Report on the findings of the workshop: Indicators for modelling critical load of N based on vegetation effects

Workshop in Gothenburg, Sweden, 3-4 September 2007

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Introduction

A workshop investigating the use of the ground vegetation composition as an indicator for calculating Critical Loads (CL) of Nitrogen (N) for terrestrial ecosystems was held in Hindås, Sweden, between September 3 and 4 2007.

This document reports the questions, discussions and results from the CL of N workshop. A short summary about the workshop is first presented, followed by a restatement of the specific questions addressed at the workshop and finally a presentation of the main answers reached at the workshop. Two appendices are annexed to the document, the first containing the background document in which the workshop questions were set, and the second a detailed description of the day by day workshop discussions developments.

Summary

Critical loads are defined as the load of deposition above which undesired effects on the ecosystem can occur (Nilsson and Grennfelt, 1988). According to this definition, the CL of N workshop looked for ways to define an indicator of ecosystem change reflecting changes in the composition of the ground vegetation. Once the indicator defined, the workshop put forward a set of criteria which determine when an undesired change occurs. Finally, the workshop defined a reference ecosystem state which represents ecosystems that are not affected by exogenous N deposition.

The workshop resulted in the proposal of using species occurrence as the indicator of ecosystem changes for CL calculations as described in details below. The criteria for undesired change were defined for three groups of the vegetation community, namely the dominant species, the sub-dominant, and the marginal species. The reference level was defined as the dynamic theoretical composition of the ground vegetation under background N deposition levels but including the effects of other environmental drivers such as climate, deposition of acidifying compounds, and land use.

Workshop objectives

A background document was compiled as a basis for the workshop discussions (Appendix 1) and circulated to the participants prior to the meeting date. The two main objectives of the workshop were defined in the background document as follows:

1- To propose a definition for a reference level for the composition of the ground vegetation, i.e. the ground vegetation composition which we strive towards protecting or re-establishing. This definition should account for the simultaneous changes caused by land use practices and changes in other environmental factors.

2- To suggest specific and testable criteria for using the ground vegetation as an indicator for ecosystem response to N deposition.

Three specific questions were put forward, the answers to which are the main results of the workshop:

1- What indicator should be adopted in using the ground vegetation in the CL of N calculation?

2- How much change in the indicator of choice can be tolerated before the effect is declared undesired?

3- How can a reference for the composition of the ground vegetation be identified?

Results

This section presents the final results from the workshop in response to the questions listed above. A detailed description of the development of the discussion day by day is presented in Appendix B. The points presented below will form the ground for the subsequent modeling work to test the new CL of N method.

1- Indicators

The ground vegetation community is sorted into three groups: dominant, sub-dominant, and marginal (Figure 1). The classification is carried out based on the percent cover of the different species present at a certain site. The dominant group can contain one to three species or plant types, occupying at least 50% of the site cover. The marginal group represents species or plant types occupying at most 10% of the site cover. The subdominant group represents at most the remaining 40% of the site cover or any fraction under the dominant cover and higher than 10%. If the total cover of the marginal and subdominant plant species or types is below 20%, both are treated as a marginal group.

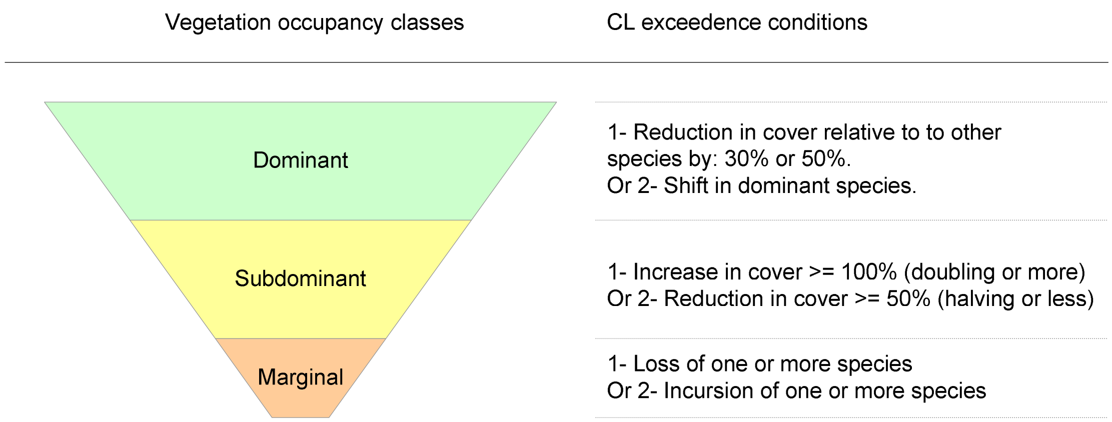

Figure 1: plant species or types distribution based on % cover and the group specific criteria for acceptable limits of change.

The distribution in Figure 1 relates the modeled composition of the ground vegetation community to the traditional plant associations, without having to follow the exact definition of these associations. For example, trivial changes in the % cover of blueberries in a blue berry type association would still preserve the integrity of the habitat. On the other hand, having a specific class for marginal species would allow the methodology to detect changes in rare or red-listed species as well as eventual invasions by species or plant types which were not present at the original association. Plant species or types in the marginal group have the potential of displacing or disturbing the dominant group or the marginal group, but may still oscillate within small enough margins that they do not cause a shift in association.

2- Criteria

The criteria of change were defined for each of the three vegetation classes in Figure 1. At this stage, two scenarios of limits are proposed for the dominant class and will be tested numerically as described below before one of the two scenarios is adopted. Firstly, the cover of the dominant class should not be allowed to be reduced by either 30% (scenario 1) or 50% (scenario 2) and at the same time (valid for both scenarios) no shift in the dominant species or plant type (with the largest area cover) is allowed. Secondly, the total cover of the subdominant class should not be allowed to double or be reduced by half, and no shift in the species or plant types making up this class should occur. Thirdly, no loss or incursion of species or plant types should be allowed in the marginal class. Within these limits the vegetation is allowed to change without it being considered undesired change.

3- Reference level

The change in the composition of the ground vegetation community is evaluated against a reference community. This later is the composition under background N deposition but including historical changes in climate, land use and the deposition of other compounds (ex. SO_4^{2-}). The background N deposition is defined as the total pre-industrial deposition of NH_4^+ and NO_3^-. Obviously, the reference composition is a theoretical community composition, but it is used to isolate the change in the composition caused by N deposition. Linking the reference level to the background N deposition implies that we are trying to protect or revert to the vegetation communities under pre-industrial N deposition conditions, but still under today's climate, land use, and other elements' deposition.

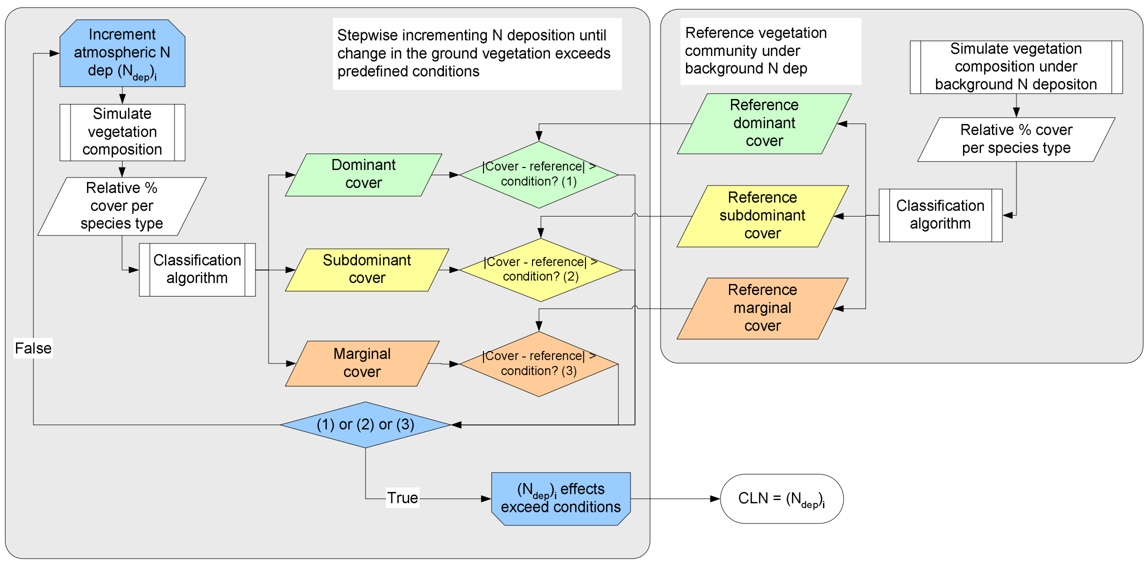

Figure 2: proposed algorithm for calculating critical loads of N based on divergences of the composition of the ground vegetation from the reference community.

Implementation

The guidelines described above will be tested initially using the ForSAFE-Veg model according to the algorithm in Figure 2. The validity of the model and its reliability are investigated in parallel efforts and will not be discussed in this report. Initially, the theoretical composition of the ground vegetation under background N deposition and historical (real) trends of climate, land use and other elements deposition will be estimated by the model (right part in Figure 2). Subsequently, a loop (left side in Figure 2) will use the model to simulate the composition of the ground vegetation under different N deposition levels. The N deposition levels will start at the background level plus an increment step which defines the resolution of the CL calculations (the smaller the steps, the higher the resolution). The simulated vegetation community under will be compared with the reference level, and as long as the criteria for CL exceedance are not fulfilled the deposition is incremented and the comparison carried out again. This loop will run until a deposition is found which produces a ground vegetation community sufficiently different from the reference community (i.e. fulfills at least one of the criteria above). The N deposition at this stage will be taken as the critical load of N.

Conclusions

The workshop produced the first set of testable guidelines for using the ground vegetation as an indicator for calculating critical loads of nitrogen deposition. The methodology proposed uses the area cover as the basis for the plant composition indicator. The vegetation community is classified into dominant, subdominant and marginal classes, and criteria are defined for each of the classes which determine the unacceptable levels of change. The reference level of the ground vegetation composition was defined as the dynamic community composition over time under historic climate, land use and deposition of elements other than N, and the unchanging background N deposition.

The set of guidelines for calculating CL of N put forward by at the workshop need to be tested using the ForSAFE-Veg model. Work is currently ongoing to consolidate the validity of the model based on tests on data intensive sites in Sweden and Switzerland. Further work is needed for testing the guidelines of the workshop, with the aim to present CL levels open for evaluation and revision.

Acknowledgments

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Appendix A: Background document

Indicators for modelling critical load of N based on vegetation effects

Workshop in Gothenburg, Sweden, 3-4 September 2007

Background document, compiled by Salim Belyazid,
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Background

There is a growing need to refine the methods used for calculating critical loads (CL) of Nitrogen (N) for terrestrial ecosystems considering the ongoing changes in climatic conditions and land use methods. Two paths of development are of particular interest: 1- a methods that allows for the estimation of CL of N under changing environmental conditions, i.e. not under steady state; and 2- a biological indicator of early stages of change in an ecosystem due to atmospheric N deposition. The composition of the ground vegetation communities has emerged as a relevant and early indicator of ecosystem change due to increased N loads in terrestrial ecosystems.

In March 2007 a workshop about "Nitrogen critical loads for terrestrial ecosystems in low deposition areas" was held in Stockholm (Nordin, 2007, http://www.unece.org/env/documents/2007/eb/WGE/ece.eb.air.wg.1.2007.15.e.pdf). The Stockholm workshop concluded that the current empirical critical load levels for N adopted in the modelling and mapping manuals can still cause exogenous change at ecosystems with low historic N deposition. In line with the outcome from other modelling and mapping meetings, the Stockholm workshop further concluded that the methodology for calculating dynamic critical loads should be developed along with a revision of the empirical critical loads.

Important progress has been made in modelling the effects of N loads on terrestrial ecosystems, particularly with regard to changes in the composition of the ground vegetation communities (Rowe et al, 2005; De Vries et al., 2007). The dynamic modelling tools should form the basis for the next generation of CL calculations, and should be utilised to explore the feasibility of using the ground vegetation as an indicator of ecosystem change. The current workshop (Sep 3-4, 2007) will try to define the practical foundations for the dynamic CL calculations based on changes in the ground vegetation.

Objectives

The objectives with this workshop are two fold:

1- To propose a definition for a reference level for the composition of the ground vegetation, i.e. the ground vegetation composition which we strive towards protecting or re-establishing. This definition should account for the simultaneous changes caused by land use practices and changes in other environmental factors.

2- To suggest specific and testable criteria for using the ground vegetation as an indicator for ecosystem response to N deposition.

The workshop will result in a report outlining the proposed rules for carrying out critical loads calculations, including a concrete proposal about how to model critical loads of N based on vegetation effects.

Indicators and criteria

Possibly the first question that needs to be addressed at the workshop is the clarification of the indicator and criteria to be adopted for calculating CL of N based on changes in the ground vegetation. The aim of the workshop is to bypass the chemical indicators traditionally used as proxies for the biological effects of deposition. Using the chemical indicators assumes a strong dependency of the biological indicator (ex. trees) on the chosen chemical indicator (ex. BC/Al). These responses can, however, be alleviated or worsened by other factors in the ecosystem, stressing the desire to use the biological indicators directly in the CL calculations.

As an early indicator of ecosystem changes, the ground vegetation biodiversity draws attention as a potential indicator of the effects of N deposition. The March workshop concluded that biodiversity should be approached from different angles, including abundance of trivial and rare species and the provision of ecosystem services to human societies (http://www.unece.org/env/documents/2007/eb/WGE/ece.eb.air.wg.1.2007.15.e.pdf). The workshop recommended considering both species diversity and ecosystem functions, in particular species that are functionally important for ecosystem processes or species that other species depend on. Foundation species, specifically discussed in the workshop, are usually important for the function of ecosystems, and their health could indicate the entire ecosystem vitality. Species associations could also be a useful indicator, considering the importance of the ground vegetation services and their dependence on the composition of the vegetation community or association. From here stems the following question: **what indicator should be adopted in using the ground vegetation in the CL of N calculation?** Or in other words, what is the aspect of biodiversity that should be put in focus?

Once the indicator of choice defined, the next question becomes the definition of change, i.e. **how much change in the indicator of choice can be tolerated before the effect is declared undesired?** The answer to this question is closely related to the indicator defined in the previous question. An undesired level of change can be the disappearance of a certain species of interest, invasion by undesired species, change in the plant community association, or change in the relative occurrence of different plants or plant functional types at a given ecosystem.

Reference level

Changes in the ground vegetation are early indicators of the environmental effects caused by N deposition (Emmett, 2007). Most of the European terrestrial ecosystems have seen changes in the composition of their ground vegetation communities due to exogenous N deposition, and the extent of the changes in different geographical regions depends on the historic and present N loads. While an increase in N load can lead to higher species richness in low N ecosystems, it may lead to species loss and a decline in species richness in N rich sites. The wide range of atmospheric deposition in European ecosystems, ranging from 2 $kg \cdot ha^{-1} \cdot yr^{-1}$ in northern Europe to 30 $kg \cdot ha^{-1} \cdot yr^{-1}$ in central Europe, illustrate the different effects of continued N deposition on the composition of the ground vegetation in ecosystems with different N loads. While N addition experiments show significant changes in the composition of the ground vegetation in N-poor ecosystems in northern Sweden for example (Nordin, 2005), little or no change in species richness is seen at N-rich sites in the UK (Emmet, 2007). Together with other findings, a picture emerges whereby species richness increases with N load from very N poor sites, and declines as low N value species are eliminated from the ecosystems at high N loads. Species richness alone, however, can give a misleading proxy for biodiversity, and other indicators such as species associations maybe more relevant to investigate.

With this in mind, one of the most important questions to be addressed at the workshop would be: **how can a reference for the composition of the ground vegetation be identified?** If such a reference level indicates the state of an ecosystem before the interference from N deposition, is it plausible to assume that the vegetation composition at that ecosystem can be recover if N deposition is reduced? In other words, are changes in the vegetation composition reversible?

Critical loads and the steady state concept

The concept of steady state is central to the definition of critical loads. The steady state concept assumes a system free of exogenous interference that in theory is able to reach a state of no (or negligible) change. This concept has been very useful in defining the current methodology of critical loads calculations using the traditional abiotic indicators (pH, BC/Al, ANC) as surrogates for biological targets in the ecosystem. Yet, the steady state concept may not be directly transferable to critical loads calculations based on changes in the ground vegetation as an indicator. The internal dynamics of plant competition together with the continuously changing climate and land use practices require that the critical loads be calculated dynamically. This requires a rethinking of the modelling methodologies used for the calculations, but not necessarily a review of the definition of critical loads.

The ForSAFE-Veg model

ForSAFE-Veg is a mechanistic model that builds on the integrated forest ecosystem model platform (ForSAFE) to simulate the composition of the ground vegetation (the Veg module) in response to changes in environmental and land use conditions (Belyazid, 2006; Sverdrup et al, 2007). The model is designed to simulate the composition of the ground vegetation community in a forest stand by integrating the effects of light intensity reaching the forest floor, soil moisture and nutrient contents, soil acidity, temperature, plant competition and grazing. It is therefore possible to look directly at the net effects of n deposition on the composition of the ground vegetation, rather than having to use an intermediary chemical or other abiotic indicator.

ForSAFE-Veg can be used to isolate the effect of different drivers on a given forest ecosystem, and work is being currently carried out to expand the model application to non-forested terrestrial ecosystems. It is possible to use the model to isolate the effects of N deposition and taking into account the effects of other drivers (climate, land use). One of the important questions the model also deals with partially is the speciation of N in the soil, primarily with the aim to differentiate between the effect of NH_4^+ and NO_3^-. An attempt has been already carried out to use ForSAFE-Veg in the calculation of critical loads of N assuming a 5% change in the composition of the ground vegetation from pre-industrial communities as reconstructed by the model. This exercise put the critical loads levels significantly below the current values adopted by the Gothenburg protocol. The initial definition of vegetation change used in the test calculations may be too strict, but the exercise illustrates the feasibility of calculating dynamic critical loads of N based on changes in the ground vegetation as a direct indicator.

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Appendix B: Daily discussions

Monday Sep 3.

The first question discussed was about what indicators should be adopted in using the ground vegetation in the CL of N calculations. Three dimensions describing the ground vegetation community were put forward:

1- the probability of presence/survival of rare and red listed species,
2- associations and habitat integrity
3- vegetation biomass

1- The group discussed the importance of including red listed species in the CL calculations, due to their importance in shaping the biodiversity discussion and the is prominence in policy making. Arguments against the use of red listed species included the occurrence of these species is marginal and based on unusual site specific conditions that may be hard to capture in a model. Yet, the group leaned more towards the use rather than the exclusion of red listed species due to their importance in the public mind in relation to biodiversity. It would, however, be impractical to include the red listed species in the modeling through the entire chain at this early stage, but rather estimate the probability of their existence based on the modeled associations and possibly the effects from other biogeochemical factors.

2- Associations would form the core indicator to base the CL calculations on, with the aim of preserving biodiversity and thereby habitat integrity. The associations would be based on the vegetation community composition as simulated by the model, and not modeled directly as a result of the environmental conditions at a site. The associations are defined by the dominant species group, the accompanying species and marginally present species (difference between group 2 & 3). The definition of the associations lack numerical ratios of the different species, and can be too broad in capturing change. It is then suggested to look at the change in relative species composition fractions within the associations to narrow the sensitivity of the CL calculations (to be further discussed on Tuesday).

3- the biomass of the ground vegetation was also discussed as a possible indicator, but the group felt that it was too closely related to changes in the composition of the community. Yet, the change in the biomass (ev. LAI, NPP) can provide an early indicator of change preceding changes in the species composition, particularly in low N deposition areas, or an indicator of site 'saturation' (grasses on sand dunes) in high N deposition areas. The biomass of the ground vegetation would not be adopted for the first rounds of CL testing.

The questions of the temporal and spatial scales of the CL calculations were also raised. As with ongoing dynamic modeling, the CL simulations will be carried out at stand level with the assumption that stands are homogeneous,

Tuesday Sep 4.

The use of associations as an indicator was questioned, and doubts were raised about the relevance of using the associations due to that they are too coarse and would not capture changes in the vegetation which may be perceived to be too large in response to increased N loads. Instead, an approach was proposed whereby the vegetation community is divided into three classes, dominant, subdominant and marginal, and change in each of these classes would be monitored. A change that would cause CL exceedance would require a 50% relative change in the occurrence of the dominant species or a shift in the dominant species, a doubling or halving of the subdominant species, or the loss of or invasion by one species.

The question was raised to how the plant community will be classified, and it was agreed that the report would put forward a proposal for this that should be open for revision at any stage.

The discussion then turned to the definition of the background vegetation community which would form the reference level to the CL criteria. It was proposed to set the reference vegetation community at the hypothetical composition under pre-industrial N deposition levels but changing historical climate, land use and deposition of other elements. This means that the reference line is a moving target that reflects possible changes in the vegetation community due to other drivers than N deposition (Figure 1). N deposition would then be allowed to increase as long as the corresponding vegetation composition does not change more than within the tolerated criteria range (Figure 1).

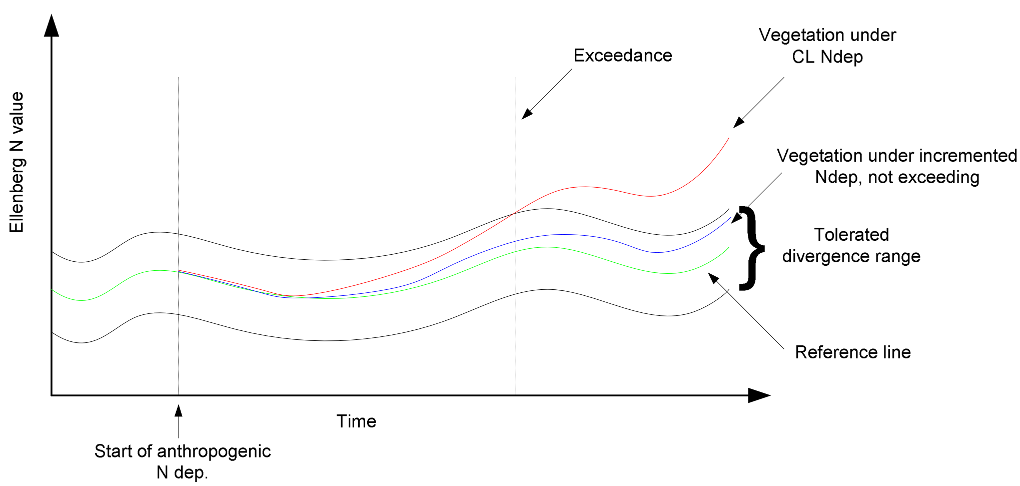

Figure 1: A simplified analogy to the reference community composition using the Ellenberg N value as a proxy. N deposition should be allowed to increase as long as the resulting vegetation community is within the tolerated divergence range from the reference level.