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Eutrophication

The deposition of nitrogen compounds favours forest growth, but at the same time leads to the chemical disruption of a long list of ecosystems on land and in the sea, and results in the impoverishment of biodiversity.

Most people probably think of stagnating lakes when eutrophication is mentioned. In fresh water environments eutrophication is almost always caused by phosphates, since phosphorus is the substance that usually limits biological growth in water.

On land and in the sea, however, it is nitrogen that is the limiting factor in the majority of cases. The deposition of nitrogen – originating from emissions of nitrogen oxides and ammonia – therefore acts as a fertilizer in nature.

While this favours some species of plants that can easily make use of the extra nitrogen, it does so at the expense of others. It also affects the growth of mycorrhizal fungi. The impoverishment of ecosystems that results from the deposition of nitrogen is a real and very serious problem in large parts of

Europe. The increased growth rate that results from nitrogen deposition also increases biological acidification, see factfile on page 93.

Another important effect of nitrogen deposition, at least in those parts of Europe where it is most extensive, is that nitrate ends up in the groundwater, where it causes problems in the production of potable water.

This chapter describes the emissions into the air that cause these problems, the areas that are affected, how much nitrogen deposition nature can “tolerate”, and gives an idea of the extent to which recovery is possible. The biological effects of nitrogen deposition are described in chapter 2.

CAUSES

The atmospheric deposition of nitrogen compounds in Europe is due, in roughly equal parts, to emissions of nitrogen oxides and ammonia. The problems are largely unrestricted by national borders, especially in the case of nitrogen oxides and their transformation products. Ammonia is generally not transported such long distances. The emissions, transport and deposition of nitrogen compounds are described in detail in chapter 5.

Note that it is not just airborne nitrogen that ends up in nature. In many environments nitrogen is also added in the form of fertilizer. Large amounts are spread on fields, and sometimes also on natural grazing land, which leads to impoverishment of the natural flora. Fertilizer is also spread on forest land to increase forestry yield. In addition to direct deposition, nitrogen also reaches the sea through leaching from the land and discharges from wastewater treatment plants and individual households.

WHICH AREAS ARE AFFECTED?

The atmospheric deposition of nitrogen compounds in Europe is greatest in the Netherlands, Belgium, France, southern England, northern Germany, and northern Italy. The reason why the situation is worst in areas with intensive agriculture is that a large part nitrogen from ammonia, 90 per cent of which comes from livestock farming, is deposited relatively close to the source of emissions.

The amounts involved are not small by any means. In local areas of the Netherlands, for instance, annual deposition on forest soil can exceed 100 kilograms of nitrogen per hectare. This is roughly the same amount as is spread as a fertilizer dose on intensively farmed fields. In southern Scandinavia the annual atmospheric fallout on forest soil is 10–20 kilograms per hectare, and in the far north just a few kilograms.

WHAT CAN NATURE TOLERATE ON LAND?

In order to get a picture of the areas that are affected by eutrophication it is not sufficient to determine the quantities deposited – we also need information about the sensitivity of the ecosystems. But nitrogen has a twofold effect; it causes both eutrophication and acidification. This fact, together

The fallout of atmospheric nitrogen is a threat to biodiversity in many nitrogen-poor ecosystems, such as this heath with pasque flowers (Pulsatilla vulgaris).

with the complexity of the nitrogen cycle, makes it difficult to give unequivocal critical loads for different ecosystems.

Mass balances

One way to define the critical load for nitrogen is to calculate the level at which nitrogen starts to leak from the system into the groundwater. This is done with the aid of what are known as mass balances. These look at the way that nitrogen is converted in the ecosystem – its uptake by vegetation, fixing in

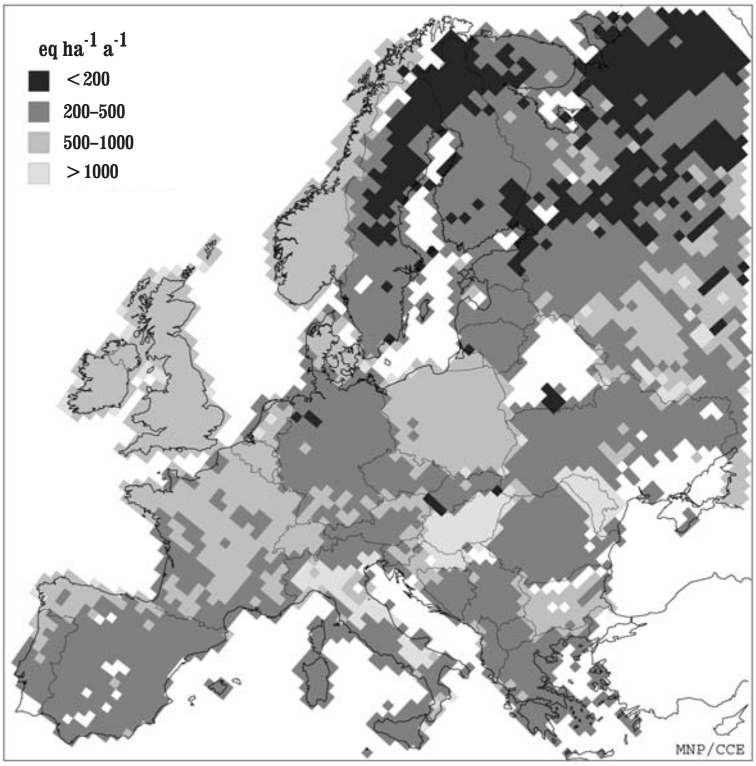

FIGURE 6.1. Critical loads for nitrogen, Europe. Nitrogen-equivalents per hectare per year. The darker the shade, the greater the sensitivity. (Max Posch, CCE/RIVM, Netherlands, 2003.)

the soil, conversion by micro-organisms in the soil (nitrification and denitrification), its removal if biomass is harvested, etc. These plus and minus entries are then weighed against each other to give a measure of how much nitrogen can be added without the loss from the system exceeding a certain limit.

Calculations of mass balance show that Swedish forest soils can take between 3 and 20 kilograms of nitrogen per hectare each year, for areas of low and high productivity respectively, without increasing nitrogen leakage from the system. In virgin forest, where no nitrogen is removed through the harvesting of biomass, the critical load has been calculated as 1–3 kilograms per hectare each year. Figure 6.1 shows the critical load limits calculated using the mass balance method for the whole of Europe.

Uncertainties in models

It should be said that there are forest researchers who question the validity of this model, since it has been possible to add considerably higher doses of nitrogen during field trials without observing any increase in leakage. One explanation of this may be that the addition of nitrogen changes the ecosystem in such a way that it is able to take up more nitrogen. The addition of nitrogen may also have important environmental effects that come into play before leakage into groundwater occurs.

It is also possible that the models underestimate the capacity of soils to lock up nitrogen. This capacity has been calculated using historical data, but without making allowance for the fact that a large amount of nitrogen has probably disappeared from the system as a result of recurring forest fires.

From experience it seems that the risk of nitrogen leaking from forest soil is small if annual deposition is less than 10 kilograms per hectare. In the range 10–25 kilograms the degree of leaching increases in certain locations. When annual deposition exceeds 25 kilograms per hectare there is significant leaching out, and many soils become saturated with nitrogen, i.e. the rate of loss equals the rate of supply.

Calculations based on mass balances show that in 1990 the critical load for nitrogen was exceeded over an area of roughly

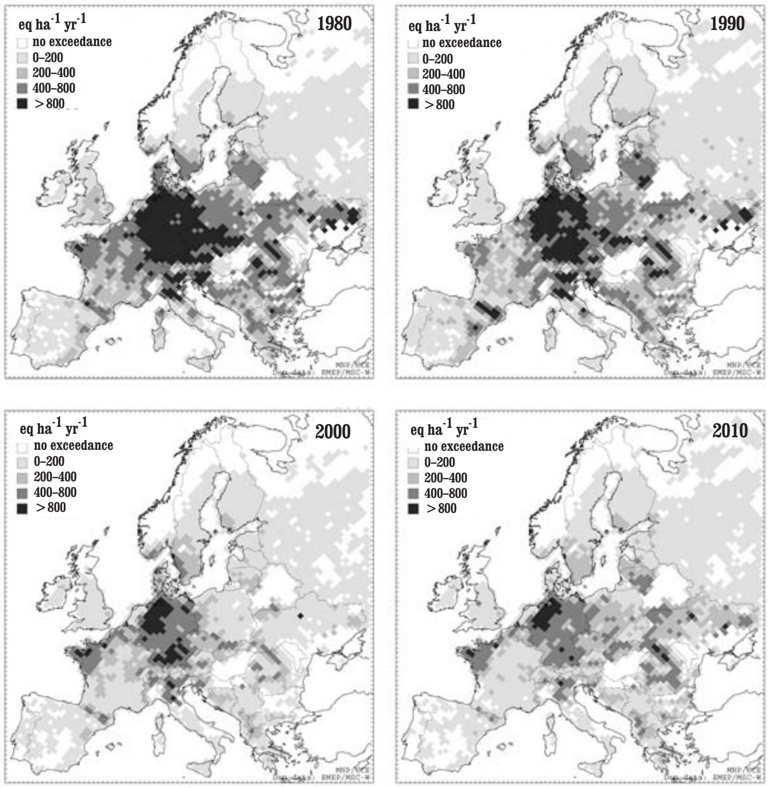

FIGURE 6.2. Areas where the critical loads for eutrophication were exceeded in 1980, 1990 and 2000, and the forecast for 2010. The latter is based on all countries meeting their undertakings in the Gothenburg Protocol. (Max Posch, CCE/RIVM, the Netherlands, 2003.)

213 million hectares of European ecosystems. Emissions have fallen since then however.

Preliminary calculations indicate that the exceeded area had shrunk to 140 million hectares by 2000. If all signatory countries do as promised under the Gothenburg Protocol (see table 9.2) and if emissions in non-signatory countries develop as officially projected the area will however increase to 159 million hectares in 2010. This increase is mainly due to projected increased emissions of nitrogen compounds in some large eastern European countries. The four maps in figure 6.2 illustrate the progress.

Changes in ecosystems

Another way of determining the critical load for nitrogen is to study the deposition levels of nitrogen at which visible changes start to appear in ecosystems, e.g. changes in the composition of species. The results of such surveys are shown in table 6.1.

TABLE 6.1. Empirical critical loads for nitrogen deposition to natural and semi-natural ecosystems – *some examples*.

Ecosystem type	kg N/ha · yr	Indication of exceedance
Temperate and boreal forests	10–20*	Changes in soil processes, ground vegetation and mycorrhiza. Increased risk of nutrient imbalances and susceptibility to parasites.
Tundra	5–10*	Changes in biomass and species composition, decrease in lichens.
Arctic, alpine, and subalpine scrub	5–15(*)	Decline in lichens, mosses, and evergreen scrubs.
Dry heaths	10–20**	Transition heather to grass, decline in lichens.
Sub-Atlantic semi-dry calcareous grassland	15–25**	Increase in tall grasses, decline in diversity.
Non-Mediterranean dry acid and neutral closed grassland	10–20*	Increase in graminoids, decline in typical species.
Raised and blanket bogs	5–10**	Change in species composition, N saturation of Sphagnum.
Poor fens	10–20*	Increase in sedges and vascular plants, negative effects on peat mosses.
Soft water lakes	5–10**	Isoetid species negatively affected.
Coastal stable dune grasslands	10–20*	Increase in tall grasses, decrease in prostrate plants, increased N leaching.

** Reliable   * Quite reliable   (*) Expert judgement

Knowledge in this area is however incomplete, since it is difficult to establish which changes are due to nitrogen deposition and which are caused by other changes, such as the way that land is used. Moreover, changes only appear in the flora after the critical limit has been exceeded, and in some cases only after it has been exceeded for an extended period of time.

A further obstacle to establishing critical limits in this way is the lack of reference material. It is unusual to find comparative data that stretches back more than 50 years, and it is probable that significant effects had already taken place in many areas by the 1950s.

The critical load is also affected by a number of chemical and physical factors. Researchers recommend that the lower values in table 6.1 are used when the weather is cold or dry, during long periods of frost and/or when there is a limited supply of base cations. Conversely, the high values can be used when the weather is warm, humid, free from frost and when there is a good supply of base cations, or if nitrogen is removed from the system through use of the land, for haymaking or grazing for example.

Quite recently researchers also discovered that the chemical form of nitrogen has a significance on the effects that occur in ecosystems – it makes a difference whether nitrogen is supplied as nitrate or ammonium ions. There is still inadequate knowledge in this area.

NITROGEN IN THE SEA

Eutrophication problems in the sea are largely due to the supply of nitrogen, although the supply of phosphorus is also significant (however, phosphorus is not regarded as an airborne pollutant and is not considered in detail here).

Most nitrogen reaches the sea as run-off from the surrounding land. Some of this is airborne nitrogen that is deposited on land and then leaches into surface water and is carried to the sea. In the case of the Baltic Sea it is estimated that the nitrogen that is deposited directly on the water surface accounts for around a third of the total supply.

There is some risk that the transport of nitrogen from the land to the sea will increase in the future. This is because deposition on many types of land leads to a gradual build-up of

The airborne attack by nitrogen is a threat to biodversity in all open, nutrient-poor land, even where we try to protect and preserve it through good management and the creation of reserves.

nitrogen that could be released as a result of human actions, see below.

Another aspect worth mentioning is that a warmer climate leads to faster decomposition of organic matter, with a risk of increased leaching of nitrogen from the land into the sea.

No critical load limit has been established for nitrogen in the sea.

IS NATURE RECOVERING?

Emissions of nitrogen oxides in Europe are expected to decrease markedly in the future. Reductions are also expected in emissions of ammonia, although not to the same extent.

As with acid deposition it is of interest to find out what happens in the soil and in ecosystems when the supply decreases.

In a number of places in Europe researchers have built roofs over small areas of forest to shield them from pollutant deposition. In all these trial areas it has been found that the amount of nitrogen leaking from the system falls considerably soon after the supply is stopped, even though the load has been high for a long time and a large reserve of nitrogen has therefore built up in the soil. The same effect has been observed when forest fertilization trials lasting several years have come to an end.

The store of nitrogen in the soil does not decrease as quickly as the leaching out of nitrogen. Large amounts may be bound up in vegetation and humus layers, and in many cases nitrogen is conserved very effectively; little of it disappears. Interference, such as forestry felling or liming of the soil can accelerate decomposition, however, and lead to the risk of increased leakage. This risk may remain for a long time.

Vegetation responds very slowly to reductions in the supply of nitrogen. In the trial areas that are covered by a roof, no change has yet been seen, even though almost ten years have passed since deposition was greatly reduced. This is probably because the soil and plants are still "charged" with nitrogen that is continuing to circulate within the system. Only when the supply of nitrogen starts running out will the original plants be able to compete again, but this recolonization may take a very long time.