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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.

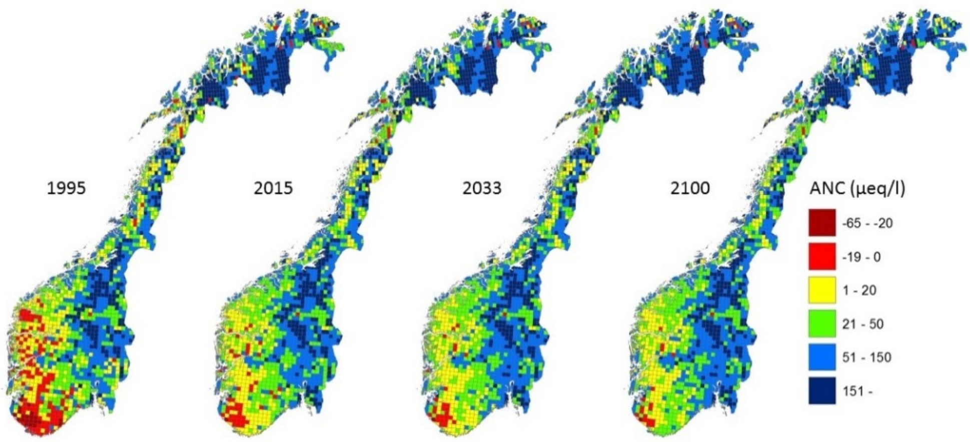

Figure NO-1. Modelled ANC per grid cell for 1995-2100.

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.

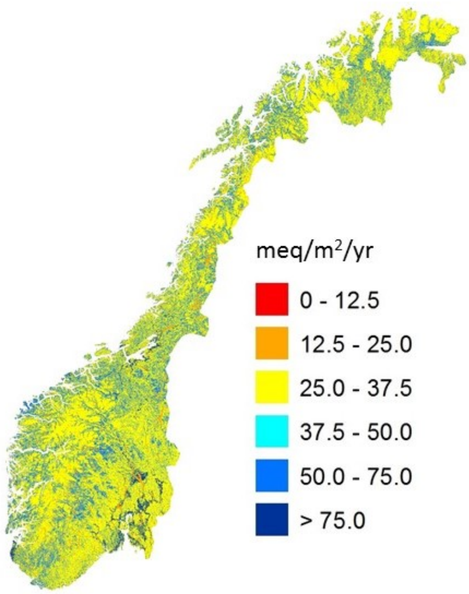

Figure NO-2. Map of empirical critical loads for nutrient nitrogen (dark blue areas agricultural/urban land, not submitted).

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.

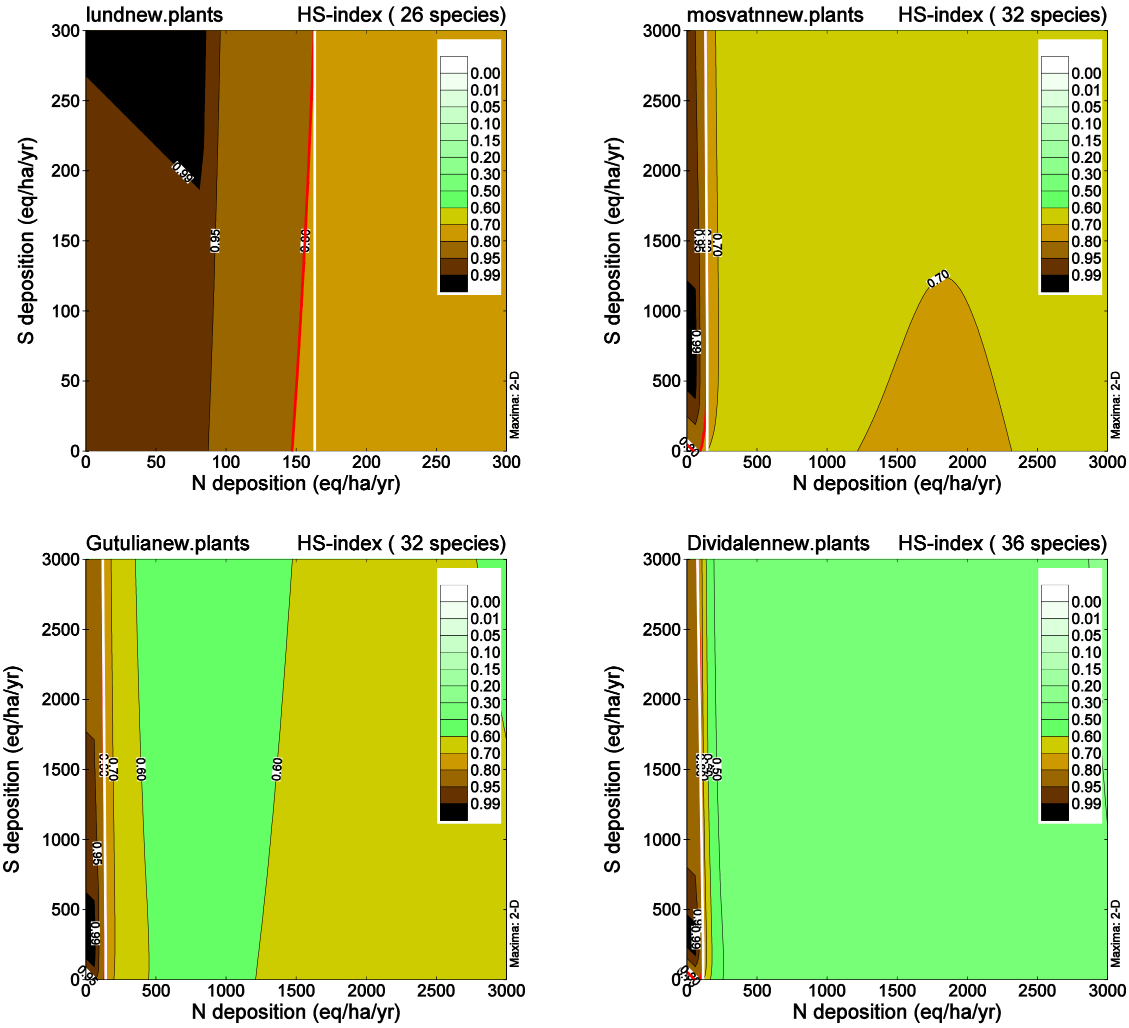

Figure NO-3. Critical loads plots for the four different sites. Upper left: Lund. Upper right: Møsvatn. Lower left: Gutulia. Lower right: Dividalen. Note: The Lund plot was double peaked, making it necessary to reduce the range of the axes to be able to calculate the CLNmax.

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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