ORIGINAL PAPER

Changes in the distribution area of vascular plants in Flanders (northern Belgium): eutrophication as a major driving force

W. Van Landuyt · L. Vanhecke · I. Hoste · F. Hendrickx · D. Bauwens

Abstract   In large parts of Western Europe agricultural intensification after World War II has led to an increased use of fertilisers. The resulting nutrient enrichment (=eutrophication) has a huge impact on the occurrence and distribution of plant species and is one of the main pressures on native plant communities. We used the distribution maps (grid size: 16 km²) of individual plant species, obtained through two consecutive survey projects (1939–1971 and 1972–2004) in Flanders (northern Belgium), to estimate the relative change in their distribution area. The comparison of changes in range size among groups of taxa classified according to habitat preference and Ellenberg indicator values, demonstrated a marked decline in distribution area in species that are characteristic for nutrient-poor habitats. To assess geographic patterns in the change of species assemblages, we calculated the mean Ellenberg N- and R-values for every grid cell during each of both survey periods. Differences between these values were analysed in relation to soil type and estimates of atmospheric nitrogen deposition. The largest shifts in Ellenberg N-values, reflecting a decline of species from nutrient-poor conditions and/ or an increase of nitrophilous plants, were observed in areas with nutrient-poor, acid sandy soils and high nitrogen deposition rates. Hence, shifts in species composition were modulated by geographic variation in soil type and levels of nitrogen deposition. As the levels of atmospheric nitrogen deposition are still very high in Flanders, it is likely that species from nutrient-poor habitats such as heathlands, will further decline in the near future.

Nomenclature—Lambinon et al. (2004) for vascular plants.

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Introduction

Over the past few decades there has been increasing concern about the effects of human activities on the natural environment (McNeill 2001). It became clear that ecosystem interference largely predates the 20th century and that it has far reaching consequences beyond the major industrialised areas of the world (Crosby 1972; Richards 2003; Simmons 1989; Turner et al. 1990). Along with the effects of habitat destruction, nutrient loading is one of the most important threats to plant diversity, leading to declines of distribution area and even regional extinctions (Walker and Preston 2006). Worldwide, the increase of fertiliser use during the second half of the 20th century (Leigh 2004; Smil 2001) has been a major cause of changes in the distribution of native species (Bobbink et al. 1998).

The northern part of Belgium, known as Flanders, has since centuries been one of the most densely populated and intensely urbanised regions in Europe. More recent and intensive changes in land use have accelerated the modification of its landscapes (Vanhecke et al. 1981). Belgium and especially Flanders is exposed to environmental pressures that are among the highest in Europe: the nitrogen surplus (nitrogen balance kg/ha) is among the highest in Europe (Nixon et al. 2003), herbicide usage is the highest in Europe (Nixon et al. 2003) and the degree of habitat fragmentation by transport and urban infrastructure is extremely high (Anonymous 2003). As a consequence, highly diversified man-made landscapes were replaced by a more homogenous landscape during the 20th century (Deckers et al. 2005). The loss of habitats and agricultural intensification caused declines and local extinctions of numerous indigenous plant species, while others benefited from human interactions and expanded (Van Landuyt et al. 2006c).

During the last decade, several studies have documented on the changes in plant distribution at national scales. Some are based on the comparison of atlas data over two or more periods, such as those from the UK (Preston et al. 2002a) and the Netherlands (Tamis et al. 2005). Others are based on especially designed monitoring surveys such as the UK Countryside Survey (Smart et al. 2003; Smart et al. 2005; Haines-Young et al. 2003) or on updating surveys of a selection of atlas data (Rich and Woodruff 1996). These studies have shown a marked decline in distribution area in species that are characteristic for nutrient-poor habitats, and increasing ranges in species that occur typically in nutrient-rich environments. Despite this growing body of evidence demonstrating shifts in species composition towards more nitrophilous species, no large-scale studies have related this directly to factors such as soil type and levels of nitrogen deposition.

It is expected that ecologically distinct areas will be differentially affected by eutrophication. Soil nutrient levels, which depend in part on soil type, can be highly heterogeneous in space (Aplin 2001). The levels of (atmospheric) nitrogen deposition are also likely to vary geographically. Hence, unravelling the changes in the composition of species assemblages in relation to soil type and levels of nitrogen deposition is of crucial importance both for understanding the trends in flora composition and for the preservation of species assemblages on a wide geographic scale.

In the present study we use data from two successive plant survey schemes (1939–1971 and 1972–2004) that covered the whole territory of Flanders (13,750 km²). This allows to examine changes in the size of the distribution area of individual species and to investigate geographic changes in plant species composition using nitrogen and acidity as ecological

indicators. More specifically, we address following questions: (i) are changes in the size of the distribution area of individual plant species related to their ecological characteristics? (ii) are there geographic patterns in changes of species composition, as indexed by the species' preferences for nitrogen and acidity? (iii) are these putative geographic patterns related to soil type and nitrogen deposition levels?

Material and methods

Changes in distribution area of individual plant species

Plant distribution data

Data on the distribution of wild vascular plant species in Flanders were collected during two successive surveys that were executed by numerous professionals and volunteers and that covered the whole area of Flanders. The first survey, conducted between 1939 and 1971, was part of a wider survey in Belgium and Luxembourg and resulted in an atlas that contained detailed species distribution maps (Van Rompaey and Delvosalle 1972). The second survey, that ran from 1972 to 2004, resulted in an 'Atlas for Flanders and the Brussels Capital Region' (Van Landuyt et al. 2006a). Both mapping projects used the same methodology, as described in (Van Rompaey 1943; Van Landuyt et al. 2006b). Briefly, field surveyors investigated 1 km² grid cells and scored the presence or absence of all wild vascular plant species (indigenous, archeophytes and neophytes). Subsequently, the original grid cells were combined into units of 16 km² and the observed presence of each plant species in these grid squares was presented in the atlases (Fig. 1). By assembling the original 1 km² cells into larger units, the effect of spatial differences in observation densities and recorder behaviour is reduced (Rich and Smith 1996).

Species selection

We obtained distribution maps for both survey periods for a total of 1,417 native or naturalised species. However, we excluded from further analyses species that fitted into one of following categories. (1) Species whose data are less reliable than for others; this is especially the case for taxa that are difficult to identify in the field. (2) Taxa that changed taxonomic status between the two mapping periods. (3) Introduced, yet naturalised species, often planted in forests parks and gardens, that were largely ignored during the first survey but received more attention during the second (see also Rich and Woodruff 1992). (4) Species that, for a variety of reasons, were surveyed more intensively during one of both periods; examples are taxa that were subject to detailed studies, most often during the second survey period (Hoffmann et al. 1996; Hoste and Verloove 2001; Vanhecke 1976). (5) Species recorded in five or less grid cells during the first survey period. Exclusion of these five groups of species resulted in a total of 875 taxa that were retained for further study.

Estimating the relative change in species distribution area

Distribution maps obtained during different periods can provide estimates of changes in the range size of individual species. However, caution must be taken when comparing data from different surveys. In the present study, virtually all grid cells were explored at least once during each of both survey periods, such that geographic coverage could be
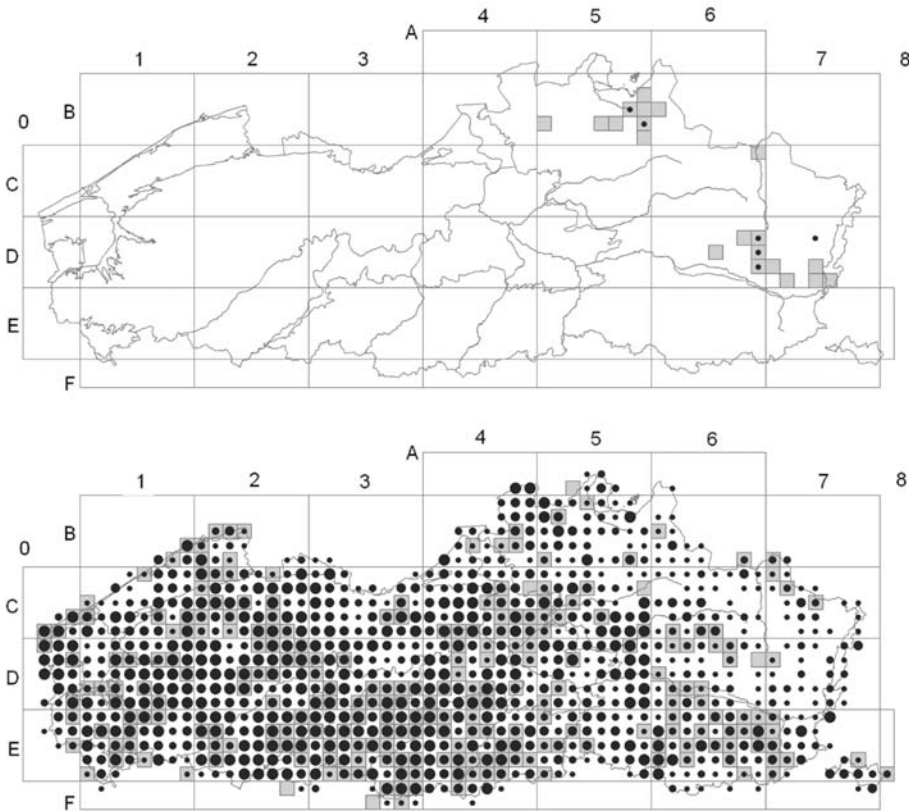
Fig. 1 Distribution of *Lobelia dortmanna* (upper map) and *Cardamine hirsuta* (lower map) in both survey periods. Squares represent grid cells (16 km²) occupied during the period 1939–1971, dots show cells occupied in the period 1972–2004

considered as virtually complete and identical for both surveys. Nevertheless, the first survey provided 245,036 records (the number of recorded presences of all species in all 16 km² grid cells), while the second survey yielded 343,971 records. This difference reflects increased survey efforts in the second period. To minimise bias due to differential collection effort, we adopted the method developed by Telfer et al. (2002). This method assumes that during the two surveys field recorders attempted to observe as many species as possible in each grid cell. The size of the distribution area of individual species in a given period, i.e., the number of 16 km² grid cells where the species was observed, was expressed as a proportion of the total number of grid cells studied during that period. To summarise the changes in distribution area for all species, we performed a linear regression of the logit-transformed proportions in the second survey as a function of the logit-transformed proportion in the first survey (Fig. 2). We then calculated an index of relative change in distribution area for each species by its standardised residual from the fitted regression line. Species that increased their distribution area obtained positive values of this index, taxa whose distribution area decreased in size had negative values, whereas values equal to zero indicate no change in range size between the two survey periods. (Indices of relative change in distribution area for the individual species are in the additional material on doi:10.1007/s10531-008-9415-3).
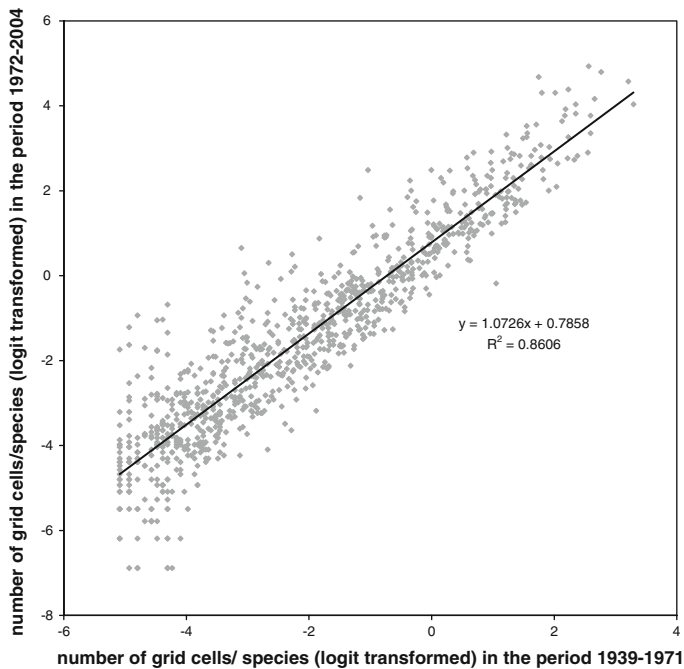
Fig. 2 Scatterplot and linear regression of the size the distribution area of individual plant species in the period 1972–2004 versus range size in 1939–1971. Size of the distribution area is calculated as the proportion of the total number of 16 km² grid cells (logit transformed) occupied in each survey period

Habitat preferences and Ellenberg indicator values

We assigned the preferred habitat type to each of the 875 selected plant species, according to the classification of Stieperaere and Fransen (1982).

We also assigned to each plant species its Ellenberg value (Ellenberg et al. 1991) for nitrogen (N) and reaction (R). The Ellenberg value for nitrogen (N) classifies plant species into 9 classes ranging from 1 (indicators for extremely infertile soils, e.g. *Andromeda polifolia*) to 9 (indicators for extremely rich situations, e.g. *Urtica dioica*). The Ellenberg value for reaction (R: soil pH or water pH) classifies plant species into 9 classes ranging from 1 (indicators for extreme acidity, e.g. *Lycopodium clavatum*) to 9 (indicators of basic reaction, always found on calcareous or other soils with high pH, e.g. *Orobanche caryophyllacea*).

For each of the categories according to habitat type, and Ellenberg N and R-values, we tested whether the mean index of relative change in distribution area differed from zero (=no change) with a two-sided *t*-test (SAS 9.1), and judged significance by the sequential Bonferroni method using an experiment-wise (or table-wide) error rate of α = 0.10 (Chandler 1995).

Changes in geographic distribution of species assemblages

Geographic distribution of Ellenberg N- and R-values

To explore the geographic distribution in the ecological characteristics of the plant species assemblages, we used the Ellenberg indicator values for nitrogen (N) and reaction (R). For

each 16 km² grid cell we calculated the mean of the N and R-values for all species present in each of the two survey data sets. These values summarise the preference for nitrogen (N) and reaction (R) of the species assemblage that is present in each cell during each survey period. Shifts in the mean values between the two survey periods indicate changes in species composition and particularly in the species' preference for nitrogen (N) and reaction (R). These changes presumably reflect shifts in ecological conditions.

Distribution of soil types

We used the digital soil map of Flanders (Ondersteunend Centrum GIS Vlaanderen 2001; original data collected between 1945 and 1970), and distinguished among six soil types: acid sand, calcareous sand, sandy loam, loam, clay and 'anthropogenic' (soils altered by human activities and that were not plotted in the original soil map). We used a GIS (ArcGIS 9, ESRI) to overlay the soil map with the 16 km² grid and assigned to each cell the soil type that covered most of the cell. This resulted in a distribution map of the six soil types (Fig. 3).

Distribution of atmospheric nitrogen deposition

We used data from a digital map with atmospheric nitrogen deposition (NO_y and NH_x) in 1990 (Van Gijseghem et al. 2003). These data represent the oldest detailed information available and the timing coincides with the midpoint of the time course of the second survey. An overlay of this the soil map with the 16 km² grid allowed calculation of average atmospheric nitrogen deposition in each grid cell.
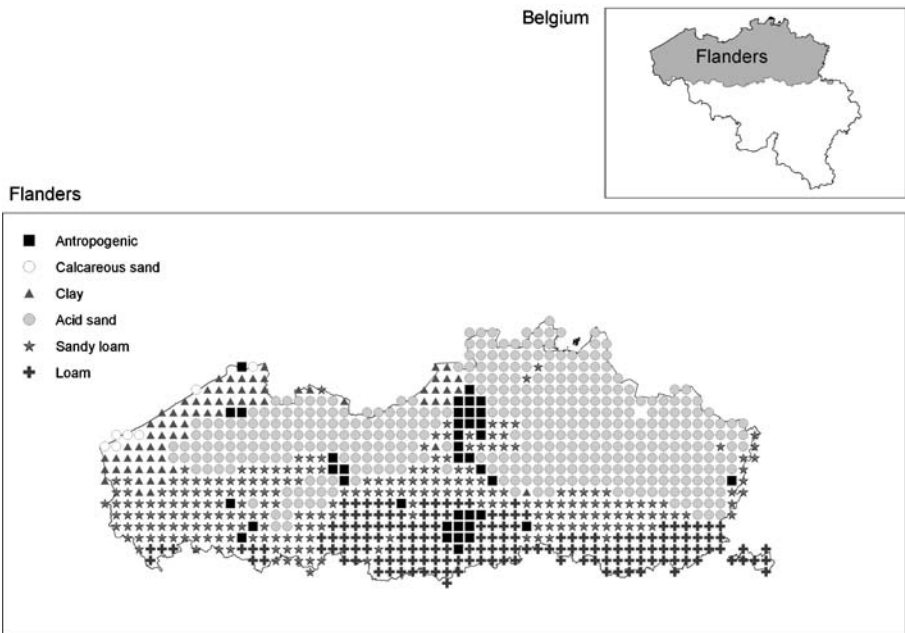

Fig. 3 The distribution of soil types in Flanders

Examining changes in Ellenberg N and R-values

We used a general linear model (proc mixed in SAS 9.1) to explore differences among grid cells in the mean Ellenberg N- or R-value during the second period (N_2 or R_2), the dependent variable, in relation to the mean Ellenberg N- or R-value during the first survey (N_1 or R_1), soil type, atmospheric nitrogen deposition and their respective interactions. Spatial power was used as a covariance parameter to correct for spatial autocorrelation.

Results

Changes in distribution area of individual plant species

The overall change in the range size of the different plant species is summarised by the regression relating the number of occupied grid cells (logit-transformed) during the second survey to that in the first survey. The regression equation (Fig. 2) has a slope that is close to unity, but an intercept that is considerably larger than zero. This indicates an average increase in distribution area, probably reflecting an increased effort in the second survey, which is not related to the size of the distribution area in the first survey.

We examined the relative change of distribution area of individual species as a function of their habitat preferences according to the classification of Stieperaere and Fransen (1982). Mean values of the relative change index differed significantly among species groups (Table 1). Significant declines were noticed in the groups of plant species of 'heathlands, fens and semi-natural acid grasslands', 'mesotrophic grasslands' and 'dry semi-natural grasslands'. By contrast, a significant increase in range size was detected for species of pioneer vegetations, especially those of man-made habitats such as arable land, roadsides and waste tips (Table 1).

The relative change of the range size also differed among the classes of the Ellenberg N-values (Fig. 4). Species from nutrient-poor environments (classes 1–3) had change indices that were significantly lower than zero and thus exhibited a decrease of their distribution area. By contrast, a significant increase in distribution area was detected in plant species that typically occur in the most nutrient-rich habitats (classes 7–8).

Table 1 Relative change of size of the distribution area (mean ± SE) in major species groups according to their habitat preference (classification according to (Stieperaere and Fransen 1982)

Habitat	Change index Mean ± SE	N species
Heaths, fens and semi-natural acid grasslands	−0.59 ± 0.09[a]	87
Mesotrophic grasslands	−0.24 ± 0.09[a]	63
Dry semi-natural grasslands	−20 ± 0.07[a]	100
Aquatic and riparian vegetation	−0.15 ± 0.07	120
Salt-marshes, beaches and coastal front dunes	0.04 ± 0.14	29
Forests	0.08 ± 0.07	119
Scrubs, forest edges and clearings	0.19 ± 0.08	84
Natural pioneer vegetation on wet and mineral substrate	0.22 ± 0.09	68
Anthropogenic pioneer vegetation	0.30 ± 0.05[a]	179

[a] Indicates that the mean value differs significantly from zero (t-test, Bonferroni adjusted at $\alpha = 0.10$)
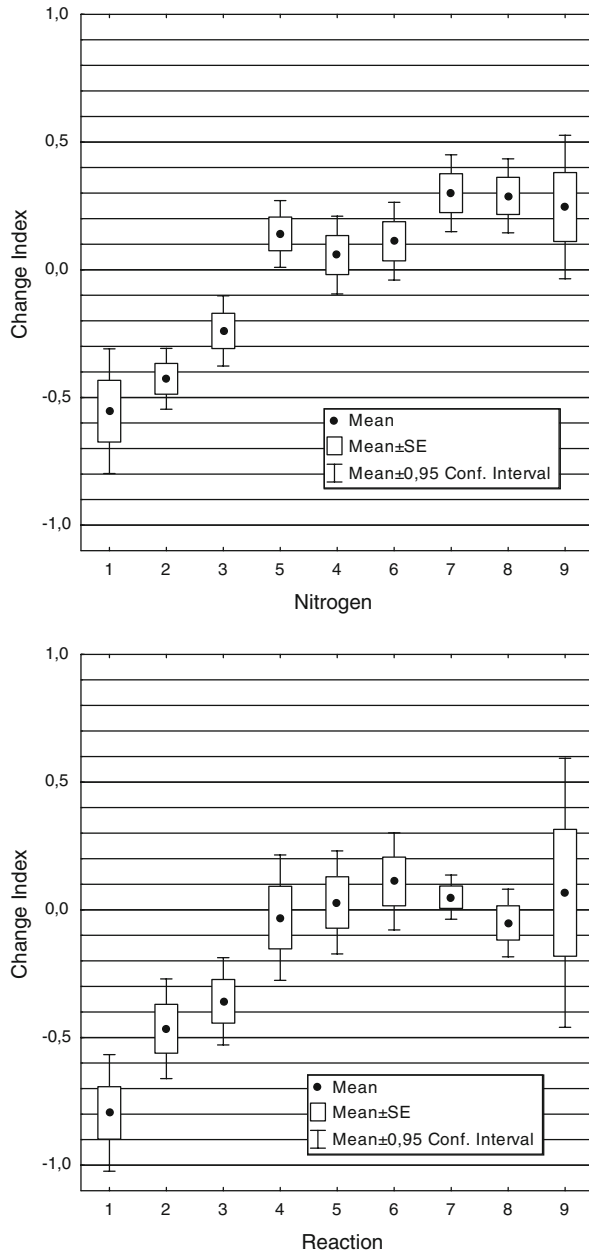
Fig. 4 Relative change of size of the distribution area (mean ± SE, 95% confidence interval) in major species groups according to their Ellenberg values for nitrogen (N), reaction (R). * Indicates that the mean value differs significantly from zero (*t*-test, Bonferroni adjusted at $\alpha = 0.10$)

Differences in the relative change index were also obvious among the nine Ellenberg R-classes (Fig. 4). The distribution area decreased strongly in species that are indicative for extremely acid to acid conditions (classes 1–3), whereas no changes were detected in species from weakly acid to alkaline conditions (classes 4–9).

Changes in geographic distribution of species assemblages

The spatial distributions of mean Ellenberg N-values during both survey periods and their relative change are shown in Fig. 5. During both survey periods grid cells exhibiting low mean N-values, reflecting the presence of species with a preference for nutrient-poor conditions,
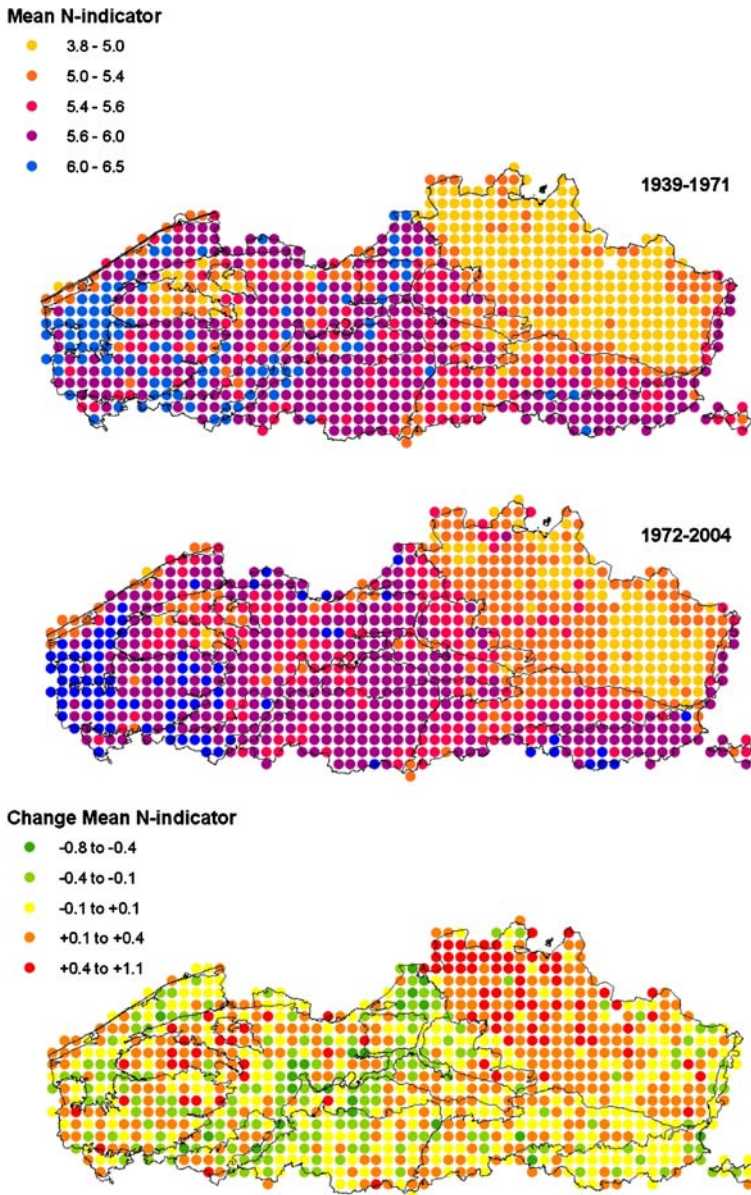

Fig. 5 Geographic distribution (4 × 4 km² grid cells) of mean Ellenberg N-indicator values during the first (1939–1971) and second survey period (1972–2004) and of the change in mean Ellenberg N-value between both periods

were mainly concentrated in the north-east part of Flanders. Grid cells with high mean N-indicator values, testifying the occurrence of plants of nutrient-rich conditions, were mainly found in the western half of Flanders (Fig. 5). Grid cells that experienced a positive change in mean N-value between the two survey periods, reflecting a decrease in species from nutrient-poor and/or and increase plants from nutrient-rich conditions, were found throughout the region, but were mainly concentrated in the north-east part (Fig. 5).

Changes in mean R-value between the survey periods were positively correlated with changes in mean N-value ($r = 0.77$, $P < 0.001$). Hence, the spatial distributions of mean Ellenberg R-values during both mapping periods and of the changes between these values were highly comparable to those of the mean N-values.

A general linear regression model indicated that mean Ellenberg N-values for the grid cells in the second period (N_2) were strongly related to the corresponding N-values of the first period (N_1) ($P < 0.001$) and on soil type ($P < 0.02$). In addition, the significant interaction effect of the independent variables N_1 and soil type ($P < 0.05$) indicates that the relationship between N_2 and N_1 differs among soil types. For grid cells on acid sand, sandy loam, loam, clay and anthropogenic soils the slope of the response line is significantly smaller than 1. This indicates that grid cells with a low N_1-value exhibit on average an increase in N_2 value, whereas grid cells with the highest N_1-values surprisingly show a slight decline in N_2-value (Fig. 6).

Spatial variation in the amount of atmospheric nitrogen deposition explain additional variation ($P < 0.05$) in the mean N-values of the grid cells in the second period: cells with higher nitrogen deposition values experienced a stronger increase in N_2-value. The effect moreover interacts negatively with soil type, indicating that nitrogen deposition has a relatively stronger effect in areas with nutrient-poor soils.

The mean Ellenberg values for reaction in the second period (R_2) are strongly related to the values for reaction in the first period (R_1) ($P < 0.001$) and on soil type ($P < 0.0005$) (Fig. 7). In areas with acid sandy soils more species of neutral and basic conditions were found during the second survey. In areas where the soil is dominated by clay or calcareous sand we noticed a shift to more species typical for more neutral conditions. In general, there is a trend of loosing the more extreme acid and basic conditions in favour of the more neutral situations.

Discussion

Our analysis of distribution data collected during two successive surveys revealed no differential change in range size in relation to the initial commonness of different plant species. However, the strongest signal of the changes in the flora of Flanders was the demonstration of a marked decline in distribution area in species that are characteristic for nutrient-poor habitats. This decline is comparable to the situation in the UK (Preston et al. 2002a) and the Netherlands (Tamis et al. 2005). In the UK, this change in favour of indicators of more nutrient rich habitats is also dependent on the region; it is less pronounced in Wales, Northern Ireland and Eastern Scotland and even absent in the Scottish Highlands (Preston et al. 2002a).

A first and obvious reason for the decline of species from nutrient-poor habitats is the loss of appropriate habitats (e.g., acid grassland and heathland). Information on these changes is only available at local levels. De Blust (2004) compared land use between 1956 and 1965 with that in 1995 in two areas in Flanders, revealing that only 11% of the original heathland remained in 1995. About two-thirds of the former heathland range was converted
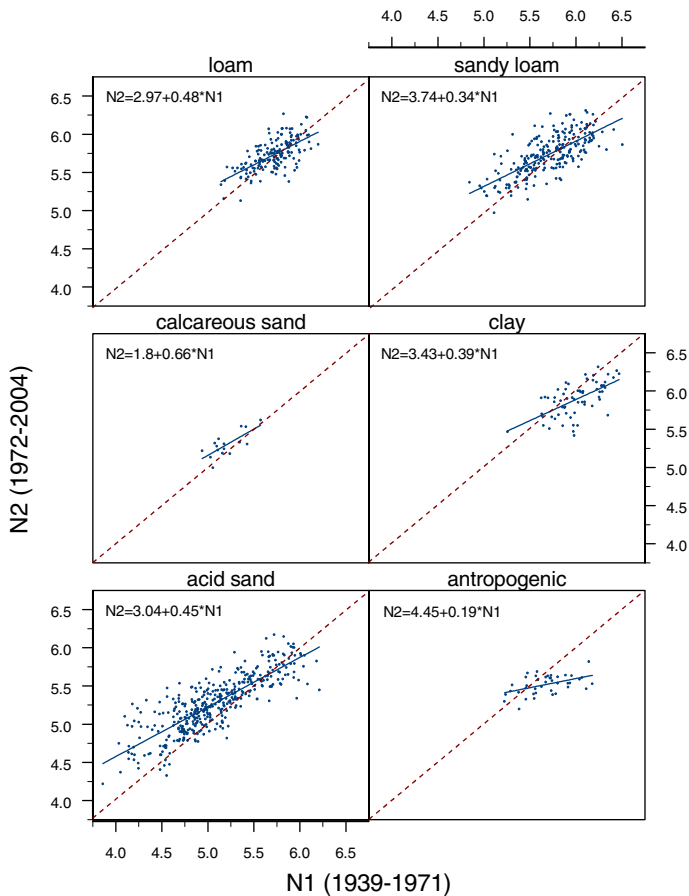
Fig. 6 Scatterplots and linear regression lines between the mean Ellenberg N-value in individual grid cells based on plant species composition during survey period 1972–2004 (N_2) versus survey period 1939–1971 (N_1) for the different soil types. The dotted line indicates 'no change'

into plantations of conifers (i.e., *Pinus sylvestris* and *Pinus nigra*), whereas deciduous forest occupied 9%, farmland 7%, urbanised areas 5% and the remainder comprised of a wide range of land uses.

A second important reason for the decline of species from nutrient-poor habitats is an overall increase in nutrient levels in the environment. Environmental drivers for this decline are related to various land use changes, such as intensification of agriculture and expanding urbanisation. The major factor increasing the nutrient loads in rural areas within Flanders came from the standard practice of repeatedly spreading onto the land manure from intensive pig farming. This became the simplest method of disposing of the manure and was not related to soil improvement for optimising crop production. Intensive pig farming is most often located in areas of nutrient-poor, acid sandy soils. The high concentrations of livestock are the major source of NO_x and NH_3 emissions in Flanders (Van Gijseghem et al. 2003). As a result, nutrients increased and resulted in nitrogen run-off polluting waterways, which remains a major problem in the water management of Flanders. The average N-deposition in Flanders in the period 1990–2001 was around 50 kg/ha year and
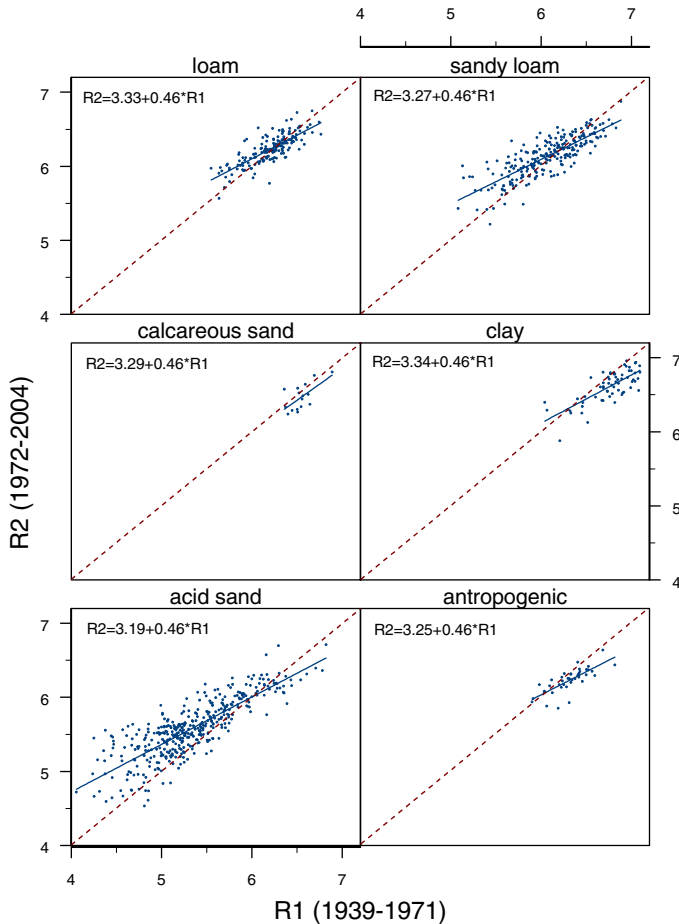
Fig. 7 Scatterplots and linear regression lines between the mean Ellenberg R-value in individual grid cells based on plant species composition during survey period 1972–2004 (R_2) versus survey period 1939–1971 (R_1) for the different soil types. The dotted line indicates 'no change'

the majority of Flanders had atmospheric N-deposition loads above 30 kg/ha year. Locally the N-deposition values even exceed 90 kg/ha year (Van Gijseghem et al. 2003).

The effects of atmospheric N-deposition on species diversity of nutrient-poor ecosystems is well documented (Bobbink et al. 1998; van den Berg et al. 2005). The average N-deposition in Flanders is twice the maximum that many heathland species can sustain and three times the amount that acid grassland communities can tolerate (Van Gijseghem et al. 2002). N-deposition in those habitats leads to an increase in acidification and to dominance of the highly competitive grass *Molinia caerulea* (Aerts 1993; Stevens et al. 2004; Stevens et al. 2006) and to a decline and eventually the local extinction of less competitive species (e.g. *Hammarbya paludosa*, *Pedicularis sylvatica*, *Scleranthus perennis* and *Antennaria dioica*). In oligotrophic fens acidification leads to declines in most aquatic species (e.g. *Lobelia dortmanna*, *Ranunculus ololeucos*) with only species like *Juncus bulbosus* persisting (Roelofs et al. 1984; Schuurkes et al. 1987).

Our results also indicate that the effect of increasing nutrient levels differs in magnitude among areas within Flanders. In areas that had the lowest nutrient status in the first survey,

we observed the greatest decline in species of nutrient-poor conditions, while species of nutrient-rich conditions increased here most. Changes in the composition of species assemblages were especially notable in areas with nutrient-poor, acid sandy soils. We also demonstrated that spatial variation in the amount of atmospheric nitrogen deposition influenced the changes in species composition and that this effect was most stringent in areas with nutrient-poor soils. Hence, the shift in species composition towards more nitrophilous plants is modulated by geographic variation in soil type and levels of nitrogen deposition.

In areas characterised by high Ellenberg N-values during the first survey, we observed a decrease of these values in the second mapping period. This contrasts with the general high nitrogen deposition rates in Flanders and was unexpected since these areas have very intensive agriculture. In these areas, species of anthropogenic pioneer communities showed the greatest increase in abundance (e.g. *Vulpia myuros*, *Reseda luteola*, *Oenothera* ssp.). The lower mean Ellenberg N-values in the second period can be explained by the effects of urbanisation and in some regions by the transformation of large areas of farmland into industrial sites. It is common practice in large industrial areas to raise the ground with a sand-in-water slurry mix, resulting in calcareous sandy soils with reduced fertility. The decline of the mean Ellenberg N-values is particularly strong in industrialised areas such as the harbour areas of Antwerp and Zeebrugge.

Our analyses also evidence a decline of species of acidic conditions relative to species of the neutral part of the pH spectrum. This has also been shown in the UK and the Netherlands (Preston et al. 2002b; Tamis et al. 2005). However, contrary to the findings in the UK we did not detect a significant decline of species of basic conditions (Preston et al. 2002b), nor a significant increase of those species like in the Netherlands (Tamis et al. 2005).

The largest changes in mean Ellenberg R-values between the two surveys occurred in grid cells that exhibited the lowest mean R-values in the first period, especially those located in regions with acid sandy soils. These shifts reflect the disappearance of plant species that are indicative for acid conditions and/or an increase of species that are typical for neutral or basic conditions. Changes in mean Ellenberg R-values in grid cells were highly correlated with changes in mean Ellenberg N-values, causing a problem of data interpretation that was also mentioned by Tamis et al. (2005). Indeed, the species that declined (e.g. *Diphasiastrum tristachyum, Nardus stricta, Andromeda polifolia, Carex limosa, Hypericum elodes*) are also indicators of nutrient-poor conditions. Hence, both N-deposition and extreme acidification can cause a decline in species that are typical for habitats with a moderately low pH. Consequently, it is difficult to distinguish between acidification and eutrophication as the direct cause of their decline.

In grid cells with soils dominated by clay or calcareous sand, the mean Ellenberg R-values were lower in the second than in the first mapping period. These areas already had the highest Ellenberg R-values in the first mapping period. The changes can be explained by a shift in the balance between species from base-rich and species of neutral conditions, with the former declining and the latter becoming more frequent. However, the causes of those trends remain unclear.

In summary, we demonstrated important decreases in range size in plant species that are typical for nutrient-poor habitats. Our results also indicate changes in composition of species assemblages, as indexed by the Ellenberg N- and R-values, that were especially evident in areas with acid sandy soils. On the other hand, species that increased their distribution are typical for nutrient-rich habitats, such as roadsides and areas with intensive agriculture. We conclude that the influence of intensive agriculture determines most of the changes in the distribution area of plants species in Flanders.

The surface area of nature reserves in Flanders increased from 5,000 ha in 1988 to 28,000 ha in 2004 (Decleer et al. 2005). Although an important part of that area was established especially to maintain the flora and fauna of nutrient-poor habitats, this apparently did not prevent the decline of these species. It is unlikely that this trend will be changed as long as nature reserves are exposed to nitrogen deposition rates that are above the critical loads of species from nutrient-poor habitats. This will be especially the case in the regions dominated by acid sandy soils. The Flemish government formulated, in its 'environmental policy plan of Flanders 2003–2007' (Ministerie van de Vlaamse Gemeenschap 2004), the objective to reduce towards 2030 the overall atmospheric emission of NO_x and SO_2 by 74% relative to the level in 1990. In addition, the Flemish government aims to limit regional emission levels especially in sensitive areas, so that the acidifying deposition will be below the critical levels for the survival of habitats like heathlands and oligotrophic fens. However, until that objective will be reached, it is likely that some species will experience a further decline in their distribution.

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