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The respond of the German NFC to the Call for Data (CCE 2014) focus on new developed critical load based on biodiversity. Despite this, the “classical” critical load protecting ecosystems against acidification and/or eutrophication was submitted as well. The dataset was completed by the empirical critical load values for EUNIS classes relevant for Germany (see table DE-1). The German dataset consists of 540,019 records representing 29.7 percent of the territory. Unlike the former data submissions, now the critical loads were computed based on polygons instead of the former 1 km² grid structure.

Table DE - 1: EUNIS classification for selected receptors of the critical load computation in Germany

EUNIS Code	Proportion of the receptor area [%]	Proportion of German territory [%]	EUNIS Code	Proportion of the receptor area [%]	Proportion of German territory [%]
A.x	0.03	0.01	G1.8	0.16	0.05
D.x	1.06	0.31	G1.A	0.99	0.29
E.x	1.34	0.39	G3.1	28.51	8.36
F.x	0.28	0.08	G3.4	13.06	3.83
G1.2	1.63	0.48	G3.E	0.90	0.26
G1.4	0.29	0.08	G4.3	10.24	3.00
G1.5	0.76	0.22	G4.7	0.18	0.05
G1.6	20.77	6.09	G4.F	19.80	6.20

Mass balance based critical load of sulphur and nitrogen

Critical loads are calculated following the methods described in the Mapping Manual (ICP Modelling & Mapping 2015). New data of long-term annual means of precipitation surplus (1980 – 2010) were available (BGR 2014a) and with a new land use dependent soil map (BGR 2014b) more detailed information on soil dependent input parameter could be derived. The former 72 soil units now are sophisticated into 674 combination types of soil form, landuse form and climate zone. For each of these combination types a typical soil profile is attached. A lot of soil chemically and physically data are attributed to the horizons, such as field capacity, row density, pH-class, CEC, class for organic matter and others. Furthermore new deposition estimates for base cations and chloride were available (PINETI 2015). A sensitivity study for the influence of the changed parameters was conducted (see below).

Critical load of Acidity, $CL_{max}S$ and $CL_{max}N$

The calculation of critical load of acidifying sulphur for forest soils and other (semi-) natural vegetation was conducted according to the simple mass balance equation V.22 of the Mapping Manual. For base cation and chloride deposition the 3-year means (2009 – 2011) were included in order to smooth large variations of this parameter due to meteorological influences (PINETI 2015). The critical load calculation for each polygon of the dataset was done by using 3 different chemical criteria: the critical aluminium concentration (equation V.29), the critical base cation to aluminium ratio (equation V.31) and the critical pH-value (equation V.35). The minimum value determines the $CL_{max}S$ for the specific ecosystem.

The critical load for acidifying nitrogen, $CL_{max}N$, was computed with equation V.26 of the Manual.

Empirical and mass balance critical load of nutrient nitrogen, $CL_{emp}N$ and $CL_{nut}N$

The mass balance based calculation of critical load of nutrient nitrogen is described in detail in the Mapping Manual (equation V.5). Different criteria and, consequently, different protection targets were used for acceptable N concentrations in soil solution for the critical load computation. Following the Manual (Chapter V.3.1.2 and Table V.5) the limit can be set between 0.2 mg N per litre (vegetation change from lichens to cranberry) and 6.5 mg N per litre (upper range for deciduous forest). Specific values for acceptable N concentrations $[N]_{crit}$ were derived on the base of these ranges due to computed specific critical load for NATURA 2000 habitat types in Germany BMVBS 2013. For 1990 various habitat types specific $[N]_{crit(plant)}$ are published (ARGE StickstoffBW 2014).

Table DE - 2: Matrix of applied acceptable N concentrations in soil solution (adaption of Manual Table V.5)

Sensitive species of the vegetation type	N_{crit} [mg N/l]
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

In addition to the calculation of critical loads with the steady-state mass balance approach empirical critical loads of nitrogen ($CL_{emp}N$) following the updated and reviewed values from the expert workshop in Noordwijkerhout 2010 (Bobbink & Hettelingh 2011) were broadly assigned to national maps. The difference between these approaches is fundamental and ranges from different levels of uncertainty to protection aims which are not congruent. Therefore the $CL_{nut}N$ and the $CL_{emp}N$ for Germany should not be mixed or combined in order to derive another critical load dataset. Only the German $CL_{nut}N$ dataset shall be used in integrated assessment modelling and not the minimum value of both as discussed as the ICP M&M meeting in Zagreb.

Critical load to protect biodiversity

Description of the model approach

The model BERN (**B**ioindication for **E**cosystem **R**egeneration towards **N**atural conditions) was designed to integrate ecological cause-effect relationships into environmental assessment studies including the derivation of critical load (Schlutow et al. 2015).

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 including more than 45,000 relevés at more than 7,600 locations in Europe. It is assumed that these 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 percent 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 site state parameters 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):

- 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).

Input parameters from the BERN model for biodiversity critical load

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 "Simple Mass Balance" (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-1). Complying with these values, the natural reference plant community just can exist at the maximum possibility of its occurrence (100 percent). We define the values as critical limits.

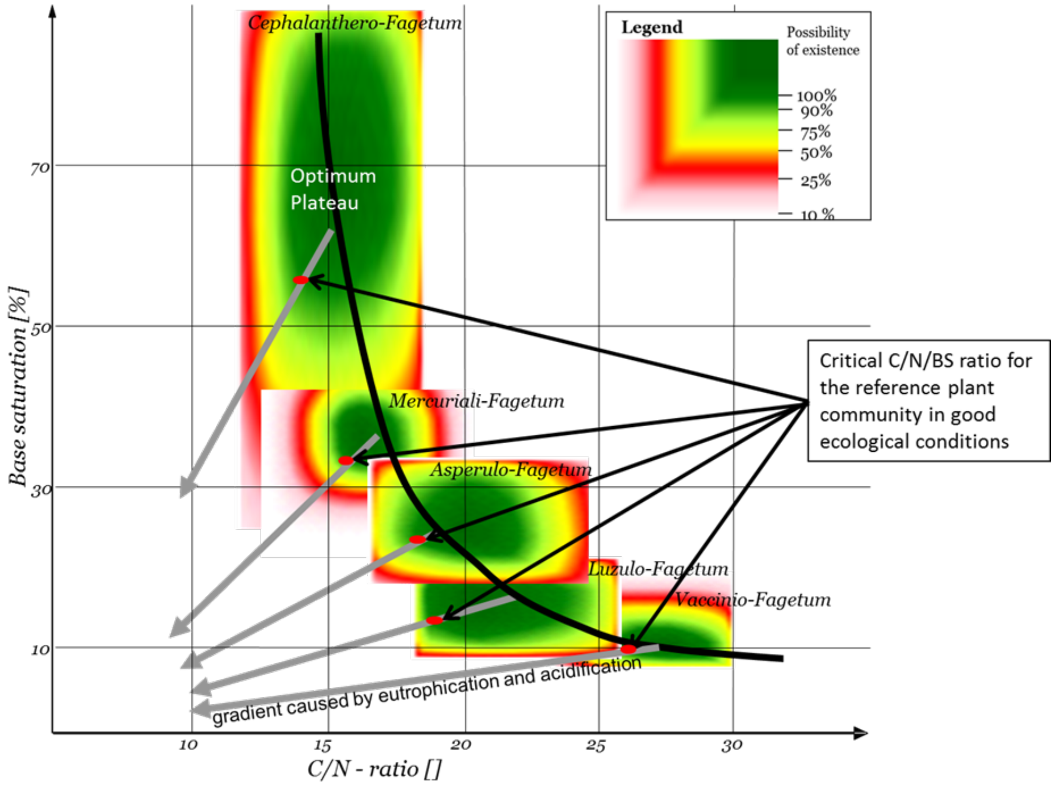

Figure DE-1: (1) The red-to-green fields show the distribution of the possibility function of all beech communities in the planar-subatlantic region with a plane relief, groundwater distance >2 m; (2) the black line shows an obviously regular arrangement of the natural plant communities, which demarcates an indirect proportional correlation between the base saturation and C/N-ratio at the optima of possibility ranges; (3) the grey arrows indicate the trend of nutrient imbalance after acidification and eutrophication; (4) the red points define the critical limits of the communities.

Biodiversity critical load for Acidification

The substitution of the critical limits found in the "classical" critical load calculation with threshold determined by plant communities allows the application of the SMB approach as described in the mapping manual. For the threshold of acid deposition (CLS_{max}) the critical base saturation ($BS_{crit(biodiv)}$) e.g. could be used in equation V.38. In addition the critical acid neutralization capacity ($ANC_{le(crit)}$) was computed using the empirical GAPON exchange coefficients (deVries and Posch, 2003) as well as the relation H^+/Al^{3+} (Table V.9 of the Manual).

Biodiversity critical load for Eutrophication

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 $[N]_{crit(biodiv)}$ in order to fit into the simple mass balance equations according to the manual (eq. V.6). The following approach is proposed.

$$[N]_{crit(biodiv)} = \frac{N_{\min(crit)}}{\theta \cdot z} \text{ with } N_{\min(crit)} = N_{t(crit)} - N_u - N_{de} - N_{org}$$

with

$[N]_{crit(biodiv)}$ = 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)

$N_{t(crit)}$ = 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}]

$$N_{t(crit)} = \frac{C_{org}}{C/N_{crit(biodiv)}} \text{ mit } C_{org} = \frac{OM \cdot \rho \cdot z}{f_{C/OM}}$$

with:

C_{org} = amount of organically fixed carbon as long-term annual mean [kg C m^{-2}]

OM = share of organic matter in the soil [%]

$f_{c/OM}$ = transformation factor ($f_{c/OM} \approx 1{,}72$ for mineral soils and $f_{c/OM} \approx 2$ for peats and humus soil layers)

ρ = dry bulk density of the soil [g cm^{-3} = 1000 kg m^{-3}]

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

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 θ, z, OM, ρ and clay content 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. This landuse specific database is provided by the BGR (2014b). 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 $[N]_{crit(biodiv)}$ for the same community; therefore the values for the $[N]_{crit(biodiv)}$ needed aggregation to one value. The 50th percentile (median) was chosen as threshold representing a rather conservative approach since the maximum values still contain vital plant communities. The choice for median was made in order to reduce data uncertainties which might lead to unrealistic results.

The results for natural and semi-natural plant communities range between 0.07 mg l^{-1}(5th percentile) and 4.7 mg l^{-1} (95th percentile) with a median of 1.2 mg l^{-1}.

Results

The regional distribution of resulting critical load to protect biodiversity is shown for Sulphur, CLS_{max} in Figure DE-2 and nitrogen, CLN_{max} in Figure DE-3 and the results for the "classical" critical load is shown in Figure DE-4 and Figure DE-5.

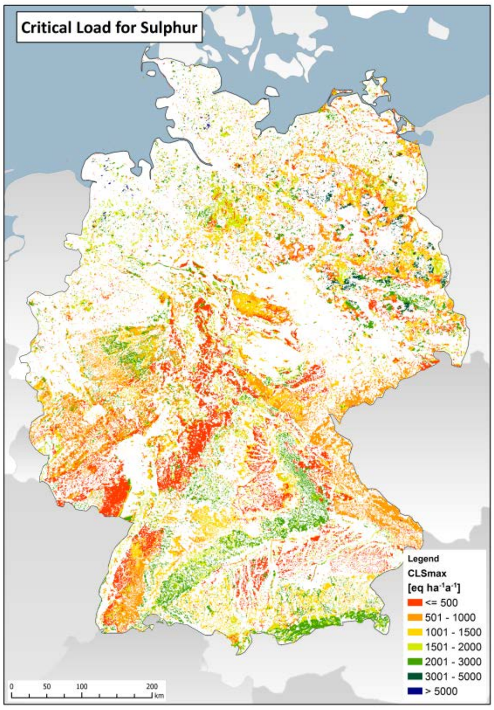

Figure DE-2: CLS_{max}

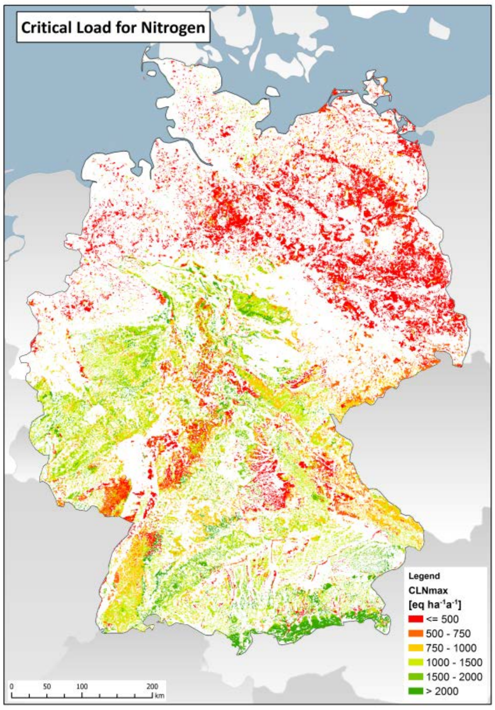

Figure DE-3: CLN_{max}

In comparison with the “classical” critical load computed with critical limits according to Table DE-1 the application of new critical limits to protect biodiversity derived from the BERN database result in a higher sensitivity of acid and nitrogen deposition. Ecosystems with high risk for acidification (CLS_{max} below 500 eq ha^{-1} a^{-1}) were identified for about 25 percent of receptor area instead of 17 percent without biodiversity limits. And more than 30 percent of the ecosystems showed biodiversity critical load for nitrogen deposition below 500 eq N $ha^{-1}yr^{-1}$ (see Table DE-2). In addition Figure DE-6 shows the overall distribution of the resulting datasets and underpins the trends described above.

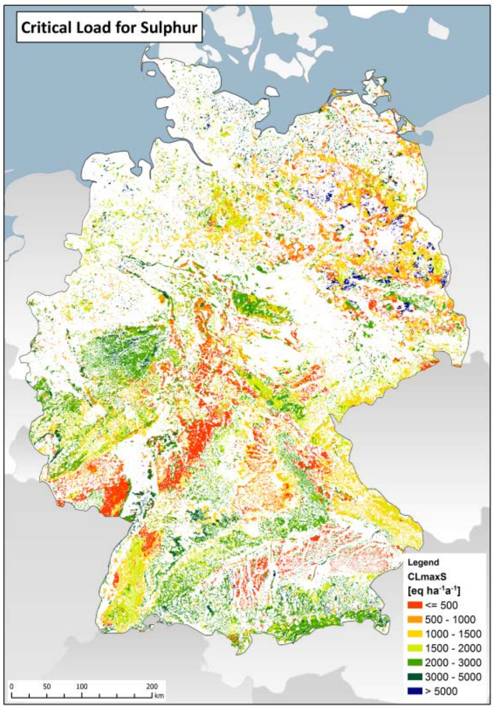

Figure DE-4: $CL_{max}S$

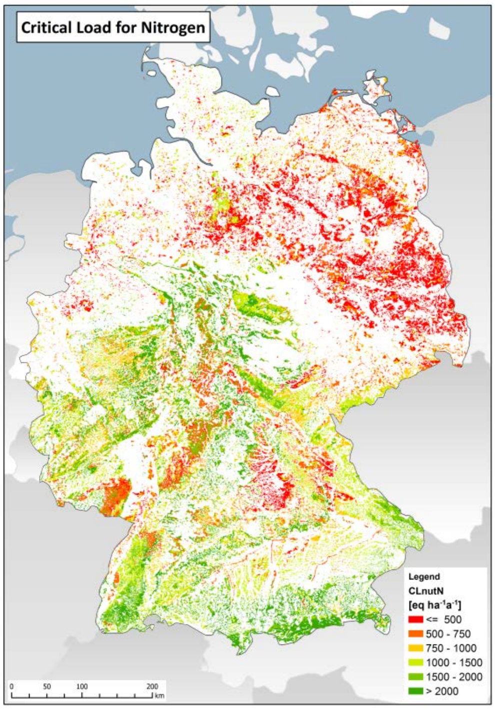

Figure DE-5: $CL_{nut}N$

Table DE - 3: Results for different critical load approaches (share of the receptor area in [%])

Range [eq ha^{-1} a^{-1}]	$CL_{max}S$ (1)	CLS_{max} (2)	$CL_{max}N$ (1)	$CL_{nut}N$ (1)	CLN_{max} (2)	$CL_{emp}N$ (3)
< 500	17.56	25.21	0.06	21.53	30.84	0.00
500 - 1000	11.49	24.94	15.04	29.57	27.39	63.39
1000 - 1500	18.92	21.06	11.04	19.31	27.18	36.13
1500 - 2000	18.17	11.74	9.98	12.55	7.96	0.48
2000 - 3000	27.18	15.39	63.88	17.04	6.64	0.00
3000 - 5000	4.81	1.52				
> 5000	1.87	0.13				

(1) “Classical” critical load applying the SMB method as described in Chapter V.3 of the Mapping Manual (data submitted with the CFD 2015)

(2) Critical load of biodiversity resulting from the BERN model (data submitted with the CFD 2015)

(3) Empirical critical load according to Bobbink & Hettelingh 2011

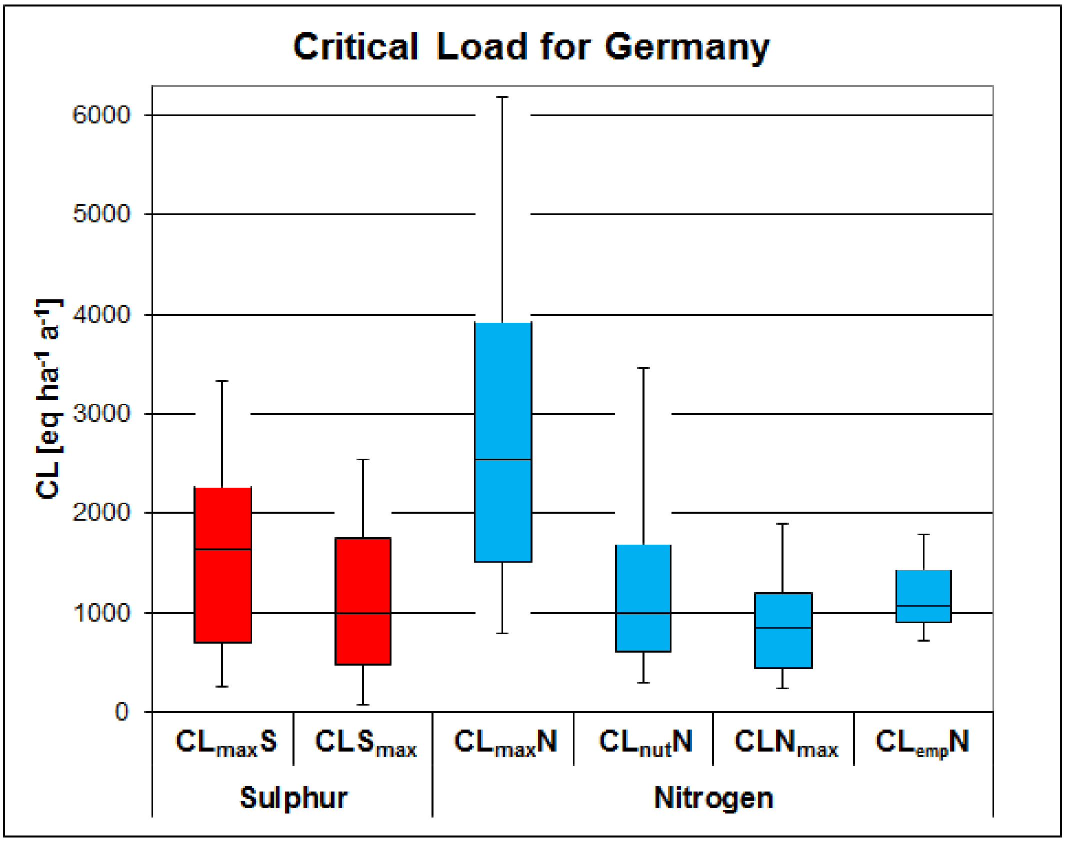

Figure DE-6: The distribution of the submitted critical load datasets

Critical load sensitivity

Updates for several input parameter are available and were included in the latest critical load computation. In order to estimate the impact of the changed input parameters a sensitivity analysis was carried out. The results of a reference run (calculation with the current method and most recent input data) were compared with results for simulation runs (calculation with the current method but changed input parameters). The changed considered parameters are:

- precipitation surplus *PS* [mm]
- deposition of base cations BC_{dep} [eq ha^{-1} a^{-1}]
- uptake of base cations and nitrogen Bc_u [eq ha^{-1} a^{-1}] and N_u [eq ha^{-1} a^{-1}].

For the selection of the subset for the sensitivity analyses the GIS data sets of the most recent input data of *PS* and BC_{dep} were intersected with the old input data for critical load submission (see CCE Status Report 2012 p.81 ff.). The changes of *PS* and BC_{dep} from one dataset to another are not evenly distributed and contain spatial patterns. Therefore cumulative distribution functions (CDFs) of the changes were calculated. Such CDFs allow the identification of the real-value of the parameter at different levels of probability (percentiles). Values at the 5th and the 95th percentile and equal to the median were selected for the sensitivity analysis. The absolute parameter values at the percentiles thresholds (5th, 50th and 95th) for *PS* and BC_{dep} were chosen as the constant absolute change of the input parameters for the simulation. This approach implies a constant absolute change of the input parameters (for the different percentiles) but realistic variations in the reference input data. The change of the uptake input data doesn't show spatial patterns and was therefore excluded from this identification process.

The method and input data of the reference run is equal to the data of the recent call for data submission. Four critical load calculations were performed in addition to the reference run. Three runs with single variating input parameter (*PS*, BC_{dep} and Bc_u/N_u) and one run with variation of all parameters.

Firstly, the absolute change of the input parameter was compared with the absolute change of the critical load ($CL_{nut}N$ and $CL_{max}S$). In order to identify the direction of the dependency and to qualify the sensitivity of critical load based on changes in the input data. Therefore, the slope of the linear regression was chosen as indicator for the strength and direction of the impact of the parameter. Secondly, the resulting critical load in the reference and the simulation run was compared directly. This analysis provided the standard deviation of the absolute (SD abs. in [eq ha^{-1} a^{-1}]) and relative (SD rel. in [%]) critical load change as indicator for the spread around the mean critical load change. A further parameter out of this direct comparison is the coefficient of determination (R^2) of the regression.

Table DE - 4: Influence of precipitation surplus (PS), deposition of base cations (BC_{dep}) and uptake of nitrogen/base cations (N_u/Bc_u) on the change of calculated critical loads. Table shows calculated results for the slope of the linear regression between absolute change of input parameter and critical load (Slope), the coefficient of determination (R^2) and the standard deviation (absolute/relative) of the change of critical load results (SD (abs./rel.)) for the critical load of eutrophication ($CL_{nut}N$) and acidification ($CL_{max}S$).

	$CL_{nut}N$				$CL_{max}S$			
	Slope	R^2	SD abs. [eq ha^{-1} a^{-1}]	SD rel. [%]	Slope	R^2	SD abs. [eq ha^{-1} a^{-1}]	SD rel. [%]
PS	2.5	0.98	266	8.9	0.5	1.00	64	6.0
BC_{dep}	0.0	1.00	0	0.0	1.5	0.97	234	75.3
N_u/Bc_u	1.0	0.99	138	12.0	-1.2	0.91	374	49.6
All		0.97	305	13.5		0.90	403	253.1

The results in *Table DE - 4* are based on the analysis of all five runs and give indication about impact strength and direction of the different input parameters (single and as combination) as well as the relative and absolute impact on the critical load.

The *PS* is positively correlated with the $CL_{nut}N$ and $CL_{max}S$ which was expected because the amount of leaching water determinates the amount of accepted nitrogen leaching ($N_{le(acc.)}$) and the $ANC_{le.}$. The data also indicates, that the effect on $CL_{nut}N$ is stronger (see slope) and is more scattered (see SD (abs./rel.) and R^2) than the effect on $CL_{max}S$. The reason for these differences is caused by differences in the equations for the N_{le} and ANC_{le} within the calculation of the $CL_{nut}N$ and the $CL_{max}S$, respectively.

The BC_{dep} has of course no effect on the $CL_{nut}N$ and a strong positive effect on $CL_{max}S$ which is easy to comprehend. The more base cations are available the more acid neutralization potential has an ecosystem. The changes in the BC_{dep} have rather small impact in absolute numbers (see SD abs.) but quite high impact on the relative change of the critical load (see SD rel.). This might be an indication for higher sensitivity to changes of BC_{dep} on sites with rather low critical load for acidification.

The effect of a changing site growth potential (N_u and Bc_u) is bidirectional. While the effect on $CL_{nut}N$ is positive, the effect on $CL_{max}S$ is the opposite and seems to be a bit stronger. Again this was anticipated since higher uptake of nitrogen means higher site potential of nitrogen fixing. On the other hand higher uptake of base cations means less site potential of acid neutralization.

Comparing the strength of the different parameters it seems that the *PS* has the highest impact on the $CL_{nut}N$ (Slope = 2.5). On the other hand the *PS* has the lowest impact on the $CL_{max}S$, while the deposition of base cations (BC_{dep}) has the highest influence (Slope = 1.5).

Applying changes on all selected input parameters show the highest scatter (SD and R^2). Especially the relative impact on the $CL_{max}S$ (see SD rel.) is remarkable and gives an indication for increased sensitivity to changes of the input parameters on sites with low critical load. An overall trend for the recent critical load dataset (e.g. generally higher/lower than the previous one) was not detected. The trend varies from region to region since not only average numbers of the input parameters changed but also the spatial pattern within Germany.

Conclusions

The critical load approach offers a number of tools to parameterize biodiversity targets. Obviously, the determination of the protection aim is the most crucial part. This report proposes a method combining ecological niches of 226 German plant communities with specific limits of soil properties (C/N ratio, base saturation) to ensure high vitality and sustainability of these site specific reference species compositions. These specific limits are used to calculate critical load for biodiversity, which are generally more sensitive. Uncertainties of this approach lay in (a) the generalized approach of attribution of soil parameters to vegetation data within the BERN database. Several relevés are combined only with verbal descriptions of the site factors, therefore values for soil chemical and climate parameters were assigned from similar sites. (b) Secondly uncertainties lay in the generalized approach of attribution of vegetation communities to land cover and soil maps.

However the approach can be seen as a first step to map broad scaled Biodiversity critical load. If it is a valuable approach for integration into integrated assessment modelling, has to be proven yet.

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