Arbejdsrapport fra DMU nr. 23

Revision of Calculated Critical Loads for Nitrogen in Denmark

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Miljø- og Energiministeriet, Danmarks Miljøundersøgelser

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Miljø- og Energiministeriet
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Data Sheet

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Abstract:

Critical loads for nitrogen has been calculated for Danish forests. Beech and oak forest have higher critical loads (17-28 kg N/ha/year) than spruce and fine forests (7-15 kg N/ha/year). Empirical critical loads for heathlands and bogs (10 and 5 kg N/ha/year, respectively) have been used for mapping.

Critical loads for nitrogen are presently exceeded in all Danish heathlands and bogs. Spruce and pine forest have exceeded the loads for 91 and 87%, respectively, of total area. For beech and oak forest 58 and 54%, respectively, of total area has exceedances. Exceedances are largest in mid, West and southern parts of Jutland where animal husbandry densities are highest. Ammonia deposition is the most important reason for the calculated exceedances.

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1 Dansk sammendrag

Luftforurening med kvælstofilter og ammoniak er både lokal og grænseoverskridende og medvirker til forsuring og "gødskning" af naturområder og skove. Grænsen for en acceptabel påvirkning kaldes en tålegrænse, der er defineret som et estimat af den højest accepterede deposition af kvælstof til naturområder uden målbare ændringer i økosystemernes struktur eller funktion.

Tålegrænser for kvælstof (incl. kvælstofilter og ammoniak) er beregnet for danske skovområder. Rapporten indeholder den første danske beregning af tålegrænser for kvælstof som næringsstof $Cl_{nut}(N)$ baseret på massebalance-ligningen, og der er anvendt en justeret Multi Machine version af PROFILE.

Bøge- og egeskov har højere tålegrænser (hhv. 17-27 og 17-28 kg N $ha^{-1}år^{-1}$) end gran- og fyrreskov (hhv. 8-15 og 7-10 kg N $ha^{-1}år^{-1}$). De beregnede værdier varierer mellem områder med forskellige skovdriftsformer, jordbundstyper, nedbør og depositioner af basekat-ioner. For heder og højmoser er der anvendt empirisk fastsatte værdier på hhv. 10 og 5 kg N $ha^{-1}år^{-1}$. Figur 1 (øverst) viser, hvordan de beregnede tålegrænser er fordelt geografisk over landet.

Beregningerne viser, at tålegrænsen for kvælstof er overskredet overalt i landet på kvælstoffattige naturtyper som heder og højmoser. For skovene er der er overskridelser især for gran og fyrreskov (hhv. 91 og 87% af arealet), mens overskridelserne for bøge- og egeskov findes på hhv. 58 og 54% af arealet. Overskridelserne varierer lokalt og findes især i Midt- Vest- og Sønderjylland, hvor husdyrtætheden og dermed depositionen fra indenlandske kilder af ammoniak er stor (se Figur 1, nederst). Ammoniak-bidraget er den væsentligste årsag til de beregnede overskridelser af tålegrænser for kvælstof for skove i Jylland.

Arbejdet med beregning af tålegrænser for kvælstof udføres løbende af det nationale Fokuscenter for Tålegrænser hos Danmarks Miljøundersøgelser for Miljøstyrelsen. Resultaterne anvendes i arbejdet under Genevekonventionen for Grænseoverskridende Luftforurening i FN's Økonomiske Kommission for Europa. Resultaterne indgår i europæisk kortlægning af tålegrænser og deres overskridelser samt i forhandlinger af reduktiontiltag, f.eks. den pågående forhandling af en ny kvælstofprotokol. De præsenterede beregninger understøtter samtidig det danske arbejde med en ammoniakhandlingsplan.

2 Introduction

This work on calculating critical loads for nitrogen supports the Geneve Convention on Long-Range Transported Air Pollution (LRTAP) under the auspices of UN-ECE. The Danish National Focal Centre at NERI is responsible for updating the calculations used for the international mapping exercises undertaken by Coordination Center for Effects under the convention.

The concept and calculations of critical loads is continuously being discussed in international fora, but the working definition adopted from the international workshop at Lökeberg is widely accepted for critical loads for nitrogen:

> *"A quantitative estimate of an exposure to deposition of N as NH_X and/or NO_Y below which empirical detectable changes in ecosystem structure and function do not occur according to present knowledge."* (Bobbink *et al.* 1992).

Critical loads have been used as an important basic concept in the elaboration of scenarios of airborne pollution and effects on ecosystems, even when the concept still was in a young and developing phase. Today the concept has "matured" and has been established as an important tool for assessment of the effects of sulphur and nitrogen compound depositions. The definition is basically scientific, but strategic or political elements are also included as the individual countries can select the receptors or sensitive elements of the ecosystems for the mapping exercises.

The work presented here is the first calculation of critical load for nutrient nitrogen based on the mass balance equation and should be seen as background work for the elaborations of a new nitrogen protocol under the LRTAP convention and the Danish work on preparing an ammonia action plan.

3 Methods for calculations

Calculation types

For the calculations the following steps are defined (UBA, 1993):

1. Choose receptor type(s):
The receptor could be an ecosystem threatened by atmospheric deposition such as heathland, bog or natural (unmanaged) forests.

2. Determination of the critical chemical value:
A critical chemical value is a relationship between the chemical composition of soil water, ground water or surface water and a biological indicator organism or population. Traditionally tree growth and health has been used for forests and vegetations changes are used for bogs and heathlands. Understorey vegetation studies are also used today to support the calculated critical loads for forests.

3. Choose calculation method:

Three calculation levels

Basically three levels for calculating critical loads are used (for further details see Bak *in press*):

Level 0: Empirical judgement by experts based on observed effects of acidification and eutrophication:

- Changes in vegetation
  (composition, diversity, succession)

- Changes in forest vitality
  (dieback, growth rates, understorey vegetation)

- Changes in soil fauna
  (composition, diversity, reproduction)

Level 1: Model calculations of acidification and eutrophication including:

Input/output models
Mass balance models

Level 2: Dynamic models

Level 0-calculations

For a number of natural or semi-natural ecosystems such as forests, heathlands, bogs and permanent grazing areas, empirical values or intervals of chemical concentrations leading to changes in the vegetation can be established (Bobbink *et al.* 1992). Such values have been found from data on typical ecosystems covering a gradient of deposition and are not specific for the local ecosystem. This gives quite generalized values. So far it is the only possibility for a range of natural and semi natural ecosystems in the Nordic countries. The Mapping Manual (UBA 1993) could be combined with national investigations and a reasonable estimate can be obtained.

Level 1 and 2-calculations

For level 1 calculations a steady state mass balance of the ecosystem is used and only the final state of the system at a certain deposition level is used. This means that the time perspective should be 150-300 years for forests and 20-40 years for biological indicators with shorter lifespan.

For the level 2 calculations, the chemical criterion is calculated as a function of time. This requires a lot of detailed data for construction and validations of models and has so far mainly been used for selected components of an ecosystem and is not yet useful for large scale calculations. It is recommended to use dynamic models on a limited number of sites where the required information is available in order to validate the results of the steady state models and to apply both level 0 and level 1 calculations in the assessment of critical loads using the lowest value for mapping.

4. Determine the distribution of the receptor(s):

Receptors

Distribution of receptors is found by combining available maps, e.g. land cover maps, forest productivity maps, soil maps. A suitable spatial dissolution is selected, in this case the calculations are based on 1 x 1 km grids and aggregated on the presented maps to 5 x 5 km grids.

5. Collect input data:

For each receptor in every cell in the mapping net data are collected. This includes deposition data, hydrological data, vegetation data, soil chemical data etc.

6. Calculations of critical loads:

The critical loads are calculated by an accepted method, including critical deposition values and exceedances of this value

7. Elaboration of maps:

Elaboration of maps

Maps presenting the results in a comparable way are elaborated. The dissolution is freely selected, but existing rules for cartographical legend etc. should be followed.

PROFILE calculations

The presented results and maps are based on PROFILE calculation of the mass balance equation for forest ecosystem (level 1) and application of empirical values (level 0) for heathlands and bogs. The PROFILE model calculates the weathering rate and hence the availability of base cations and sustainable uptake for each soil layer through the rooting zone. This is an important difference from the simple steady state mass balance approach, where the soil water chemistry is calculated as an average over the whole rooting zone. The application of a multi-layer approach can in general be expected to give slightly lower critical loads than a one layer approach.

In calculating the critical load for nutrient nitrogen, the mass balance equation for nitrogen is solved by the model calculating weathering and nutrient uptake at critical load. The limiting nutrient approach is also in this calculation applied for the different soil layers.

Mass balance equation for nutrial nitrogen

The applied version of the mass balance equation is (UBA 1993):

$$Cl_{nut}(N) = N_{l(crit)} + N_{i(crit)} + N_{u(crit)} + N_{de(crit)}$$

where:

$Cl_{nut}(N)$ = critical load for nutrient nitrogen ($mol_c ha^{-1} yr^{-1}$)

$N_{l(crit)}$ = accceptable level of nitrate leaching from the base of the rooting zone ast which no damage occurs in the terrestrial or linked ecosystem ($mol_c ha^{-1} yr^{-1}$)

$N_{i(crit)}$ = N immobilization (sustainable annual net N accumulation in the soil humus minus annual fixation of N from the atmosphere ($mol_c ha^{-1} yr^{-1}$)

$N_{u(crit)}$ = nitrogen uptake in the tree biomass at critical load ($mol_c ha^{-1} yr^{-1}$)

$N_{de(crit)}$ = annual flux of N to the atmosphere as a result of denitrification at critical load ($mol_c ha^{-1} yr^{-1}$)

The applied stratification of the root zone is in general a 5 cm thick A/E horizon, a soil dependent B and C horizon, and a maximum root depth dependent on the vegetation type:

	beech	oak	spruce	pine
Root dept	0.7m	0.9m	0.5m	0.5m

All calculations are made for beech, oak, spruce and pine dominated forests. The basic data have been collected on a 1x1 km national grid and calculations performed for ecosystems covering more than 25 ha within a gridcell. The total number of calculations are:

	beech	oak	spruce	pine
Calculations	2,825	448	5,480	1,035

4 Sources of data

The major sources of data for these calculations are shown in Table 1.

Major data sources

Table 1. Major sources of data for the critical load calculations.
Vigtigste datakilder anvendt til tålegrænseberegningerne.

Parameter	Resolution	Source
Soil mineralogy	60 points	DLD, literature
Soil texture	1:500,000	DLD
Geological origin	1:500,000	DLD
Forest limits	1:500,000	DLD
Forest production, species	1:500,000	DLD, DSO
Ecosystem cover	1 km grid	NERI
Deposition NO_y, NH_x	1/5 km grid	NERI, EMEP
Meteorological data	1:1,000,000	DLD, DMI

DLD: Danish Institute of soil and Plant Science, Dept of Land data
DSO: Danish Statistical Office
NERI: National Environmental Research Institute
EMEP: European Monitoring and Evaluation Programme
DMI: Danish Metorological Institute

4.1 Deposition

Depositions of NO_y and NH_x have been calculated at a national 5x5 km grid. For the NO_y wet deposition, the relationship to measured data was too poor. Therefore, the average measured wet deposition of NO_4 was used.

4.2 Vegetation

Vegetation types

A total registration of trees species, forest age and productivity was carried out in 1979-82. These data are available on a digital form and have been compared to more recent statistical information. The removal rate of nitrogen and base cations has been related to production classes for forest based on N content of stem and branches:

	beech	oak	spruce	pine
N uptake	10.4 x pc	10.4 x pc	3.9 x pc	3.4 x pc
BC uptake	5.4 x pc	6.8 x pc	3.7 x pc	1.8 x pc

where pc is production class for forests in $m^3\ ha^{-1}year^{-1}$.

For vegetation types as heathlands and bogs the critical loads are based on empirical values, i.e. values based on data from field studies. For heathalands the field observations have been transformed to a critical load by application of a dynamic model. The empirical values used have been 5 kg N $ha^{-1}year^{-1}$ for bogs and 10 kg N $ha^{-1}year^{-1}$ for heathlands. These values have been established as precautionary values on recommendation from Danish experts due to the presented lack of published evidence. Ongoing research on heathlands and raised bogs in Denmark are expected to give better basis for setting the critical loads, probably resulting in slightly higher values.

4.3 Soil

Maps are available of the texture and geological origin of the Danish topsoils. The content of primary minerals has only been analyzed at 60 sites. A map of mineral content in the A/E, B and C horizons has been constructed by interpolating the point information within 11 classes of topsoil geology.

4.4 Constants

A critical leaching, $N_{lea(crit)}$ of 2 kg N $ha^{-1}yr^{-1}$ and a immobilization $N_{im(crit)}$ of 3 kg N $ha^{-1}yr^{-1}$ has been applied. $N_{u(crit)}$ has been calculated with the PROFILE model applying the limiting nutrient approach. N_{de} has been calculated with the PROFILE model applying a kinetic equation.

The most difficult values to assess in the mass balance equation are the value of the critical nitrogen leaching, $N_{lea(crit)}$, and the sustainable immobilization, $N_{im(crit)}$.

The critical nitrogen leaching can be determined from a critical concentration for the protection of groundwater resources. There are, however, not data to establish a relationship between nitrate concentrations in runoff and observed vegetation changes. Alternatively the value can be set to protect the ecosystems from loss of basecations as a result of nitrate leaching. The susceptibility of different ecosystems to loss of basecations will be largely determined by the soiltype and input from atmospheric deposition. There have, however not been data available to differentiate between different ecosystems and a rather conservative value between 2 and 5 kg have thus been recommended for the European mapping of critical loads for temperate forest. In this first Danish calculation a value of 2 kg N ha^{-1} y^{-1} has been chosen, mainly to be in line with the calculations in the other Nordic countries. This value is likely to be changed in future calculations on the basis of new knowledge.

The sustainable immobilization rate has either been estimated by dividing the total N content in the soil by the soil forming period giving very low estimates, or been estimated from field observed immobilization rates, which in areas with exceedances of the critical load can be much higher than the sustainable level. Both methods are thus not satisfactory. As a compromise a value of 3 kg N ha^{-1} y^{-1} has been used in the Danish calculations. This value will, however, also probably be adjusted in the future and differentiated between different ecosystems.

5 Presentation of data and maps

Calculated and empirical critical loads

The calculated critical loads for forest ecosystems and empirical critical loads for heathlands and bogs as well as exceedances are presented in table 2.

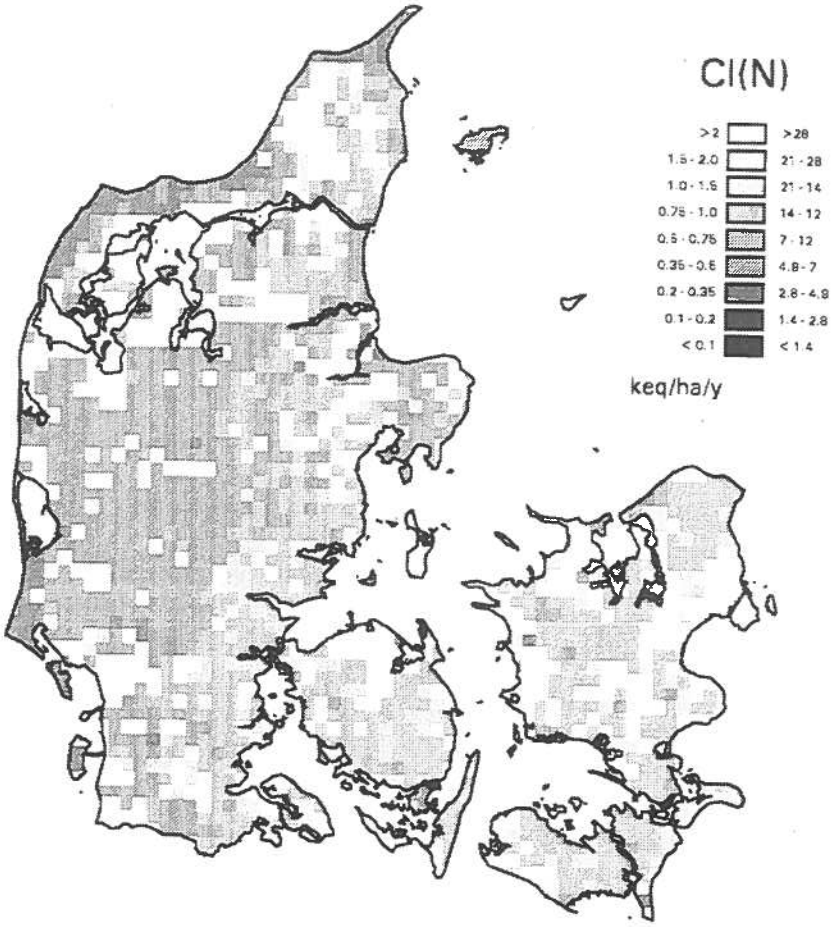
Table 2. Calculated critical loads for nitrogen and exceedances of CL in absolute figures and percentages for different vegetation types in Denmark. The critical loads and exceedances are given in keq ha^{-1} yr^{-1} as the interval between 5 and 95 percentile values. The critical load can be multiplied by 14 to give values in kg N ha^{-1} yr^{-1}.

Beregnede tålegrænser for kvælstof og overskridelser heraf i absolutte tal og procent for forskellige vegetationstyper i Danmark Tålegrænserne og overskridelserne er angivet i keq ha^{-1} år^{-1} som intervallet mellem 5- og 95- percentil værdierne. De angivne værdier for tålegrænser kan multipliceres med 14 for at give enheden i kg N ha^{-1} år^{-1}.

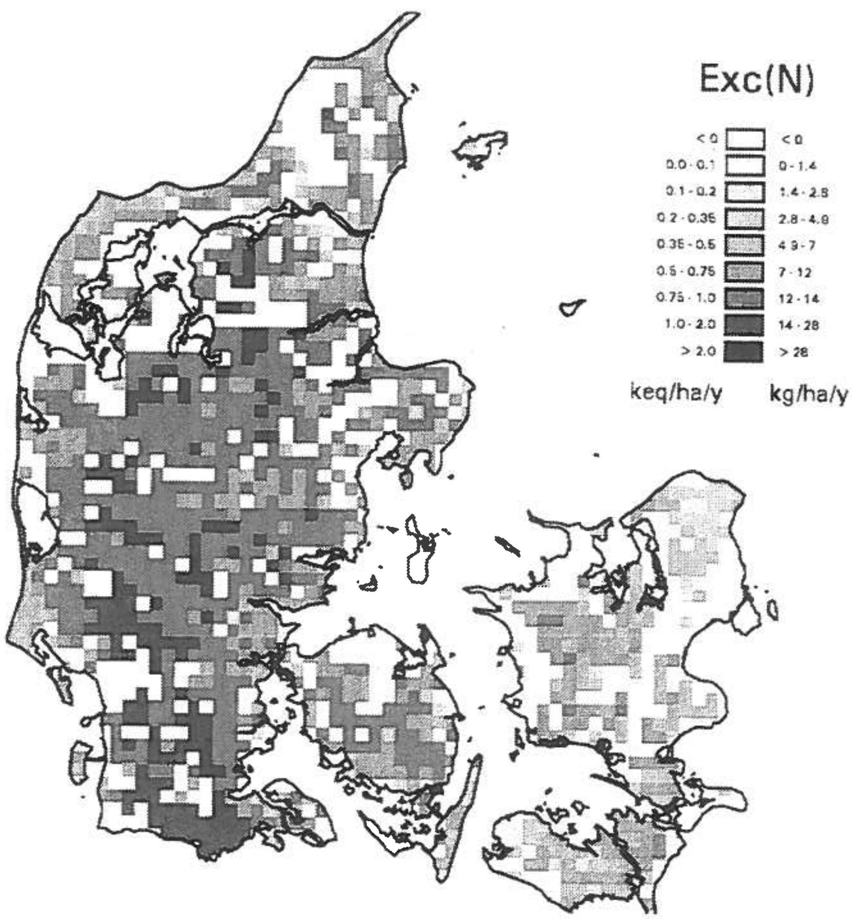
Ecosystems	**Heathlands**	**Bogs**	**Oak forest**	**Beech forest**	**Spruce forest**	**Pine forest**
Total area (km^2)	976	137	92	758	1.884	445
Critical load for nitrogen (keq ha^{-1} yr^{-1})	0.71	0.36	1.2-2.0	1.2-1.9	0.6-1.1	0.5-0.7
Exceedances of critical load (keq ha^{-1} yr^{-1})	0.5	1.1	(-0.3)-0.7	(-0.3)-0.6	(-0.4)-1.2	0.3-1.2
No critical load exceedances (% of total area)	0	0	46	42	9	13
Critical load exceedances from 0-10 kg N ha^{-1} yr^{-1} (% of total area)	72	13	37	51	11	32
Critical load exceedances > 10 kg N ha^{-1} yr^{-1} (% of total area)	28	87	17	7	80	55

Maps of critical loads for nitrogen for forests and exceedances are presented in Figure 1.

Figure 1. Maps of Denmark showing the calculated critical loads for nitrogen for forests (CL (N), upper map) and exceedances (Exc (N), lower map) in 5 km grids. White grids are mainly where forests do not cover suffient area within the grid. The critical loads are lowest in mid and west Jutland on sandy soils where the typical forest is spruce and pine. The exceedances are highest in mid, west and southern Jutland where the density of animal husbandry is highest. The local input from ammonia is the most important reason for exceedances of critical load of nitrogen to forests.



Kort med 5 km grids som viser tålegrænsen for kvælstof for skove (CL(N), øverste kort) og overskridelser heraf (Exc(N), nederste kort). Hvide gridceller findes hovedsageligt, hvor skovene ikke har haft tilstrækkelig dækning i cellen til en beregning. Tålegrænserne er lavest i Midt- og Vestjylland på sandede jorder, hvor skovene typisk er fyr og gran. Overskridelserne er størst i Midt- Vest- og Sønderjylland, hvor husdyrtætheden er størst. Det lokale bidrag fra ammoniak er den væsentligste årsag til de store overskridelser af tålegrænserne for skove i Jylland.



6 Discussion and conclusions

First nutrient nitrogen calculation

This first calculation of critical load for nutrient nitrogen (Cl_{nut}(N)) based on the mass balance equation reveals insight into airborne nitrogen as nutrient source for vegetation. Earlier calculations has been critical loads for total acidification Cl_{max} (S) for forest soils including acidifying effects of nitrogen.

Large exceedances

As shown in Table 2 the calculations of critical loads and exceedances for Danish ecosystems reveal very large and widespread exceedances. All Danish heathlands and bogs are presently receiving nitrogen in excess of the expert judged empirical critical loads, whereas the estimated exceedances are less for forested ecosystems with higher critical loads. Spruce and pine forests are more susceptible to the present nitrogen load than deciduous forest.

A project aiming at harmonizing the calculations of critical loads of nutrient nitrogen in the Nordic countries has been initiated and preliminary results are discussed. A similar bilateral harmonizing exercise for the shared grids between Denmark and Germany is considered.

Work is undertaken to prepare improved national values for empirical critical loads for heathlands and raised bogs and to enhance the national calculations of exceedances of the critical load of nutrient nitrogen. This includes the effects of local sources of ammonia and results are expected to be available in 1996-97.

Significant environmental problem

While there still might be questions concerning the exact size of the exceedances, Table 2 clearly demonstrates that deposition of nitrogen is a significant environmental problem in Denmark. This fact accounts especially for low-nitrogen ecosystems as heathlands and bogs although this still remains to be proved as regards to visible effects.

7 Literature

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