The potential of the "*Programmatic Approach Nitrogen*" to protect biodiversity :

The prospects of nitrogen deposition, the reliability of the critical load and the possibilities of restoration measures

Johannes Nicolaas Cornelis Maria Koumans (s3238253)
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Abstract

The amount of nitrogen deposition on the Dutch ecosystems has increased in the last century, but did lower and stabilized in the last decade. Still, currently in more than 50% of the nature conservation areas in the Netherlands the critical load is exceeded. This means that at least 50% of the ecosystems are at risk to decrease in quality and biodiversity. In order to protect the nature in the Netherlands while allowing room for economic growth, the *Programmatic Approach Nitrogen* (PAN) was constructed by the Dutch government. However, according to the prospects of the programme this will not result in a substantial reduction of ecosystems in which the critical nitrogen load is exceeded, maybe even less than predicted, as it turns out that in some cases the critical load has been calculated too low. PAN relies on restoration measures that remove nitrogen after is has been deposited to compensate for the high nitrogen input. However, removal of excess nitrogen from an ecosystem brings a lot of disturbance, or can even be impossible due to the time the ecosystem needs to recover from these interventions. All in all, it is unlikely that PAN will remove or significantly lower the risk of decreasing quality and biodiversity in Dutch nature areas.

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Introduction

High atmospheric input of nitrogen, called nitrogen deposition, in ecosystems is currently a global problem. Although nitrogen is an essential nutrient for plants, too much of nitrogen can lead to acidification of the soil, causing biodiversity loss because not all plants can cope with this (Vries, 2008). Long term exposure to high nitrogen deposition even causes the species composition to shift towards more fast growing nitrophilic species, out-competing the more characteristic plants of (nutrient-poor) ecosystems that are less adapted to these new conditions (Bobbink et al., 2014). These problems of a high nitrogen deposition, caused by high nitrogen emission, has been recognized by governmental institutions and policy tools are installed in the form of directives. The EU adopted the habitats directive, that in combination with the birds directive results in a network of protected nature areas, also known as Natura 2000 (Heer, Roozen & Maas, 2017). For each of these areas there are specific goals for the conservation of species and habitats that have been made by the Member States. In order to achieve these goals, the nitrogen deposition appears to be a major problem considering its negative impact on the biodiversity. Not only the nitrogen deposition is a problem for achieving the nature goals, also economic growth around the Natura 2000 is in danger. In accordance with the habitat and bird directive, the Dutch Nature Conservation Act of 1998 prohibits any new creation or expansion of economic activities causing harm to nearby Nature 2000 sites. For example, no new farms or expansion of farms or industrial facilities emitting nitrogen near Natura 2000 sites is allowed. To tackle this problem of the need to reduce nitrogen deposition while keeping room for economic growth, the Dutch Programmatic Approach to Nitrogen was developed. The goal of the programme is to ensure that the conservation goals can be achieved, while economic growth around the Natura 2000 sites is facilitated within strict environmental limits (Heer et al., 2017).

In this paper I will review the potential of the Programmatic Approach to Nitrogen in achieving the nature goals of the Natura 2000 sites. I will look at the current situation of nitrogen emissions and depositions and give a short summary of how the programme works and what its intended effects are. The predictions of nitrogen deposition and critical loads of Natura 2000 will be described as will be the impact and results of the restoration measures described in the programme. In the end, I will discuss whether or not PAN really makes an impact in order to ensure the conservation goals.

Current situation

After the industrial revolution new relevant sources of nitrogen arose in addition to natural sources. Besides the emission of nitrogen rich gasses by factories and traffic, a new source of nitrogen input was the usage of industrially produced fertilizer by farmers. These developments resulted into an increase in nitrogen emissions leading to a higher deposition of nitrogen on the soil, vegetation and water surfaces. In the Netherlands this caused the deposition of nitrogen to increase up to 2700 mol (38 kg) nitrogen per hectare in 1990 (RIVM, 2019a). Because nitrogen emitting sources got cleaner through the years the nitrogen deposition has been declining since, and currently seems to level of at about 1500 mol (21 kg) nitrogen per hectare (fig. 1).

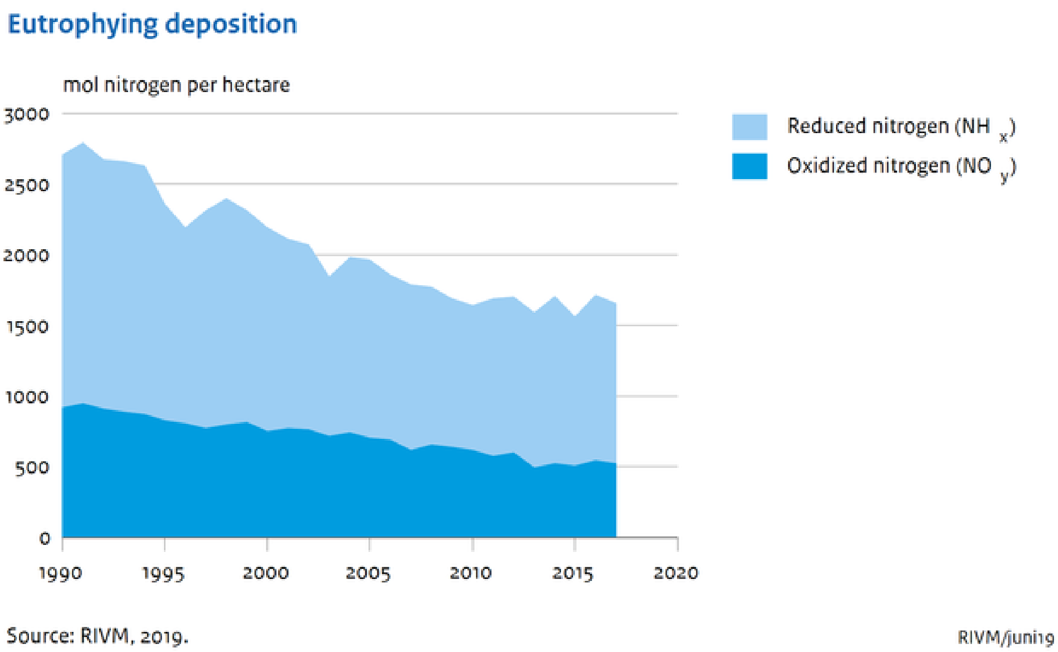

Figure 1: Eutrophying deposition of nitrogen over the years in the Netherlands.

Looking at the figure it seems as if the declining trend is slowly stagnating. Here and there it even seems as if the deposition is higher than the year before, for example between 2015 and 2016. Although this can be explained if you take into account that with constant emission levels the meteorological conditions can result in fluctuations in deposition of up to 10 percent (RIVM, 2019a). In the figure a distinction is made between the two states of nitrogen, reduced nitrogen (NH_x) and oxidized nitrogen (NO_x). These states are emitted by different sources, where agriculture is the largest source of reduced nitrogen, being accountable for 42% of deposition of nitrogen in 2017 (RIVM, 2019c). Other relevant sources causing an increase in nitrogen deposition are the industry, traffic, highways, shipping, emissions from sea and other countries. Around 30% of the deposition in the Netherlands is from nitrogen emitted in neighbouring countries (import), but on the other hand a part of Dutch emissions end up as nitrogen deposition in the same neighbouring countries (export). In total the Netherlands is an exporting country of nitrogen, exporting around 4 times as much as it receives from the neighbouring counties.

The nitrogen deposition has been declining the last decades and stabilized in recent years. However, for most ecosystems the deposition levels are still above the critical loads for sustaining good ecological quality (fig. 2).

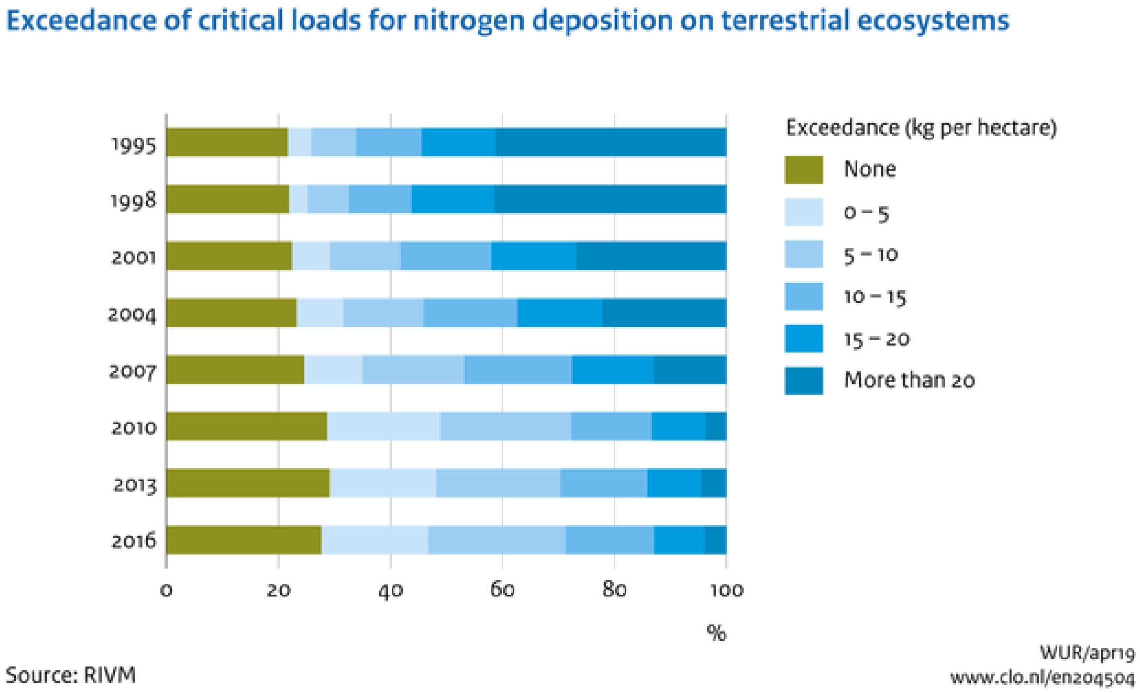

Figure 2: Exceedance of critical load for nitrogen deposition on terrestrial ecosystems in the Netherlands over the years.

From 1995 to 2016 the area of ecosystems where the critical loads were exceeded decreased from 80% to 70%. Meaning that in 2016 still 70% of all natural areas in the Netherlands are at risk to decline in ecological quality. Mostly the nutrient-poor ecosystems like heater and forest with sandy soils have a low critical load for nitrogen deposition, unlike the more nitrogen resilient ecosystems, as grasslands and marsh ecosystems on clay and peat soils (RIVM, 2019b). Not everywhere in the country the deposition levels are the same. Clustering of agriculture in the eastern part of the country results in relatively higher deposition levels there. Meaning that exceedance of the critical loads of nitrogen sensitive heather fields in the east and centre of the Netherlands are higher than exceedance of the nitrogen sensitive open dunes at the west coast.

Programmatic Approach to Nitrogen

PAN is a programme that was launched by the Dutch government in 2015 in order to achieve the objectives of the habitats directives, while providing room for economic growth and development around the Nature 2000 sites. Two types of measures are taken in order to achieve this goal: generic source measures in order to lower de nitrogen deposition and restoration measures in the Natura 2000 sites (Heer et al., 2017). Included in the source measures are the already existing Dutch and European policies on nitrogen emissions. These policies focus on both the emission of oxidized nitrogen emitted by mainly industry, traffic and transport and reduced nitrogen emitted mainly by the agriculture sector (Heer et al., 2017). Included in PAN are three new measures targeting the biggest emitter of nitrogen in the Netherlands, the agricultural sector (Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu, 2017). The first measure includes lowering the emission of ammonium by enhancing the animal households, expecting the emission of ammonia to be 5 kilotons per year less in 2030 in comparison to 2013. The second measure focusses on manure application techniques and the third focusses on feed and management. These respectively should further reduce the ammonia emission by 3 and 2 kilotons per year in 2030. In total, these measures are expected to reduce the emission of ammonia by 10 kiloton per year in 2030.

The restoration measures of PAS focusses on 118 Natura 2000 sites in the Netherlands. These are the sites that are labelled as nitrogen-sensitive with a critical load of less than 23 kg/ha/yr (Van Dobben, Bobbink, Bal & Van Hinsberg, 2013). Restoration measures work by removing the nitrogen after it already has been deposited, using techniques as sodding, burning or cutting. There are also techniques to make the nature areas more nitrogen resistant by taking hydrological measures (Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu, 2017).

In order to allow economic development, part of the reduction of nitrogen deposition is made available to be used for new nitrogen emitting developments. This availability is called ‘room for deposition’ and allows for an increases in emission related to an annual economic growth of 2.5%. Furthermore, 50% of the emission reduction achieved by the source measures is considered as room for deposition and may be used for economic developments in the agricultural sector (Heer et al., 2017). Another part of the room for deposition is room for development. This room for development can be used by the authorities to grant permission for activities that could result in a higher deposition of nitrogen on nitrogen sensitive Natura 2000 sites (Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu, 2017).

With PAN the way investors apply for a permit also changed. Instead of waiting until an actual reduction in nitrogen deposition has been realized , it is made possible to already use future, model-calculation based reductions as room for deposition. Allowing the government to give permits to investors for emission of nitrogen, based on a calculated decrease in the future (Folkert et al., 2014).

Prospects

The prognosis is that the deposition of nitrogen in the Netherlands will further decline. According to calculations made by ARERIUS Monitor 2016L the average nitrogen deposition will decline with 15% in 2030 relative to 2014. A decline from 22 kg/ha/yr to 19 kg/ha/yr (Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu, 2017). It should be realised that a lot of uncertainties are associated with this calculation. Although it is of course uncertain what the realized economic growth over the years will prove to be, the model calculations starts with the assumption that the yearly growth is maximally 2.5% Meaning that if the growth will be lower, which is a more realistic assumption for the coming years, the nitrogen deposition will most likely be lower than what has been calculated (Folkert et al., 2014). Other uncertainties are: - the effect of measures of already existing policies in the Netherlands on sources, - the effect of the new source treatments described and included in PAN, - the effect of policies concerning nitrogen emission in neighbouring countries and - the change of livestock size (Folkert et al., 2014). In worst case scenario these uncertainties could cause already one extra kilogram/ha/yr of nitrogen deposition in 2020. However, would the economic growth be lower and the effects of the policies on a lowering nitrogen deposition be larger than expected, it could be that the deposition is one kilogram/ha/yr less in 2020. All in all, it is hard to predict the absolute change of nitrogen deposition, but it is possible to find a trend. Although, it has to be taken into account that the weather conditions differ year to year, causing the nitrogen deposition to fluctuate without showing a trend of nitrogen emissions (Velders et al., 2014). Thus, charting a trend of nitrogen depositions is done by calculating with the average weather conditions.

As said before it is hard to calculate the absolute change of nitrogen deposition, but it is even harder to do so on a more local scale (read: for nature 2000 sites). For a calculation of nitrogen deposition of a square kilometre the error marge is up to 70% (DLG, 2013). Although the trend is that the nitrogen deposition will decrease over the upcoming year it is hard to tell how much and whether the deposition on the Natura 2000 sites will be below the critical load in 2030. In PAN they assume that still more than 50% of the nitrogen sensitive Natura 2000 sites will have a critical overload of nitrogen deposition, but that the restoration measures will compensate for that. There is however a chance that even more sites will be in danger as not everyone agrees on the accuracy of the critical loads.

Critical load

The definition of critical load is: ‘the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not expected to occur according to present knowledge’ (Nilsson, 1988) In PAN the relevant pollutant is nitrogen. So, if the critical load gets exceeded there is a risk the habitat directives cannot be realized because of possible decline of quality and size of the nature area. The larger the exceedance and the longer the exposure, the bigger the risk of unwanted effects on the biodiversity (Van Dobben, Bobbink, Bal & Van Hinsberg, 2012). Only if the Natura 2000 sites are exposed to a nitrogen deposition above their critical load, restoration measures are taken in order to remove nitrogen from the ecosystem and reduce the risks of a decline in quality and size. Is the critical load of a Natura 2000 site calculated wrongly and indicate that it does not exceed the nitrogen deposition, while actually the nitrogen load is much higher, there is the possibility that the site is in danger but that no restoration measures will be executed.

To calculate the critical loads used in PAN they used the following sources: Empirical critical loads of Europe, model results and expert opinions (Van Dobben et al., 2012). The empirical critical loads are established by the Economic Commission for Europe of the United Nations Economic and Social Council (UNECE) in the context of the Convention on Long-range Transboundary Air Pollution. This has last been done in September 2010 based on the result of a workshop in Noordwijkerhout (Bobbink et al., 2010). The critical loads are determined in the field or in a laboratory in combination with the harmful effects. They are formulated in the form of bandwidths, with a guideline whether to use the upper of lower range based on specific circumstances. In case of establishing a concrete critical load for the Dutch Natura 2000 sites there are two situations possible: (1) the relevant habitats types of Natura 2000 sites in the Netherlands are corresponding, or are comparable enough, to a habitat with an empirical critical load established by the UNECE or (2) the habitat does not look (enough) like a habitat the UNECE has established an empirical critical load for. The next step is (if 1) using models to specify the empirical critical load of UNECE to a unique value or (if 2) calculate the critical load with models. If the model calculations are trustworthy enough it is possible to calculate a concrete critical load of habitats in the Netherlands. If not, expert opinions are asked in order to either still specify the empirical critical load of the UNECE or come up with a critical load without the use of models and UNECE. For almost all of the habitats of Natura 2000 sites in the Netherlands it was possible to establish a concrete critical load, while only 2 habitats ended up with no concrete critical load. For these two habitats there was no relevant habitat type of UNECE and no trustworthy model calculation, even with professional opinions only a possible critical load could be established (Van Dobben et al., 2012). In figure 3 the protocol of establishing a concrete critical load is summarized in format of a flowchart.

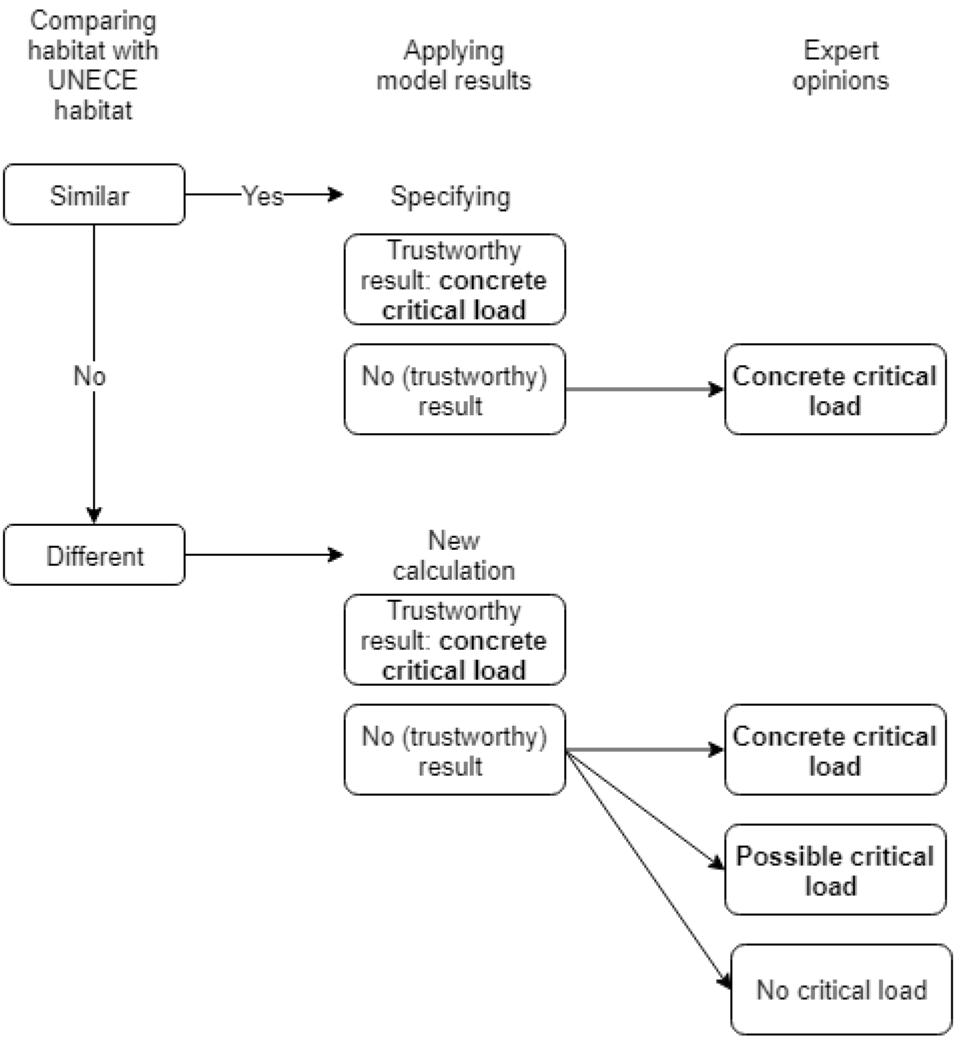

Figure 3: flowchart of establishing a concrete critical load, adapted from van Dobben et al., 2012.

Worryingly, according to a study in England it is not possible to completely rule out that there is an ecological impact of the pollutant even if under the critical load (Payne et al., 2013). In this study they found a decrease of species abundance of an acid grassland even when exposed to a nitrogen deposition under the established critical load for this habitat. Another study in England found the same result for eight out of the 12 habitats they tested (Wilkins, Aherne & Bleasdale, 2016). It must be said that these studies worked with the empirical critical loads established by UENCE and that, as described above, in the Netherlands the critical load is specified with model results and expert opinions. However, also in the acidic Dutch grey dunes a loss of species abundance was found even when under the critical load calculated with the methods described above (Kooijman, van Til, Noordijk, Remke & Kalbitz, 2017).

If the critical loads where re-evaluated and possibly lowered even more nature sites will exceed their critical load. This would mean that restoration measures will have to be taken to compensate for nitrogen deposition in even more nature areas than thought before.

Restoration measures

The prospects show that more than 50% of the Natura 2000 sites in the Netherlands will be exposed to a nitrogen deposition above their critical load. In order to preserve and protect the biodiversity of these sites PAN relies on restoration measures (Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu, 2017). The restoration measures have two main effects, they improve the habitat suitability and remove nitrogen from the ecosystem (Jones et al., 2017). Two issues that affect the potential success of restoration measures are propagule availability and hysteresis. No recovery will happen if the propagule of the targets species are not in the seed bank anymore because of long term nitrogen deposition, unless they are re-introduced (Basto et al., 2015). Hysteresis is a problem where the biotic community and the soil chemistry change in response to the restoration measure causing the system to shift into an altered state (Clark & Tilman, 2010; Suding & Hobbs, 2009). The most common restoration measures practiced in the Netherlands are mowing, prescribed burning and sod-cutting.

Mowing (cutting)

Mowing is a restoration measure that is mostly applied in meadow grasslands, heathlands and fens and on a lower scale in dune grasslands, calcareous grasslands and saltmarshes (Jones et al., 2017). If practiced well the biomass is removed after cutting, since leaving the biomass on the ground does not reduce the nitrogen pool. Leaving the litter on the ground also reduces the light that reaches the lower ground, causing effects comparable to having tall vegetation on heather and grasslands (Diemont & Homan, 1989). If the litter is removed cutting increases the light levels by up to 70% in grasslands (Borer, Seabloom, Gruner & Harpole, 2014; Hans, Rein & Martin, 2003). As a result the ground heats up more during the day and cools more during the night altering the microclimate close to the ground. This heating up of the soil during day can stimulate nitrogen mineralization in the soil and therefore increase the amount of nitrogen available for plant update (Jones et al., 2017). It must be said that cutting may not result in a removal of dominant nitrophilic species (Bakker, Elzenga & de Vries, 2003). Nevertheless, cutting does decrease the abundance of dominant species allowing the persistence of more lower or slower growing species. The timing and frequency does play a role in the species compensation as it determines which of the species are able to seed between the mowing periods (Brys, Jacquemyn, Endels, De Blust & Hermy, 2004).

Cutting does have the potential to remove nitrogen for the system, although it is possible it is not capable to keep up with the nitrogen inputs because of the high deposition rates. However in a mesocosm experiment they found that cutting a calcareous grassland twice a year would remove between 20 and 60 kg/ha/yr while in acid grass lands it would result in a removal of 7-34 kg/ha/yr (Jones, 2005). The prospect is an average nitrogen deposition of 19 kg/ha/yr, making it possible to counteract nitrification. Another experimental study in the heathlands of Germany showed that that mowing removed quantities that corresponded to about 5 years of nitrogen deposition (Härdtle, Niemeyer, Niemeyer, Assmann & Fottner, 2006). However in most cases the mowing was not applied over a shorter cycle than 10-15 years because of the time the vegetation needs for recovery (Terry, Ashmore, Power, Allchin & Heil, 2004). This would mean that with only mowing as restoration measure the heathlands will accumulate nitrogen over time.

Burning

Managed burning is commonly used in the Netherlands and other parts of North-West Europe particularly on heathlands, but also some grasslands, fens and bogs. Although, accidental burning can affect almost any type of ecosystem. Because it is usually practiced at heathlands, this is also the habitat were the effects of burning on nitrogen polluted habitats have been investigated most (Jones et al., 2017). Burning allows, just like mowing, light to penetrate again to close to the soil surface, before *Calluna* (a distinct species for a heather habitat) starts to dominate and shade out other species, thus increasing the biodiversity. This is also why, in order to keep the biodiversity at its highest at all times, short rotation burning of heater is recommended (Harris et al., 2011). It is shown that prescribed burning in montane heathers does lessen the impact of nitrogen deposition, but that on un-burned plots there was a significant loss of species richness (Britton, Marrs, Carey & Pakeman, 2000). Burning of lowland heaters on the other hand do not to seem to be more resilient against nitrogen deposition, showing an increase in growth and establishment of both *Calluna* and *Deschampsia* (an unwanted grass species) seedlings (Barker, Power, Bell & Orme, 2004; Power, Barker, Allchin, Ashmore & Bell, 2001).

By removing plant material and litter, burning is a way to reduce the pool of nitrogen. However as only the part above the ground gets affected it does not lead to any short term reductions of nitrogen in the soil (Pilkington et al., 2007). Another problem are the remains after burning; a study in Germany found out that after the burning of the vegetation 5.2 kg/ha of nitrogen returned as ash (Härdtle et al., 2009). However, besides the removal of nitrogen by the burning process, the burning may also increase the amount of nitrogen leaching from the ecosystem for a few years (Mohamed, Härdtle, Jirjah, Niemeyer & Von Oheimb, 2007; Pilkington et al., 2007). However even when with this taken into account the required burning frequency to compensate for the nitrogen deposition is unrealistically high, leaving no room for the vegetation to recover (Härdtle et al., 2006; Pilkington et al., 2007). On a heater in North Germany for example burning results in a removal of 5 years of nitrogen deposition. Although, the heather needs 10-15 years to recover before the burning can be practiced again, resulting in an accumulation of nitrogen (Härdtle et al., 2006). Besides, a disadvantage of burning is that after the burning the nitrogen enters the atmosphere again, inevitably causing it to deposit on nearby habitats, only moving the problem to somewhere else (Cresser et al., 2004). Furthermore, because of safety reasons burning often happens during the winter, the season in which most of the plant nitrogen is presumably stored underground, this not being burnt results in removing less nitrogen.

Sod-cutting

Sod-cutting is a restoration measure where the upper layer of the soil gets “cut off” and removed. One type of commercial sod-cutting that has been practices for a long time is peat harvesting. Peat harvesting is actually the process where many lowland heathlands owe their origin from (Webb, 1998). An important step of sod-cutting is establishing the depth of the cut, where cutting too deep is more costly and can result in a modified soil moisture making the habitat restoration less efficient (Niemeyer, Niemeyer, Fottner, Härdtle & Mohamed, 2007). Sod-cutting does not make a difference between removing the undesirable and desirable species and even does remove a big part of the seed bank in the top layer, making it an intervention with high disturbance (Dorland, Berg, Berg, Vermeer & Roelofs, 2004). This can lead to a positive effect if the desired species has their seeds in a more persistent seedbank lower in the ground, favouring the emergence of these species over the species of which the seed bank has been removed. However it can work the other way if the species of high conservation value have a seed bank more close to the surface, because it is more likely the near-surface seed bank is removed during the process. It is not only the seed bank that gets (partly) removed, also the spores of symbiont fungi get removed (Vergeer, Van Den Berg, Baar, Ouborg & Roelofs, 2006). Even after 2.5 years their numbers are still reduced, making it harder for species that rely on a symbiosis with fungi to re-colonize. However, in dune habitats the high disturbance can have a positive effect. After the removal of the decalcified surface, the new environment in combination with the disturbance effects favours the early successional colonizers of high conservation value (Houston & Dargie, 2010). Even in older dune grassland shallow sod-cutting led to a rapid reintroduction of characteristic dune plants (Til & Kooijman, 2007).

Because a large amount of nitrogen is stored in the vegetation and upper layers of the soil, it is clear that removing of the top layer by sod-cutting is a very effective way to remove nitrogen from the ecosystem. In lower heathlands up to 176 years of nitrogen deposition could be removed using sod-cutting, making it the most effective restoration measure for nitrogen removal (Härdtle et al., 2006). Because mostly the oxidised surface layers get removed, the nitrogen availability switches to ammonium. This makes is harder for some target species to re-habilitate, but this problem is possible to resolve by liming in order to reduce the acidity of the ground (Dorland et al., 2004). Sod-cutting may also alter the hydrological regime, as soil compaction reduces infiltration and cutting lowers of the surface (Kahlon, Lal & Ann-Varughese, 2013)**.** The latter can be beneficial in some cases where the buffering capacity of ecosystems increases by the being more in contact with base-rich ground water, allowing species of high conservational value to grow (Emsens, Aggenbach, Smolders & van Diggelen, 2015). However, a study on the heathlands of Belgium found no significant change in the abundance, proportion and cover of target species up to 19 years after sod cutting (Godefroid, Sansen & Koedam, 2017). Suggesting that after the impact of disturbance, sod-cutting may cause no effect in the long term.

Discussion

The goal of PAN is to reduce the nitrogen deposition in order to protect the Nature 2000 sites while allowing room for economic growth. According to models it will accomplish a slight decrease of nitrogen deposition in the future, but not nearly enough to protect all Natura 2000 sites from quality and biodiversity loss. Still more than 50% of the sites will exceed their critical nitrogen load and thus are at risk to be ecologically harmed. This percentage might be even higher, as it turns out that the critical load may have been calculated too low for habitats that loose species even when their critical loads are not exceeded. PAN heavily relies on the restoration measures to make up for the eutrophication caused by the high deposition of nitrogen in these habitats. However, most measures are not sufficient to both remove the amount nitrogen in the ecosystem caused by deposition and protect the biodiversity. By sod-cutting it is possible to remove a huge amount of nitrogen, but the consequences are a highly disturbed ecosystem that after the recovery may lack a beneficial effect on the target species composition. Burning and cutting do cause less disturbance than sod-cutting but remove far less nitrogen from the system. In order to keep up with the nitrogen deposition this would result in too many interventions in a short period of time, allowing no room for recovery of the ecosystem. Because the restoration measures likely will not be capable to counteract all the harm of the future amounts of nitrogen deposition, PAN fails in their goal to protect the Nature 2000 sites. PAN should reconsider the source measures or restrict their policy of providing permits, resulting in a situation where the future deposition is lowered to a point where the restoration measures that are currently available to us, can be effective in maintaining biodiversity and ecological value of our natural areas.

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