European ICP Modelling and Mapping approach to estimate Critical Loads of Eutrophication and Acidification in the San Bernardino National Forest, CA

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Abstract

Critical loads of acidification and eutrophication were estimated in the San Bernardino Mountains for terrestrial ecosystems. To result in area-wide maps of sensitivity the European mass balance approach was applied. All input data used for the critical load computation are implemented into a geographical information system with grid cells of 250 x 250 m^2.
The critical loads of acidity for terrestrial ecosystems (forest and shrubland) are calculated separately for inputs of sulphur ($CL_{max}S$) and nitrogen ($CL_{max}N$). Approximately 50 % of the ecosystems were classified as sensitive to acidification with $CL_{max}S$ below 1000 eq ha^{-1} yr^{-1}. The area-wide results for critical loads of nutrient nitrogen ($CL_{nut}N$) ranging from 3.7 to 17.0 kg N ha^{-1} yr^{-1}. In terms of critical loads for eutrophication in the San Bernardino Mountains the immobilization rate and the acceptable N-concentration in the leachate are the most important input data. After computation of critical loads and their spatial distribution in the San Bernardino Mountains the question of current exceedances by actual nitrogen deposition comes into the focus of interest.

1 Introduction

The United Nations' Economic Commission for Europe (UNECE) adopted in 1979 the Convention on Long-range Transboundary Air Pollution (LRTAP). Since the first UNECE protocols on reducing emissions of sulphur (signed in 1985) and nitrogen (1988) have come into force, ever-increasing resources have been directed to develop effect-based approaches to control air pollution. With the implementation of the second Sulphur Protocol (1994) and, more recently, the Gothenburg-Protocol, which came into force in May 2005, critical loads have been applied as guidelines for abatement strategies on the European scale. North America is also Party to the LRTAP Convention and the Gothenburg-Protocol was ratified by the US government on the 22nd of November 2004. The critical loads have been compared to actual deposition load values (critical load exceedances) and maps showing areas experiencing higher than critical loads are used as a basis for assessing potential damage and to support the development of optimised abatement strategies.

An International Cooperative Program (ICP) was established to develop an effect-based approach for the Protocols to the Convention. This ICP on Modelling and Mapping of Critical Levels & Loads and Air Pollution Effects, Risks and Trends, with the participation of 28 countries[1], is responsible for the detailed planning and co-ordination of the relevant activities related to the direct ecological effects of the Gothenburg Protocol air pollutants SO_2, NO_x, NH_3 and O_3.

With a Mapping Manual, recently revised in 2008[2], the ICP supports the critical loads programme by providing scientific and technical assistance to apply the approach and ensure data comparability between the participating countries.

Utilizing the Mapping Manual the San Bernardino Mountains were chosen as investigation area to estimate critical loads for eutrophication and acidification.
The San Bernardino National Forest, located in Southern California, is covering more than 800,000 acres (3,200 km^2) and contains 87,400 acres (354 km^2) of old growth, for example: mixed conifer

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[1] www.unece.org/env/lrtap/WorkingGroups/wge/participation.htm
[2] www.icpmapping.org

coast Douglas Fir (Pseudotsuga menziesii var. menziesii), Ponderosa Pine (Pinus ponderosa), White Fir (Abies concolor), California Black Oak (Quercus kelloggii), California Coast Live Oak (Quercus agrifolia), Canyon Live Oak (Quercus chrysolepis), Jeffrey Pine (Pinus jeffreyi) forests and Lodge Pole Pine (Pinus contorta) forests.

The vegetation is also characterized by shrublands like chaparral, riparian woodland, montane meadows, white alder and desert wildflowers (Fenn und Poth 1999).

The San Bernardino National Forest, which includes 85 threatened and sensitive species of plants and 71 endangered animal species, serves as a popular outdoor destination as well as an important watershed for the surrounding area.

2 Data and methods

2.1 Mass Balance Approach

The mapping of critical loads for acidification requires the consideration of both sulphur and nitrogen deposition on the one side, and plant uptake, weathering, and biochemical immobilization processes on the other side. The deposition of acidifying sulphur and nitrogen exceeds a critical value if they alter the chemical characteristic of the soil solution. Indicators for the chemical characterization are

a) aluminum concentration, b) base cations / aluminum ratio, c) pH value, d) base saturation of soils, and e) acid neutralization capacity (ANC).

The simple mass balance (SMB) equations for the maximum critical load for sulphur-based acidity, $CL_{max}(S)$, and the maximum critical load for nitrogen-based acidity, $CL_{max}(N)$, are given by the following equations (ICP Modelling & Mapping Manual 2008):

$$CL_{max}(S) = BC^*_{dep} - Cl^*_{dep} + BC_w - BC_u - ANC_{le(crit)}$$

$$CL_{max}(N) = N_u + N_{fire} + N_i + N_{de} + CL_{max}(S)$$

with

$CL_{max}(S)$ = Critical load for sulphur-based acidity
$CL_{max}(N)$= Critical load for nitrogen-based acidity
BC^*_{dep} = Base cations deposition (sea salt corrected)
Cl^*_{dep} = Chloride deposition (sea salt corrected)
BC_w = Base cation weathering derived from soil type and parent material class
BC_u = Base cation uptake and removal by biomass under steady state conditions
N_u = Nitrogen uptake and removal by biomass under steady state conditions
N_{fire} = Nitrogen loss in smoke by fire
N_i = Long-term immobilization of nitrogen
N_{de} = Denitrification rate
$ANC_{le(crit)}$= Acceptable leaching of acid neutralisation capacity

The SMB approach for calculating critical loads for nutrient nitrogen assumes steady-state equilibrium of nitrogen input, acceptable storage and output. In this case, the nitrogen-fixing processes (immobilization, nitrogen uptake in the harvested biomass) and nitrogen removal (denitrification, acceptable nitrogen leaching, nitrogen loss by fire) should be in balance with the nitrogen deposition for steady-state conditions. The mass balance equation to calculate the critical load for nutrient nitrogen according to the ICP Modelling & Mapping Manual 2008 is given as

$$CL_{nut}(N) = N_u + N_{fire} + N_i + N_{le(acc)} + N_{de}$$

with

$CL_{nut}(N)$= Critical load for nutrient nitrogen
N_u = Nitrogen uptake and removal by biomass under steady state conditions
N_{fire} = Nitrogen loss in smoke by fire
N_i = Long-term immobilization of nitrogen
$N_{le(acc)}$= Acceptable leaching of nitrogen
N_{de} = Denitrification rate

2.2 Data overview and sources[3]

To calculate critical loads of acidification and eutrophication in the San Bernardino Mountains the necessary input data were derived from the Soil Survey Geographic (SSURGO) database for San Bernardino National Forest Area (U.S. Department of Agriculture, Natural Resources Conservation Service, 2003) in combination with the Geological map of the San Bernardino (Miller, F.K. und Matti, J.C.). Information about spatial distribution of vegetation complexes which are described by different kinds of vegetation classification systems could be derived from the FSSDE-EvegTile54 (USDA Forest Service - Pacific Southwest Region - Remote Sensing Lab, 2003) and the published “Terrestrial vegetation of California” (Barbour, M.G., Keeler-Wolf, T. und Schoenherr, A.A., 2007). For the receptor “Forest” the SAF_COVER_TYPE classification (EYRE, F.H. 1980) and for the receptor “Shrublands” the SRM_COVER_TYPE classification (SHIFLET, T.N. 1994) was used. Additional input for average annual precipitation and temperature could be acquired from the National Climatic Data Center (NCDC 2006) and PRISM Group at Oregon State University.

All input data used for the critical load computation are implemented into a geographical information system (ArcGIS 9.2) with grid cells of 250 x 250 m^2.

3 Results

The critical loads of acidity for terrestrial ecosystems (forest and shrubland) are calculated separately for inputs of sulphur (Figure 1, $CL_{max}S$) and nitrogen (Figure 2, $CL_{max}N$).

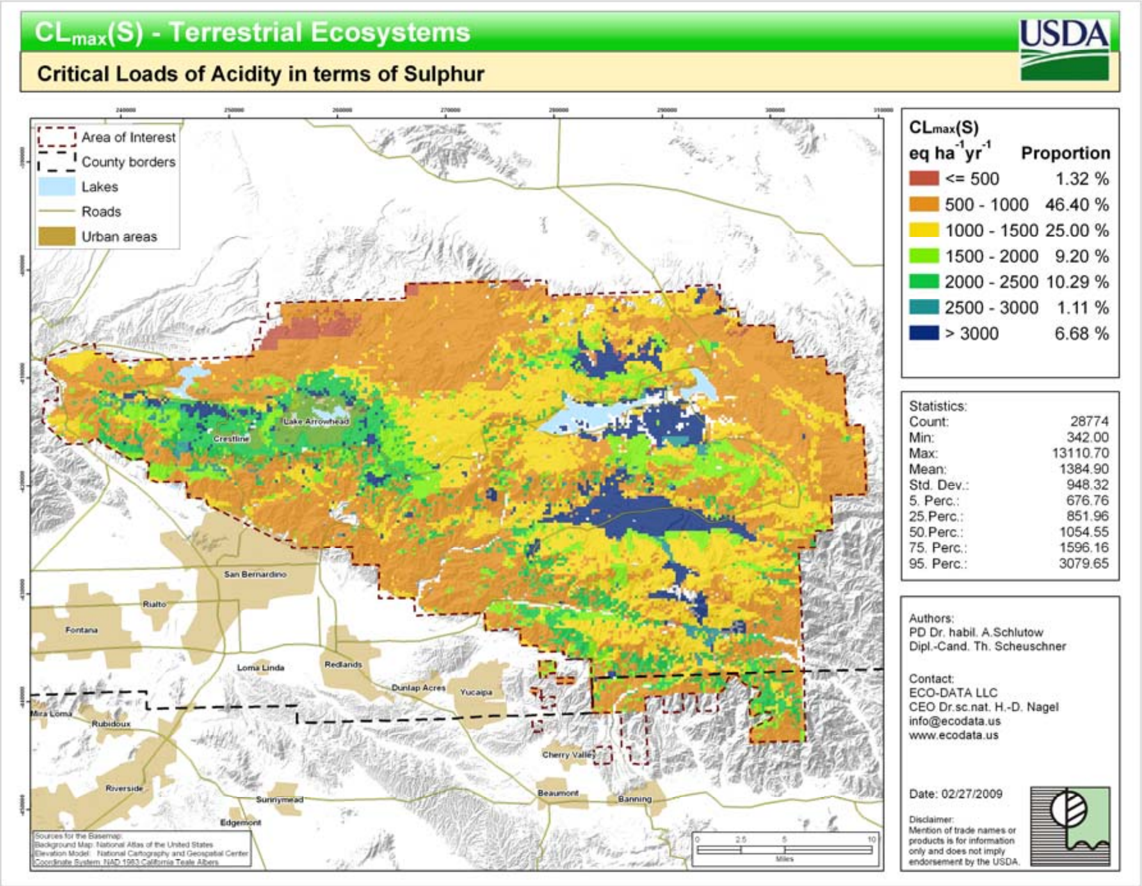

Figure 1: Regional distribution of critical loads of sulphur ($CL_{max}S$)

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[3] Mention of trade names or products is for information only and does not imply endorsement by the USDA or ECO-DATA.

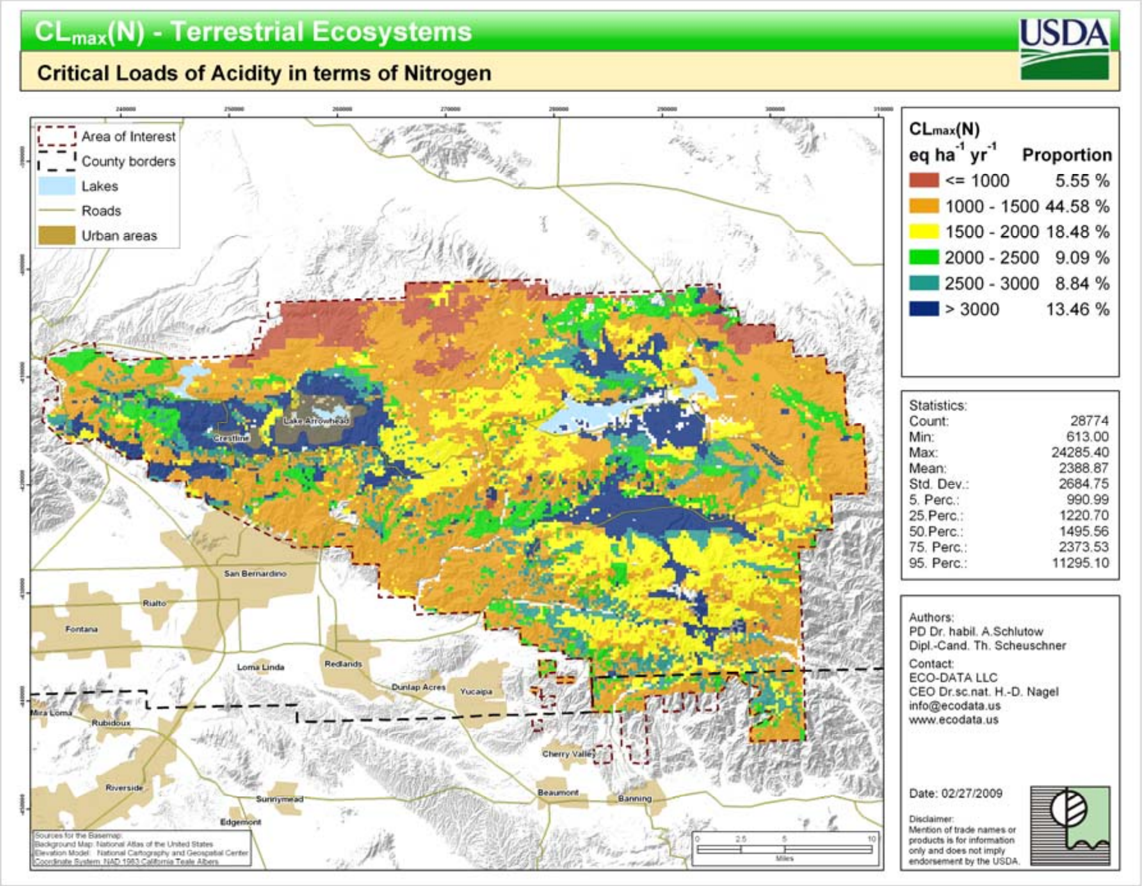

Figure 2: Regional distribution of critical loads of acidifying nitrogen ($CL_{max}N$)

Statistical distribution of sensitivity classes of acidity as percentage of the receptor area is given in Table 1.

Table 1: Proportion CL of acidity in terms of sulphur ($CL_{max}S$) and in terms of nitrogen ($CL_{max}N$) in the San Bernardino Mountains

Sensitivity class of acidification in the San Bernardino Mountains [eq ha^{-1} yr^{-1}]	Proportion CL of acidity in terms of sulphur, $CL_{max}S$ [%]	Proportion CL of acidity in terms of nitrogen, $CL_{max}N$ [%]
< 500	1.31	0
500 – 1000	46.40	5.55
1000 – 1500	25.00	44.59
1500 – 2000	9.20	18.48
2000 – 2500	10.29	9.09
2500 – 3000	1.11	8.84
> 3000	6.68	13.46

The critical loads of eutrophication ($CL_{nut}N$) for terrestrial ecosystems (forest and shrubland) in the San Bernardino Mountains are shown in Figure 3, the statistical distribution of sensitivity classes of eutrophication as percentage of the receptor area is given in Table 2.

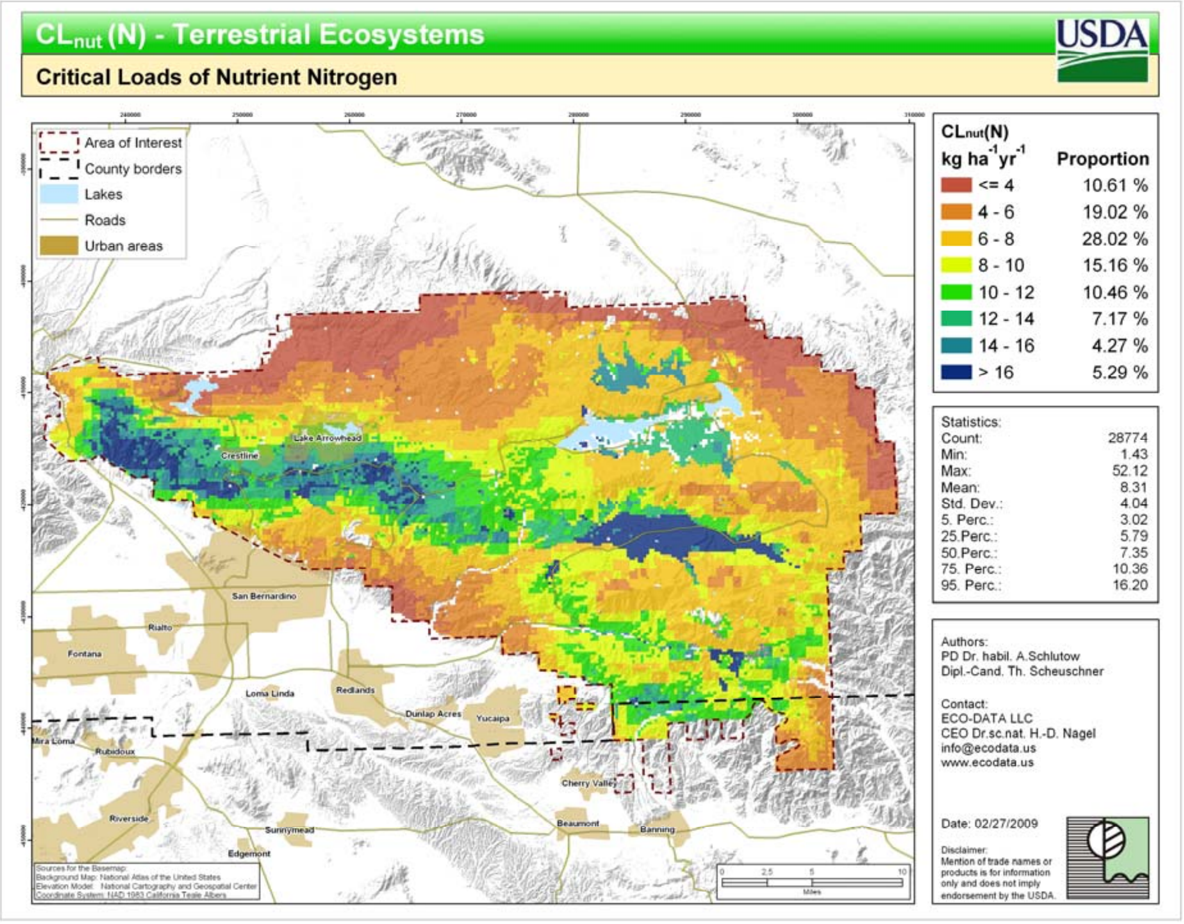

Figure 3: Regional distribution of critical loads of nutrient nitrogen, $CL_{nut}N$

Table 2: Proportion CL of nutrient nitrogen, $CL_{nut}N$, in San Bernardino Mountains

Sensitivity class of eutrophication [kg N ha^{-1} yr^{-1}]	Proportion CL of nutrient nitrogen, $CL_{nut}N$ [%]
< = 4	10.61
4 – 6	19.03
6 – 8	28.02
8 – 10	15.16
10 – 12	10.46
12 – 14	7.17
14 – 16	4.27
> 16	5.29

Both, the critical loads of acidity and the critical loads of eutrophication have high values, reflecting low sensitivity, along the middle line of peaks from East to West (Cajon Mtn. – Monument Peak – Strawberry Peak – Heaps Peak – Crafts Peak – Delamar Mtn. – Gold Mtn.). Also the alluvial terraces, fans and plains have high critical loads of nutrient nitrogen (about 14 to 17 kg N ha^{-1} yr^{-1}). At these sites a high precipitation surplus is combined with insensitive vegetation, therefore the acceptable leaching rate could be very high. In Holcomb Valley and Santa Ana River Valley (Barton Flats area) the denitrification rate is high because of the high water content in the upper soil horizons. This leads to very high critical loads.

Around the Big Bear Lake, along the San Gorgonio River, the Bear Creek, the Deep Creek around Lake Gregory and Lake Arrowhead and also in smaller valleys all over the mountain area the denitrification rate is high, resulting in high critical loads (10 to 14 kg N ha^{-1} yr^{-1}).

Medium values of critical loads (6 to 10 kg N ha^{-1} yr^{-1}) are located in the San Gorgonio Mountains wilderness and at the Sugarloaf Mountains. Low temperature leads to high immobilization rate, but sensitive coniferous communities require low N-concentrations in the leachate. The same properties are observed in the Mill Creek.
The lowest critical load values (2 to 6 kg N ha^{-1} yr^{-1}) are found in the hard chaparral and in Pinyon Juniper stands at the northern foothills. Very low precipitation in the hills results in very low leaching rates and therefore the critical loads are very low.

4 Discussion and conclusions

For validation of the results the critical loads derived by the mass balance approach were compared with published data of empirical and simulated critical loads at investigation plots (Fenn et al. 2008). The area-wide results of the SMB method with critical loads of nutrient nitrogen ranging from 3.7 to 17.0 kg N ha^{-1} yr^{-1} correspond to empirical critical loads for lichens (3.1 kg N ha^{-1} yr^{-1}), critical loads from simple mass balance for coniferous forests (8.8 kg N ha^{-1} yr^{-1}), and empirically derived critical loads for peak stream water NO_3 concentrations and root biomass reduction (17 kg N ha^{-1} yr^{-1}).
As the weathering rate of base cations from parent material has the highest influence on the critical loads of acidity, the uncertainties of $CL_{max}S$ depend on the correctness of deriving this term. Currently mineralogical information is not sufficient. The data used in this study are estimations on the basis of analogies to comparable parent material classes in Europe.

In terms of critical loads for eutrophication in the San Bernardino Mountains the immobilization rate and the acceptable N-concentration in the leachate are the most important input data. The acceptable N-concentration is in ongoing discussion within the critical load community. In this study data are used according to the current state of knowledge.
After computation of critical loads and their spatial distribution in the San Bernardino Mountains the question of current exceedances by actual nitrogen deposition comes into the focus of interest. Fenn et al. (2008) published deposition data for N-compounds at 2 forest sites in San Bernardino Mountains: at the highly polluted Camp Paivika and the less polluted Barton Flat. Camp Paivika is situated at a south-western slope directly downwind from the city area of Los Angeles. Here the deposition of total N increased from 5 kg N ha^{-1} yr^{-1} in 1930 to 70 kg N ha^{-1} yr^{-1} (2005). Comparing the deposition for 2005 with the critical loads for coniferous forest (Ponderosa Pine) on Lithic Xerothents from Granodiorite of 14.5 kg N ha^{-1} yr^{-1} a very high critical load exceedance has to be stated. This exceedance leads to a high nitrate concentration in the soil solution, to a high N-flux in the leachate followed by high N-concentration in the groundwater, to an accumulation of N-compounds in the needles and a low soil C/N-ratio (Fenn et al. 1996, Fisher et al. 2007). Furthermore the mortality rate of trees increases dramatically (Figure 4).

Figure 4: The forest in the San Bernardino Mountains already shows severe damage. (Photo: A. Schlutow, 11/19/08, location: Forest close to Camp Paivika)

Barton Flats are located at the north-western slope of San Gorgonio Mountains, the highest elevation of San Bernardino Mountains. Here the wind from Los Angeles City conglomerate is shielded by high mountains.
Fenn et al. (2008) noted that at Barton Flat the deposition had increased from 0.5 kg N ha^{-1} yr^{-1} in 1930 to 8.8 kg N ha^{-1} yr^{-1} by 2005. White Fir on alluvial Hecker-Morical soil complex will tolerate loads of up to 20 kg N ha^{-1} yr^{-1}, therefore no damage and unfavourable N-concentrations are expected at this site.

Acknowledgements

This study was prepared with the assistance of the USDA Forest Service, Pacific Southwest Research Station, Riverside, California.
Thanks for fruitful discussion and information are given also to Robert F. Johnson, UC Riverside, Center for Conservation Biology.

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