nardus stricta* swards) even after excluding dominant species, and data were not submitted for this habitat. The results (Figures UK-3a and UK-4) illustrate an overall decrease in acid-sensitivity from Dry acid grassland to Dry heath to Wet heath to Bog, reflecting greater numbers of rather acid-tolerant species in the latter habitats.

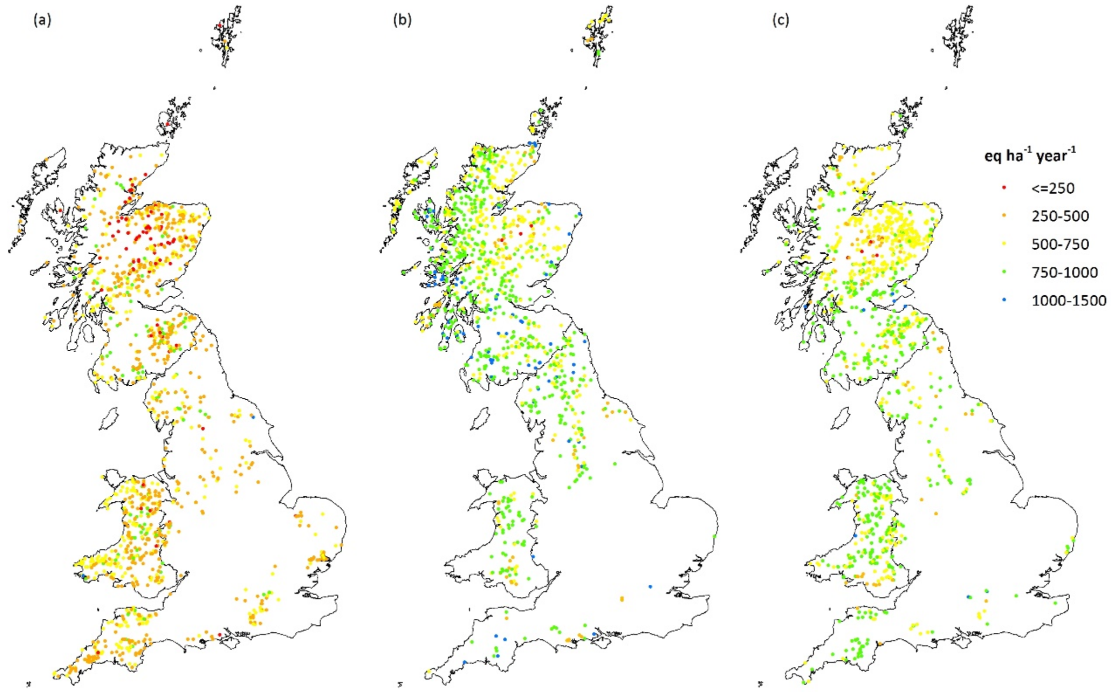


Figure UK-4. Geographical variation in CLSmax values from fitted biodiversity-based Critical Load functions, for: a) E1.7 Closed non-Mediterranean dry acid and neutral grassland; b) F4.11 Northern wet heaths; and c) F4.2 Dry heaths.

Conclusions

Calculating CL_{bdiv} functions for large sets of sites allows exploration of typical values and variation. Since the critical value for *HQI* is calculated using $CL_{emp}N$, the value of CLN_{max} is generally close to that of $CL_{emp}N$. Values of CLS_{max} calculated for bog sites were typically 50-100 % greater than values of $CL_{max}S$, which may indicate that it takes considerable quantities of S deposition to cause the same degree of damage to bog habitats as does deposition above the empirical CL for N. Results were strongly affected by the choice of positive indicator-species.

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Appendix A: (reprint of) Call for Data 2015-17: Instructions

Version 12 Oct 2016

Coordination Centre for Effects (CCE)

Introduction

At the 1st Joint Session of the Steering Body to the EMEP and the Working Group on Effects (Geneva, 14-18 September 2015) the Coordination Centre for Effects was requested to issue a Call for Data in the autumn of 2015 with a deadline in 2017. As announced at the ICP M&M meetings in Dessau (19-22 April 2016), the **deadline is set at 30 January 2017**.

This document contains the instructions on how to reply to this Call for Data 2015-17. The call asks for (updates of) critical loads of acidification (SMB model), eutrophication (CLnutN from SMB or CLempN), and critical loads of N and S for protecting plant species diversity.

Please note:

1. Even if nothing has changed in the derivation of (some of) your critical loads, and they are still valid, you have to re-submit them. There will be no mixing and merging of older and the new data base.
2. Use only the latest database template for submitting your critical loads

Documentation and other general information

To facilitate the integration into the European database at the CCE, you should use the Access database template developed by the CCE. This template is described in Section 5 and can be downloaded from the CCE website. Excel-files and comma-delimited text files will be accepted, if the column headers are identical to the variable names of section 5.

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

Please email your submission to jaap.slootweg@rivm.nl. The compressed (zipped) data can be attached to the email. Since we occasionally experienced blocking of emails, due to size or spam-filters, a submission should be accompanied by a separate, text-only mail to be able to verify the arrival of the submission.

Types of Critical Loads and how to submit them

We now distinguish three types of critical loads (variable names are also used in the Tables in Section 5):

(1) **Critical loads of acidity *(CLacid)***: This is characterised by a Critical Load Function (CLF) of S and N (See Figure V.3 in the Mapping Manual) and is quantified by by $CL_{max}S$, $CL_{min}N$ and $CL_{max}N$, and generally computed by the SMB model.

(2) **Critical loads of eutrophication *(CLeut)***: For eutrophication by N the critical load can either be computed by the SMB model (formerly known as $CL_{nut}N$) or by an empirical CL (as summarised in Bobbink and Hettelingh 2011) (formerly known as $CL_{emp}N$). In line with the definition of a critical load, if both a $CL_{nut}N$ and a $CL_{emp}N$ are determined for same ecosystem, the CL of eutrophication, denoted as $CL_{eut}N$, is the minimum of both. And only $CL_{eut}N$ should be reported.

(3) **Biodiversity critical loads *(CLbdiv)***: Vegetation modelling can be used to establish limits of chemical variables (e.g., a minimum pH and maximum N concentration) at which typical/desired/key plant species for a habitat/ecosystem can thrive/survive. Values for N and S deposition combinations, i.e. a critical load function, can then be derived with soil-chemical models (e.g. SMB) and associated data. These biodiversity N and S critical loads are named (in analogy to acidification) CLN_{min}, CLS_{max}, and CLN_{max}, CLS_{min} (see Figure 1).

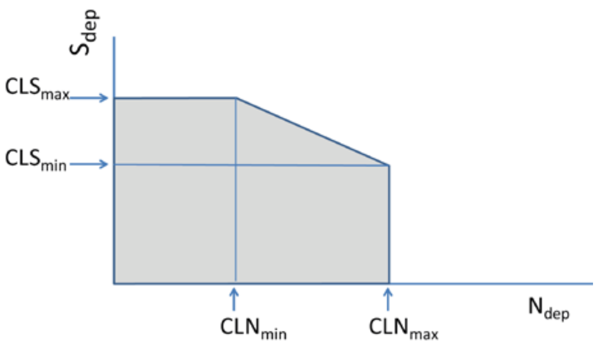

Figure 1: Critical load function for biodiversity, characterised by the two points (CLN_{min},CLS_{max}) and (CLN_{max},CLS_{min}) (see Chapter 3 in CCE Status Report 2015, www.wge-cce.org).

The grid system

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

Access Database template

The Tables in the database have different purposes and are listed below.
ecords – General site data, such as coordinates.
CLacid, *CLeut*, *CLbdiv* – Critical loads, one table for each type, with its related limits.
SiteInfo – General background data for the site.

Table 1. Attributes of the database-table 'ecords'

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

Notes on Table 1 (see last column):

1) Use integer values only (4-bytes)!
2) The geographical coordinates of the site or a reference point of the polygon (sub-grid) of the receptor under consideration (in decimal degrees, i.e. 48.533 for 48º31', etc.);
3) Please don't submit spurious records with an ecosystem area smaller than 0.5 ha, unless it has relevance other than for exceedance calculations (e.g. a Natura 2000 site). Furthermore, make sure that the total ecosystem area does not exceed the size of the land area of your country in the respective grid cell;
4) You can find information on EUNIS at http://eunis.eea.eu.int/

Table 2. Attributes of the database-table 'CLacid'

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

Table 3. Attributes of the database-table 'CLeut'

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

Table 4. Attributes of the database-table 'CLbdiv'

Variable	Explanation
SiteID	Identifier of the site (see *ecords* Table)
CLNmin	Minimum critical load of nitrogen (eq ha^{-1} a^{-1})
CLSmax	Maximum critical load of sulphur (eq ha^{-1} a^{-1})
CLNmax	Maximum critical load of nitrogen (eq ha^{-1} a^{-1})
CLSmin	Minimum critical load of sulphur (eq ha^{-1} a^{-1})
HScrit	Value of the Habitat Suitability index ud for deriving CLbdiv

Table 5. Attributes of the database-table 'SiteInfo'

Variable	**Explanation**
SiteID	Identifier of the site (see *ecords* Table)
thick	Thickness (root zone!) of the soil (m)
nANCcrit	The quantity $-ANC_{le(crit)}$ (eq ha^{-1} a^{-1})
Cadep	Total deposition of calcium (eq ha^{-1} a^{-1})
Mgdep	Total deposition of magnesium (eq ha^{-1} a^{-1})
Kdep	Total deposition of potassium (eq ha^{-1} a^{-1})
Nadep	Total deposition of sodium (eq ha^{-1} a^{-1})
Cldep	Total deposition of chloride (eq ha^{-1} a^{-1})
Cawe	Weathering of calcium (eq ha^{-1} a^{-1})
Mgwe	Weathering of magnesium (eq ha^{-1} a^{-1})
Kwe	Weathering of potassium (eq ha^{-1} a^{-1})
Nawe	Weathering of sodium (eq ha^{-1} a^{-1})
Caupt	Net growth uptake of calcium (eq ha^{-1} a^{-1})
Mgupt	Net growth uptake of magnesium (eq ha^{-1} a^{-1})
Kupt	Net growth uptake of potassium (eq ha^{-1} a^{-1})
Qle	Amount of water leaving at the bottom of the root zone (mm a^{-1})
lgKAlox	Equilibrium constant for the Al-H relationship (log10) (The variable formerly known as K_{gibb})
expAl	Exponent for the Al-H relationship (=3 for gibbsite equilibrium)
cOrgacids	Total concentration of organic acids (m*DOC) (eq m^{-3})
Nimacc	Acceptable nitrogen immobilised in the soil (eq ha^{-1} a^{-1})
Nupt	Net growth uptake of nitrogen (eq ha^{-1} a^{-1})
fde	Denitrification fraction ($0 \leq fde < 1$) (-)
Nde	Amount of nitrogen denitrified (eq ha^{-1} a^{-1})
Prec	Annual precipitation (mm a^{-1})
TempC	Annual average temperature (°C)
CNrat	C/N ratio in the topsoil (g g^{-1})
Measured	On-site measurements included in the data for CL calculations: 0: No measurements, 1: ICP Forest, 2: ICP Waters, 4: ICP Integrated Monitoring, 8: ICP Vegetation, 16: Other measurement programme. (if more than one of the listed possibilities applies, add the numbers!)

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Appendix Z

"Alea iacta est" (The die is cast)
Julius Caesar in 49 BCE after crossing the Rubicon

"*You got to roll me and call me the tumblin' dice*"
Rolling Stones in 1972 CE, album 'Exile on Main St.'

At the suggestion of our former CCE colleague Peter de Smet, we provide below the net of the cube shown on the cover. Cutting it out, you can glue it together and view it from different angles ...

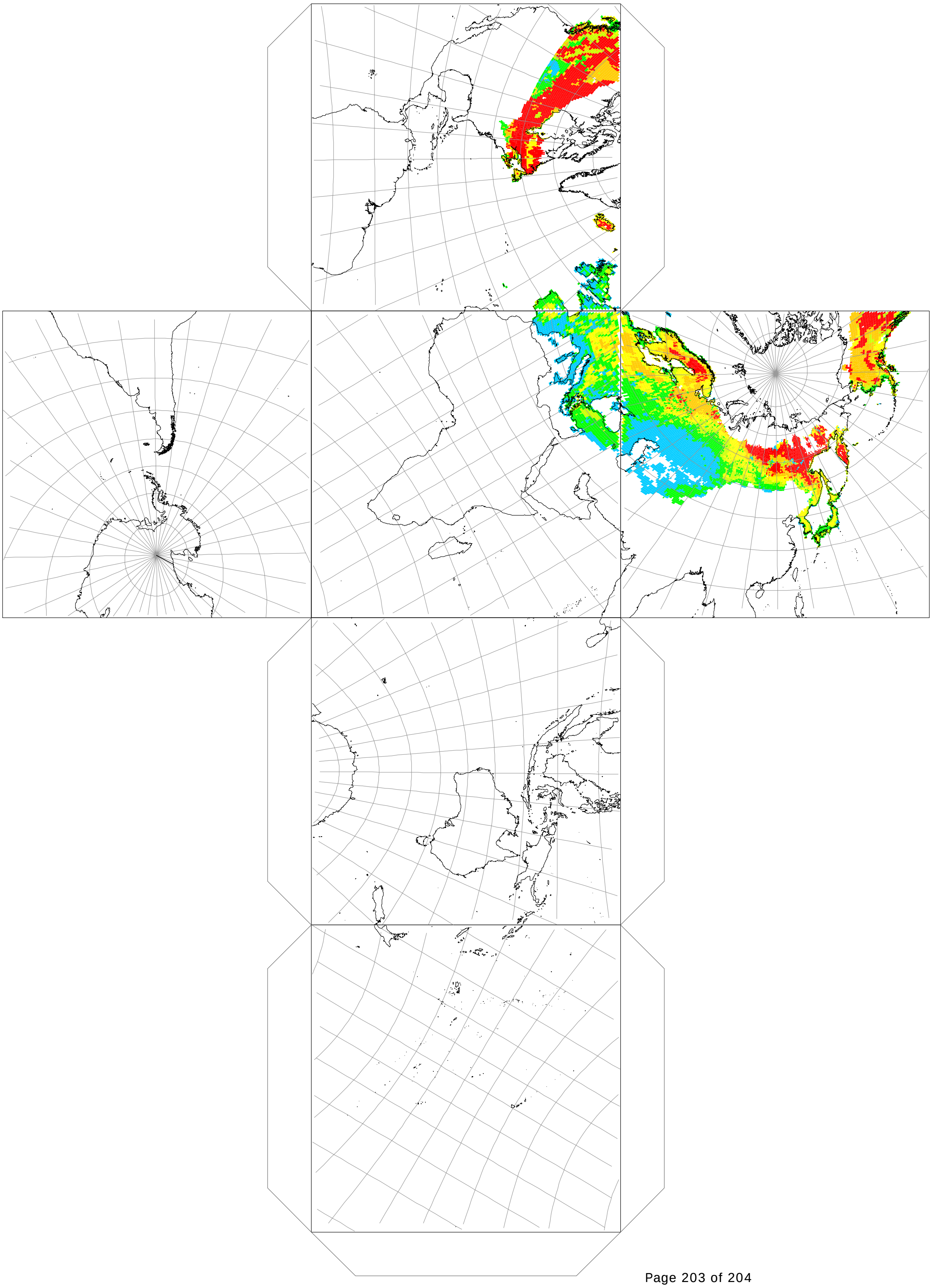
The map on the cube shows the 5-th percentile of the acidity $CL_{max}S$, computed for the northern Northern Hemisphere in Reinds et al. (2015).

References:

De Vries W, Hettelingh J-P, Posch M (eds), 2015. *Critical Loads and Dynamic Risk Assessments: Nitrogen, Acidity and Metals in Terrestrial and Aquatic Ecosystems.* Environmental Pollution Series Vol. 25, Springer, Dordrecht, xxviii+662 pp.; ISBN 978-94-017-9507-4; DOI: 10.1007/978-94-017-9508-1

Reinds GJ, Posch M, Aherne J, Forsius M, 2015. Assessment of critical loads of sulphur and nitrogen and their exceedances for terrestrial ecosystems in the northern hemisphere. Chapter 15 in: De Vries et al. (eds), *op.cit.*, pp. 403-417; DOI: 10.1007/978-94-017-9508-1_15

Overleaf: Net of the cube onto which Earth is projected, with Bilthoven at a corner.



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