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Nitrogen deposition and the reduction of butterfly biodiversity quality in the Netherlands

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ABSTRACT

Butterfly decline in Northern Europe is a cause of concern and it has been hypothesised that this is due to nitrogen deposition inducing excess early growth of plants. It has also been changing the quality of the food available to larvae. We tested these hypotheses by linking butterfly biodiversity quality indices (species richness, population, biomass, conservation value, evenness (Simpson's Index) and modelled species richness (Chao 1 and 2)) with nitrogen Critical Load Exceedence (nCLE) data. An index of butterfly sensitivity to nitrogen was also created (Species Nitrogen Value Index (SNVI)). Using PCA, datasets were tested for associations and relationships.

The results included multiple biodiversity quality indices based on 17 years of data (aggregated into three periods of six, six and five years to give 287 datasets) in four habitat types (grassland, heathland, woodland and farmland). With the exception of heathland the analysis showed that nitrogen deposition and all other indices (except SNVI) were in decline.

For heathland the last 11 years did not show any significant decline. Heathland also showed an anomalous biodiversity quality profile for these last 11 years, suggesting that the sensitivity of heathland to nitrogen deposition will require further considerable efforts to achieve a nitrogen deposition that is not in exceedence of the critical load.

Habitat restoration will take time due to the multiple hindrances to colonisation, which in the case of heathland might prevent successful butterfly colonisation for the foreseeable future. These results indicate the efficacy of butterfly biodiversity quality and nCLE as indicators for the SEBI 2020 process (Streamlining European Biodiversity Indicators) by showing the relationship between them.

1. Introduction

Butterflies are one of the two indicator taxa (the other being birds) specifically identified by the European Environment Agency (EEA) among a total of 26 indicators of biodiversity in the Streamlining European Biodiversity Indicators 2010 (SEBI 2010) process. Butterflies are said to respond more quickly to environmental change than other taxonomic groups, such as birds or vascular plants (Erhardt and Thomas, 1991; Thomas et al., 2004). In particular Weiss (1999) showed a strong linkage between nitrogen deposition impact on plant growth and the population decline of the Bay Checkerspot) butterfly (*Euphydryas editha bayensis*) alleviated by the removal of nitrogen by grazing cattle (nitrogen was exported in the form of cattle carcasses). Defined methods for butterfly population sampling exist, which in some cases have been conducted in a standardised way for a number of years (Pollard and Yates, 1993).

Butterfly populations are influenced by weather conditions and are expected to be affected by Global Climate Change (GCC), with the global expectation that many temperate region populations might extend their geographic range as temperatures increase (Settele et al., 2008; Devictor et al., 2012). However, studies by Settele et al. (2008) and Thomas et al. (2004) show many European butterflies appear to be in decline albeit obviously not the same species as are expanding.

Nitrogen pollution in the environment has several sources, all determined by human activity. The most obvious sources of these is the use of nitrates in agriculture. Many European habitats are heavily influenced by intensive farming practices and application of nitrogen. In particular, ammonia produced by cattle/pig slurry

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or from chicken deep litter/battery houses has a differential effect on the surrounding vegetation (Sutton et al., 2009). A more insidious nitrogen influence is general atmospheric deposition. Bobbink and Roelofs (1995) assessed atmospheric deposition to have a measureable effect on vegetation once it has reached a Critical Load. Below this load, the geology and vegetation are able to accommodate the nitrogen and it is incorporated into the ecosystem without too much change to the biotope. Above the Critical Load there is a possible effect on vegetation growth and species composition. This balance of deposition is modelled and expressed as the nitrogen Critical Load Exceedence (nCLE) (Bobbink and Roelofs, 1995; Hettelingh et al., 2009). These authors used remote sensing of atmospheric nitrogen combined with data derived from geological and vegetative sources to model the nitrogen effect. Nitrogen CLE is also a SEBI 2010 indicator and our working research hypothesis is that:

H nCLE above the modelled critical load has a deleterious effect on butterfly biodiversity quality

This hypothesis would therefore link to, and validate, two of the 26 indicators in the SEBI 2010 list. NCLE is here defined as nitrogen deposition per 1 km × 1 km modelled as deposition above background vegetation and geology accommodation levels and in this paper is measured as mol/ha/yr. Biodiversity quality of butterfly populations is used in the way described by Feest (2006), Feest et al. (2010, 2011) and Feest and Cardoso (2012) as the summation of the measured indices of characteristics of a population sampled in a standardised way. It is therefore expressed as a range of indices indicating the characteristics and thereby the quality of a butterfly population (see below).

2. Materials and methods

The methodology for fieldwork was based on the 1993 (Pollard and Yates) survey methodology of the Dutch Butterfly Monitoring Scheme in the Netherlands for the years 1990–2006. Data was supplied by de Vlinderstichting and converted to biodiversity quality indices using the Fungib programme (free from ecosulis ltd.). Biodiversity quality for butterflies is defined in this research as the sum of characteristics presented by following indices (Feest, 2011) calculated for each survey site for each year: To alleviate the effects of the considerable annual variation in butterfly populations, that often incorporates at least a year of lag time when populations are recovering from depressed numbers, data was also aggregated into three sets of time periods data of six, six, and five years (a total of seventeen years).

The following biodiversity quality indices were calculated following Feest (2006) and Feest et al. (2010):

1. **Species Richness**: number of species in a unit sample, which in this case is the total of a year's observation of a defined site and survey route.
2. **Simpson's Index**: a measure of the evenness of the population numbers of a site in a year's sample. Simpson's Index was used (in preference to the Shannon–Wiener Index) since it is less influenced by sample size (Magurran, 2004) and has wider amplitude of scale, and thus greater sensitivity to change in species populations.
3. **Species Conservation Value Index (SCVI)**: a scale of the rarity of different species following the scale devised by Feest (2006) and based on the occurrence of different species in the de Vlinderstichting survey of the years 1990–2006. The scale ranged from two for abundant species to 100 for extremely rare species. The resultant list of species and their scores can be found in Appendix A.
4. **Population**: the total number of butterfly individuals recorded for a site in a year.
5. **Biomass**: the sum of the product of the number of individuals of each species multiplied by the wing width, which is an approximation for relative size. Since the size range of butterflies is small, this index was related to population, but in other organisms (e.g. macrofungi) these two indices can vary greatly (Feest, 2006).
6. **Species Nitrogen Value Index (SNVI)**: an index of the relative sensitivity of different butterfly species to nitrogen pollution. For the purposes of this research, it is the averaged transformed weighted $\log(n+1)$ data of an Ellenberg series of species allocations on a scale from 1 to 10. The method follows Oostermeyer and van Swaay (1998). In effect, the lower the value, the more a species prefers nitrogen-poor soils (nitrophobic). High values indicate nitrophilia. The resultant values for species can be found in Appendix A.
7. **Nitrogen Critical Load Exceedence (nCLE)**, which was calculated as the average modelled atmospheric nitrogen deposition at a 1 km × 1 km grid minus the average critical loads of semi-natural ecosystems present in the same 1 km × 1 km grid (as mol/ha/yr). The nitrogen deposition was derived from the OPS-model (van Jarsfeld et al., 1997), using information on the emission of nitrogen in the Netherlands and other EU countries. Modelled air concentrations were calibrated with air concentration measured in Dutch air-monitoring sites. Critical loads were derived from Bobbink and Lamers (2002). These empirical critical loads are based on observed changes in the structure and function of semi-natural ecosystems, reported in a number of publications (Achermann and Bobbink, 2003). Within the broad ranges of empirical critical loads, specific critical loads were assigned to different ecosystems using dynamic ecosystem models (Van Dobben et al., 2006). When modelled loads were outside the empirical ranges, the nearest limit was used to set the empirical load.

Habitats: butterfly populations were grouped into 4 broad habitat types found throughout the Netherlands (farmland, grassland, heathland and woodland) and assessed separately.

Statistical analysis: due to the annual variability and carry-over of year effects, the data was converted to mean values for the survey period 1990–2006 as periods of six (1990–1995), six (1996–2001) and five years (2002–2006) and relationships were examined by subjecting the data to Principal Component Analysis (PCA), conducted on both the aggregated data and the individual years as six-, six- and five-year assessments. PCA was used to isolate the relationships between factors with the indices not needing to be normally distributed and showing reduced interaction (Henderson and Seaby, 2008).

3. Results

A summary of the results are presented in Table 1 which shows a summary of the indicator values. Some patterns can be observed, such as that each habitat has:

a) an increased SNVI over the 17 years
b) Species Richness and Simpson's Index have no clear pattern and
c) Population declines sharply in three out of four habitats.

SCVI and nCLE declined (nCLE by over 1000 mol/ha/yr) over the 17 years (except for the notable third time period for data for heathland nCLE where a decline of only 11 mol/ha/yr is evident and the total decline is 566 mol/ha/yr for the 17 years. The final figure was still in excess of 1000 mol/ha/yr (Table 1).