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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 [m^3 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.

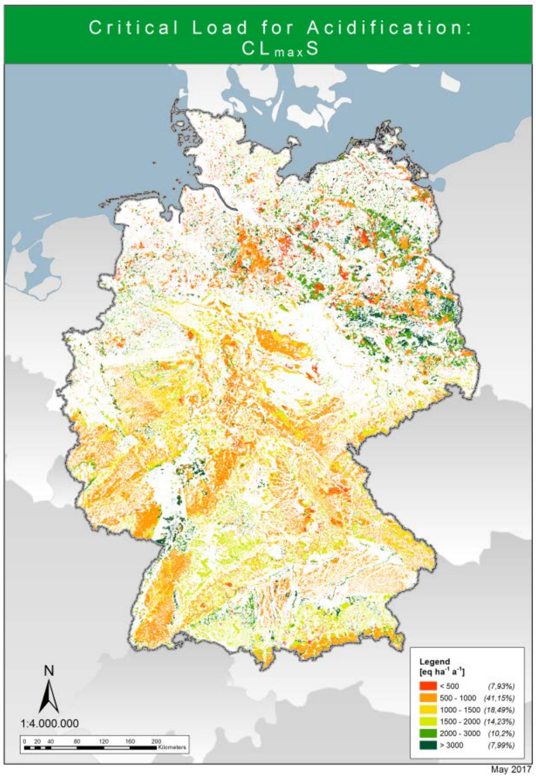

Figure DE-1. Critical loads for acidifying compounds in Germany in terms of Sulphur, $CL_{max}S$.

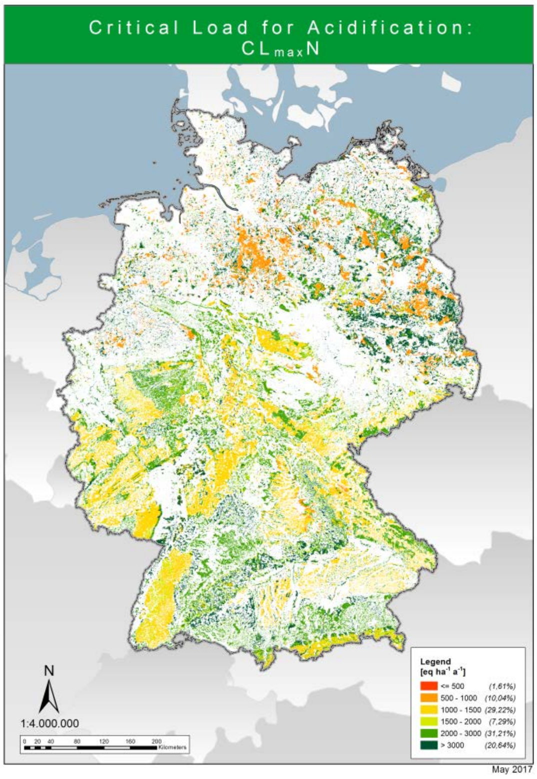

Figure DE-2. Critical loads for acidifying compounds in Germany in terms of Nitrogen, $CL_{max}N$.

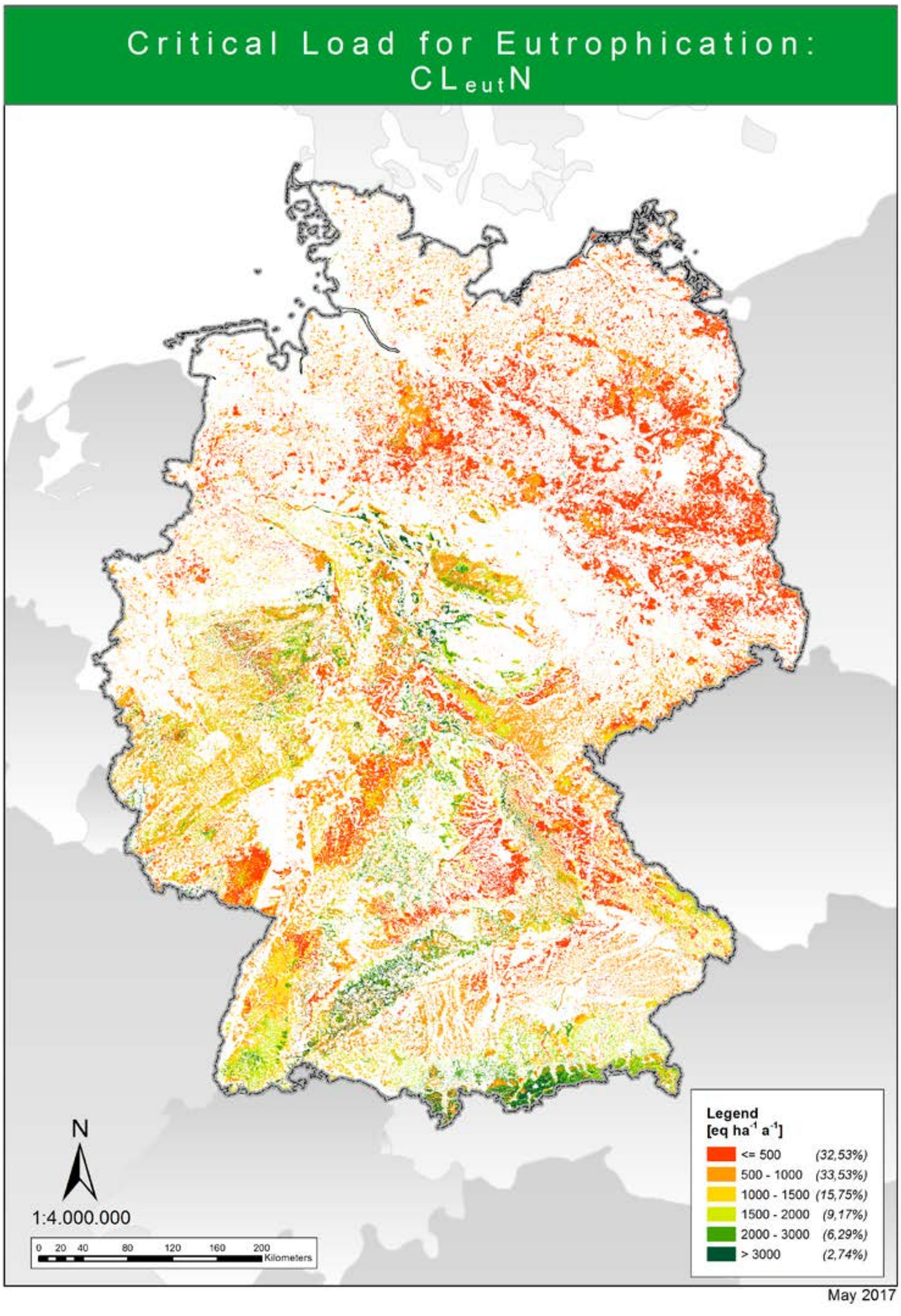

Figure DE-3. Critical loads for eutrophication in Germany, $CL_{eut}N$.

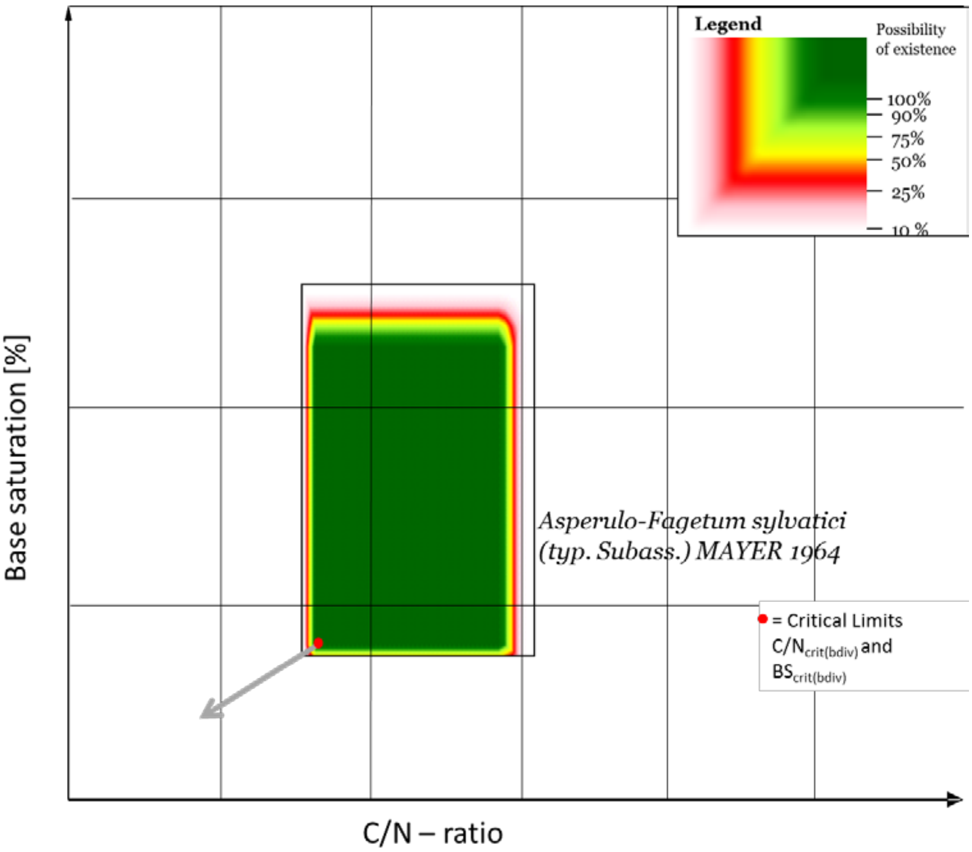

Figure DE-4. Principle for the calculation of critical limits from the possibility function of the plant society, using the example of Asperulo-Fagetum sylvatici. The grey arrow indicates the trend of nutrient imbalance after acidification and eutrophication, the red point define the critical limits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

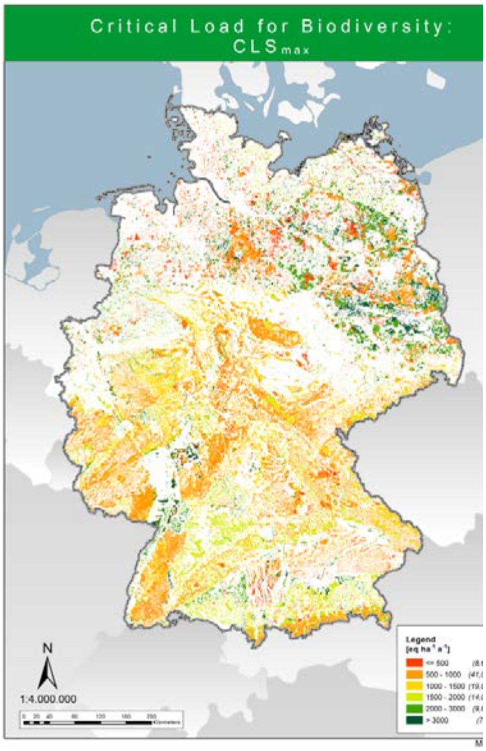

Figure DE-5. *Critical load to protect biodiversity in terms of sulphur, CLS_{max}.*

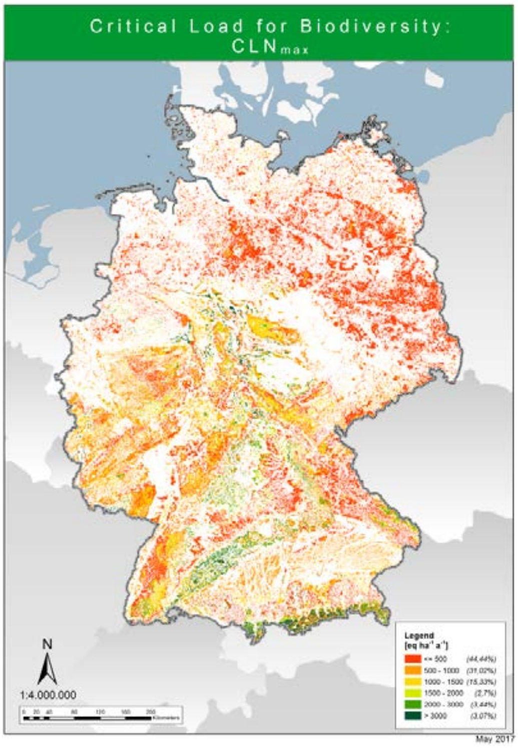

Figure DE-6. *Critical load to protect biodiversity in terms of nitrogen, CLN_{max}.*

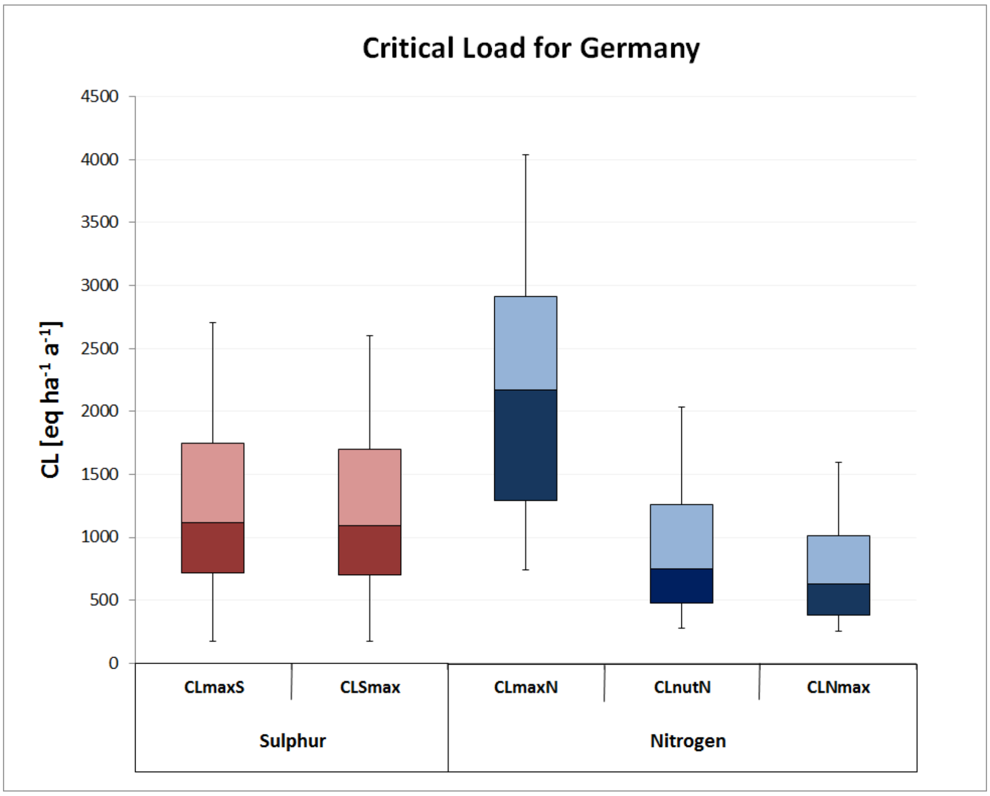

Figure DE-7. Distributions of the submitted critical load datasets.

References

BGR (Bundesanstalt für Geologie und Rohstoffe) (Hrsg.), 2014a. Nutzungsdifferenzierte Bodenübersichtskarte 1 : 1 000 000 (BÜK1000N) für Deutschland (Wald, Grünland, Acker)

BGR (Bundesanstalt für Geologie und Rohstoffe) (Hrsg.), 2014b. Landnutzungsdifferenzierte mittlere jährliche Sickerwasserrate aus dem Boden (SWR1000)

Bobbink RS, Hettelingh J-P (eds), 2011. Review and revision of empirical critical loads and dose-response relationships, Proceedings of an international workshop, Noordwijkerhout 23-25 June 2010, PBL-CCE/B-Ware Report 680359002, Bilthoven; www.wge-cce.org

CCE, 2001. NFC Report of Germany. In: CCE Status Report 2001, p.142

CCE, 2016. Call for Data 2015-2017: Instructions, Coordination Centre for Effects, Bilthoven, 12 October 2016; (www.wge-cce.org/Activities/Call_for_Data)

CLRTAP, 2016. Mapping critical loads for ecosystems, Chapter V of Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. UNECE Convention on Long-range Transboundary Air Pollution; accessed 08.03.2017 at www.icpmapping.org

DWD (Deutscher Wetterdienst), 2012. Mittlere Tagesmitteltemperatur und Jahresniederschlagssummen der Referenzperiode 1981 - 2010 für Sommer und Winter. Rasterdatei.

Schaap M, Wichink Kruit R, Hendriks C, Kranenburg R, Segers A, Builtjes P, Banzhaf S, Scheuschner T, Nagel H-D, 2017. Modelling and assessment of acidifying and eutrophying atmospheric deposition to terrestrial ecosystems (PINETI2) Part I: Atmospheric deposition to German natural and semi-natural ecosystems during 2009, 2010 and 2011, UBA-Project No. (FKZ) 3712 63 240 - 1

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

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

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