Background document on impacts of N deposition on ecosystem services in interaction with other nutrients, air pollutants and climate change

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1 The concept of ecosystem services

An increasing amount of information is being collected on the ecological and socio-economic value of goods and services provided by natural and semi-natural ecosystems and their economic value. Earliest literature on valuation date back to the mid-1960s and early 1970s (e.g. Helliwell, 1969). More recently, there has been an almost exponential growth in publications on the benefits of natural ecosystems to human society (see for example Costanza et al., 1997; De Groot et al., 2002).

Inspired by De Groot et al. (2002) who grouped ecosystem services into four primary functions, the Millennium Ecosystem Assessment has made a distinction in Provisioning services, Regulating services, Supporting services and Cultural services (Reid et al., 2005). Provisioning services are the products obtained from ecosystems, specifically the provision of food, fiber and wood/fuel. These functions are related to photosynthesis and nutrient uptake. It also includes other products such as the provision of fresh water. Regulating services refer to the regulation of e.g. climate, water quantity (ground water recharge, occurrence of floods etc), water quality and diseases and is related to the impact of ecosystems on green house gas exchange and buffering and filtering capacity of the soil affecting water and element fluxes. Supporting services relate to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through bio-geochemical cycles. These functions are indirectly related to the provisioning and regulation functions as it affects many services that have direct and indirect benefits to humans (such as clean air, water and soil).

Ecosystems provide a full suite of services that are vital to human health and livelihood. Important ecosystem services are the provision of wood and carbon storage, an adequate soil and water quality, watershed services and a habitat for a diversity of plants and wildlife. In this context, forests are among the most important ecosystems and their services are also the basis for the " Criteria and indicators for sustainable forest management" as adopted by the Ministerial Conference on the Protection of Forests in Europe. Healthy forests provide a host of watershed services, including water purification, ground water and surface flow regulation and erosion control. Furthermore, biodiversity is high in many forest ecosystems providing habitats for a wide range of animal and plant species. Forests will continue to provide their indispensable ecological and economical benefits only under the condition that they remain healthy, stable and sustainably managed.

2 Relationships between N deposition and impacts on ecosystem services with other nutrients, air pollutants and climate change

Nitrogen deposition affects, amongst others, the following ecosystem services:

- Diversity of plant species by its impact on the habitat function for wild plants, affecting biological diversity and related products (provisioning service).
- Production of crops and forests (provisioning service of timber/wood fuel) and carbon sequestration (climate regulating service).
- Production of non-CO2 greenhouse gases (CH_4, N_2O, O_3) and plant albedo (climate regulating services)
- Water quantity by affecting water uptake and thereby ground water recharge and runoff to surface waters (provisioning service of fresh water and water regulating service).
- Water/soil quality by its impact on acidity (pH) and on soil accumulation and leaching of nitrogen, aluminium and metals to ground water and surface water (regulating service, i.e. clean soil and water).
- Soil biodiversity and thereby nutrient cycling and primary production (supporting service)

Ecosystem services are not only affected by N deposition but also by changes in the cycling of other nutrients and air quality parameters in interaction with climate change. The pressures to be considered are:

- Nutrient cycling parameters such as phosphorus and trace elements in agro-ecosystems and forests and silica and phosphorus in estuaries.
- Air quality parameters, including exposure to NH_3, NOx and O_3 and deposition of N and acidity.
- Climatic parameters related to water stress, such as drought, temperature stress, such as late frost and extreme meteorological events, such as hail and windstorms.

A graph showing the major relationships between N deposition and ecosystem services, is given in figure 1, including the interaction with climate change effects and other air pollutants, such as sulphur (acidity) and ozone.

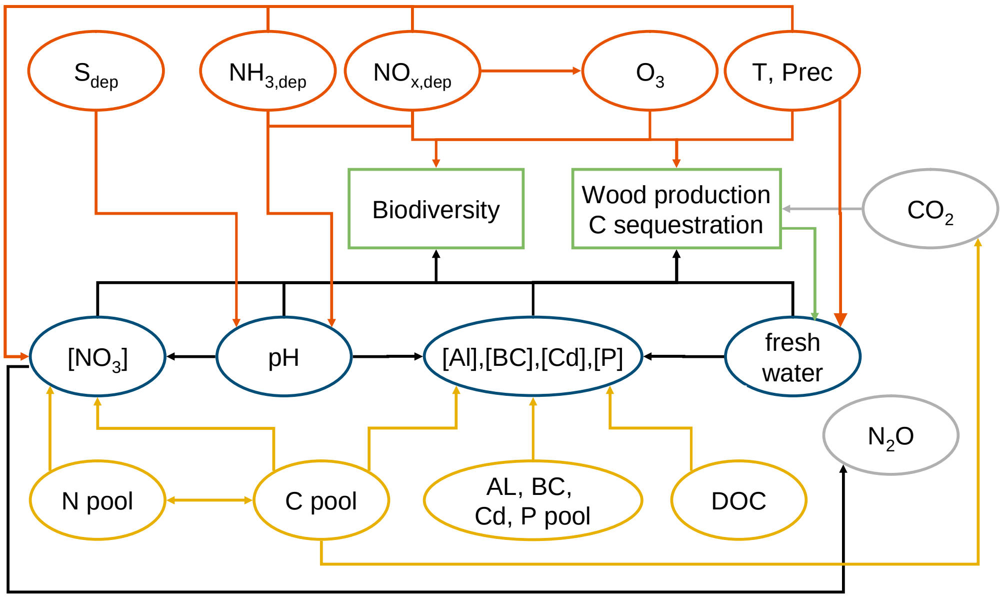

Figure 1 Relationships between N deposition and air quality (red), biodiversity and forest growth (green), water quality (white), soil quality (yellow) and green house gas emissions (gray).

Examples of the causal link between increased nitrogen availability and ecosystem services are given in Table 1, distinguishing between Provision services, Regulating services and Supporting services. There are many uncertainties in the cause – effect relationships, the interactions and the potential feedbacks listed in Table 1.

Table 1. Major relationships between N deposition and ecosystem services as distinguished in the Millennium Ecosystem Assessment (after De Vries et al., 2009)

Ecosystem services	Examples of nitrogen effects	Causal link with nitrogen deposition
Provisioning services		
Food/fiber, including - Crops - Wild plants and animal products	 Increase in crop production Impacts on biodiversity (based products)	 N deposition increases crop growth in N limited systems (low N fertilizer inputs) N induced eutrophication and soil acidification affects soil, plant and faunal species diversity and thereby biodiversity-based products
Timber/wood fuel	Increase in wood production	In N limited systems, nitrogen increases forest growth and wood production; in N saturated forests, N can induce mortality.
Natural medicines	Impacts on medicinal plants	N induced eutrophication and soil acidification affects plant species, but linkage to medicinal plants is largely unknown
Fresh water	Impacts on ground water recharge and drainage	N induced impacts on growth and plant species diversity also affect water uptake and thereby freshwater supply (see also water quantity regulation).
Regulating services		
Air quality regulation	Decline in air quality	Nitrogen deposition is correlated with increased concentrations of ammonia (NH_3), nitrogen oxides (NO_x), ozone (O_3) and particulate matter (PM10 and PM 2.5), all affecting human health and ecosystems.
Climate regulation	Increased carbon	In N limited systems, nitrogen deposition

Green house gas balance	sequestration in forests Increased/decreased carbon sequestration in peat lands Increased N_2O production Decreased CH_4 consumption Increased O_3 production	increases forest growth and related tree carbon sequestration, but can enhance mortality in some species. It also can cause an increased litterfall and reduced decomposition, leading to soil carbon sequestration. At low N deposition, additional atmospheric nitrogen deposition may stimulate net primary productivity. At high rates of N deposition, species composition changes lead to loss of peat land forming species and changed microbial activity causing degradation of peat lands Ecosystem losses as N_2O increase with increasing N loading Soil microbes decrease CH_4 consumption in response to increased NH_4 availability Increased production in tropospheric O_3 from interactions with NOx and VOC emitted from ecosystmes,, which serves as GHG directly and can inhibit CO_2 uptake through plant damage
Water quantity regulation	Increased/decreased runoff and ground water recharge Increased drought stress	Excess nitrogen may cause decreased runoff and ground water recharge due to increased water uptake (elevated growth) but also the reverse because of a lower LAI due to defoliation caused by e.g. pests/diseases. Recharge may in the long term also be affected by soil biodiversity impacts, affecting soil structure and thereby water retention in soil Excess nitrogen causes an increased need for water by an increased growth and an increased sensitivity for drought stress by an increase in the ratio of above versus below ground biomass
Water quality regulation (water purification)	Decline in ground water and surface water (drinking water) quality	Nitrogen eutrophication and N induced soil acidification increases NO_3, Cd and Al availability, leading to - NO_3, Cd and Al concentrations in groundwater and surface water exceeding drinking water quality criteria in view of human health effects. - Fish dieback by algal blooms and anoxic zones (eutrophication) and impacts of Al on fish gills (acidification). Eutrophication is also affected by silica and phosphorus in estuaries.
Soil quality regulation	Decrease in acidity buffer; change in soil structure	N induced soil acidification decreases the exchangeable pool of base cations, that may cause reduced forest growth and it decreases the readily available Al pool, affecting soil structure.
Pest/disease regulation	Increased human allergic diseases Increase in forest pests	Increasing N availability can stimulate greater pollen production, causing human allergic responses, such as hay fever, rhinitis and asthma. Increase in bark or foliar N concentrations can attract higher infestation rates, such as beech bark disease

Supporting services		
Nutrient cycling and primary production	Decreases soil biodiversity	N induced impacts on growth/litterfall and on soil biodiversity affects decomposition, nutrient mineralization and N immobilization and thereby nutrient cycling and primary production

During the breakout session these interactions will be further explained and discussed with the aim of extending and prioritizing the list of effects of nitrogen in Table 1. This background paper will be extended with explanation of the list in Table 1.

3 Discussion and recommendations

A complete and prioritized Table 1 will form the starting point of the discussion on the relation with the critical load approach for nitrogen. The focus of the breakout group on ecosystem services will be on further development of tools/indicators for N induced biodiversity loss, which should ideally take into account impacts of N addition on valuable ecosystem services such as carbon sequestration and regulating services related to soil and water quality, in interaction with climate change and with other nutrients. We are asked to come with conclusions and recommendations, referring to needs identified by the CBD and LRTAP (plenary) presentations, and addressing implications of current knowledge for policy, management and capacity building needs.

Recommendations referring to needs identified by the CBD

An important aim at EU level is to halt the loss of biodiversity by 2010. This aim requires a Set of Biodiversity Indicators for assessing the actual change in biodiversity as compared to the 2010 target of no further loss. In this context, the Pan European initiative, SEBI2010 (Streamlining European 2010 Biodiversity Indicators), was launched in 2004. Its aim is to develop a European set of biodiversity indicators to assess and inform about progress towards the European 2010 targets. Work is led by a Coordination Team. In 2005 the Coordination Team and 6 Expert groups involving more than 100 experts nominated by European countries as well as non Governmental Organisations started working for the compilation of a First European Set of Biodiversity Indicators for assessing the 2010 target. This has led to a report, describing a proposal for a first set of indicators to monitor progress in Europe (EEA, 2007). For more information on SEBI 2010 see: http://biodiversity-chm.eea.europa.eu/information/indicator/F1090245995.

The EEA (2007) report documents the achievements of the first phase (2005–2007) of the Streamlining European 2010 Biodiversity Indicators (SEBI 2010) project on the development of indicators to monitor progress towards, and help achieve the European target to halt the loss of biodiversity by 2010. The 26 indicators proposed by the SEBI 2010 process include (in italic those that are relevant in view of N deposition: NB beware that even more indicators are important when focusing on farm management and related N emissions, such as 20: Agriculture: area under management practices supporting biodiversity):

1. ***Abundance and distribution of selected species***
2. ***Red List Index for European species***
3. Species of European interest
4. Ecosystem coverage

5. Habitats of European interest
6. Livestock genetic diversity
7. Nationally designated protected areas
8. Sites designated under the EU Habitats and Birds Directives
9. ***Critical load exceedance for nitrogen***
10. Invasive alien species in Europe
11. Occurrence of temperature-sensitive species
12. ***Marine Trophic Index of European seas***
13. Fragmentation of natural and semi-natural areas
14. Fragmentation of river systems
15. ***Nutrients in transitional, coastal and marine waters***
16. ***Freshwater quality***
17. ***Forest: growing stock, increment and fellings***
18. Forest: deadwood
19. ***Agriculture: nitrogen balance***
20. Agriculture: area under management practices supporting biodiversity
21. Fisheries: European commercial fish stocks
22. Aquaculture: effluent water quality from finfish farms
23. ***Ecological Footprint of European countries***
24. Patent applications based on genetic resources
25. Financing biodiversity management
26. Public awareness

The current target of reducing biodiversity loss appears unlikely to be achieved by 2010. Nevertheless, more ambitious targets, for example to halt and/or reverse loss are being proposed for 2020. A broad overall 2020 biodiversity target could be complemented by a set of quantifiable sub-targets. On the basis of the above mentioned list of indicators, we may come up with recommendations to be shortened and worked out further

Recommendations referring to needs identified by CLRTAP
The CLRTAP focuses on the combined impacts of NO_x, NH_3, SO_2 and O_3. Until now, critical loads and related emissions ceilings for NO_x, NH_3 and SO_2 are related to impacts of eutrophication and acidification with a focus on biodiversity and undesirable Al to base cation ratios in the soil. Impacts on other ecosystem services such as carbon sequestration and interactions with ozone with respect to impacts are not yet included in the critical load assessment.

National and international policies to control the growth of NO_x emissions will affect future exposure of ecosystems to both ozone and nitrogen deposition, but there is almost no basis on which we can currently evaluate the implications of these combined changes in exposure for biodiversity and ecosystem services. Much greater attention needs to be paid to the joint effects of these two major regional pollutants in experimental studies, field observations and model development
Other recommendations can be further worked out at the workshop

Discussion issues

For the general discussion, we propose the following discussion topics:

- Are all possible ecosystem services affected by N deposition mentioned in Table 1. If not, which are lacking? Is further description required as to their mechanism of response?
- What are the most important other ecosystem services affected by N deposition. On which services should we focus most attention?
- What is the linkage between plant species diversity changes, being the main indicator for critical N loads, on faunal species diversity and biodiversity-based products, such as impacts on edible wild plants, medicinal plants.
- Is there a linkage between biodiversity changes and the ecosystem services mentioned in Table 1 or are most effects due to other more direct pathways
- Can we come up with other indicators in addition or related to effects on biodiversity that might also be used to assess critical loads
- How do other factors, such as climate, ozone, other inputs (CO_2, P), affect the ecosystem services mentioned in Table 1?
- If so, should they be taken into account in critical load assessments or are the critical limits for other effects less stringent than those for biodiversity (e.g. NO_3 leaching occurs after the biodiversity limits are exceeded)?
- Do we need to take regional difference into account and if so at what scale?
- What recommendations can we come up with in relation to the above discussion points?

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