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POLLUTION AND CLIMATE INFLUENCES ON PLANT COMMUNITIES ACROSS UK PEATLANDS

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SUMMARY

A UK wide survey was conducted in 2009 to understand how atmospheric pollution influences botanical composition in important habitats. Five habitats were selected (bogs, moorlands and lowland heaths, along with acid grasslands and sand dunes) and spatial differences in vegetation were related to variations in air quality, climate and soils. A significant pattern of species richness reduction in relation to increasing atmospheric nitrogen deposition was found in all of the habitats and most of the plant groups. However, climate and sulphur deposition could sometimes explain more variation. In bogs, the decline in species richness associated with nitrogen deposition was less steep than in other habitats, suggesting the response to nitrogen is influenced by other factors such as site hydrology and management.

KEY WORDS: peatlands, pollution, climate, biodiversity

INTRODUCTION

It is vital to understand the influence of the changing environment in modifying the ecology of peatlands in the light of increasing pressures from human activities. Bogs and heaths are thought to be especially vulnerable to nitrogen pollution (Bobbink et al., 2010), while in parts of central UK the poor condition of blanket bogs is commonly attributed to historic sulphur as well as nitrogen pollution (Caporn & Emmett, 2009). In recent years various UK vegetation monitoring schemes such as the Countryside Survey (Maskell *et al*., 2010) and specific habitat surveys across deposition gradients (Stevens et al., 2006) indicate that long range nitrogen pollution has been responsible for community changes and significant losses of plant diversity. Targeted surveys along gradients of pollution have mainly investigated single habitats, notably acid and calcareous grassland (Stevens et al. 2006, Van den Berg et al., 2010) and there is a need to make direct comparisons between different ecological communities to identify the most vulnerable systems. To achieve this, we conducted a country-wide, multi-habitat survey with the aim of understanding how changes in plant composition are related to variations in air pollution, climate and soils in the UK. We report the overall results and focus attention on the upland and lowland heaths and bogs.

MATERIALS AND METHODS

A national survey of selected UK ecosystems was undertaken by the UKREATE consortium between May and September 2009; these were upland heaths, lowland dry heaths, bogs, sand dunes and acid grasslands. Here we focus on the heaths and bogs, but comparisons with the dunes and grasslands are made where these are of interest. In the UK, upland heath vegetation, known also as heather moorland, typically occurs above 250-300 m altitude on peaty-podsolic soil, and the plants are dominated by *Calluna vulgaris* with an understorey of *Vaccinium myrtillus*, occasional *Erica* and graminoid species (e.g. *Deschampsia flexuosa* and *Festuca* spp.) and a ground layer of bryophytes and lichens. Lowland dry heath, at lower altitudes, is often composed of similar vegetation to that found in the uplands, but the organic soil layer is thinner. Bogs were chosen to represent the UK range and comprised lowland raised bogs and a smaller number of upland blanket bogs. In both types the dominant species were usually *Sphagnum* mosses along with *Calluna vulgaris* or *Erica tetralix,* and various graminoids.

Sites were sampled across climatic and pollution gradients and surveys were designed to allow separation of the effects of these variables. Approximately 25 sites were visited in each habitat, and vegetation surveyed using 2 x 2 m plots with absolute % cover of all plant species recorded. In addition to the plants, soil cores, moss and plant tissue were sampled and laboratory analysis made of tissue Carbon (C), Nitrogen (N), Phosphorous (P), soil C and N, pH and mineralisation potential, moss chlorophyll fluorescence (Fv/Fm), moss phosphatase activity and litter phenol oxidase activity. Relationships between the vegetation survey data, biogeochemical data and modelled air pollution were examined using ordination and stepwise regression techniques. The pollutant deposition data used were the 5 km^2 Concentration Based Estimated Deposition (CBED) values for 2004-2006. The climate data used were based upon UK 5 km^2 gridded data sets of precipitation and growing degree days (GDD) averaged over the period 1997-2006 provided by the UK Meteorological Office. Also included was modelled sulphur deposition from a period when sulphur emissions were considerably greater than current (1986-1988) to understand how current vegetative composition and richness is related to this historical driver.

RESULTS

Drivers of change in species richness

Across the survey sites a highly significant pattern of species richness reduction as a function of increasing atmospheric nitrogen deposition was demonstrated. This pattern was similar across all habitats. The relationship was typically non-linear, indicating a more rapid loss of species associated with increasing N deposition at lower levels of N pollution, often below the habitat specific nitrogen critical load (5-10 kg N ha^{-1} $y^{-1}$for bogs and 10-20 kg N ha^{-1} y^{-1} for heaths). In bogs, the relationship was less steep than in the other habitats, suggesting that the response to N may be moderated by other factors such as site hydrology, historic disturbance and conservation management. The magnitude of the response was large; with 30-75% lower species richness in the least diverse sites within each habitat, compared with the most diverse.

While diversity within most plant groups was negatively associated with increasing N deposition results from stepwise regressions found that climate and S deposition could sometimes explain more variation. Overall species richness in bogs was more strongly associated with sulphur than N deposition as was moss species richness in upland heaths, however, dry oxidised-N deposition explains the next greatest amount of variation in the data. Within bogs the relationship with N was strongest in forbs and lichens, but weakest with moss species; in upland heaths lichen richness fell; and in acid grasslands forbs showed a reduction in both richness and diversity. A reduction in graminoid species richness was also associated with increasing N in acid grassland, bog and upland heath habitats. Conversely, graminoid species significantly increased in cover in association with rising N deposition, suggesting that competition between species groups and shading out of lower plants may drive some of the change. Increases in graminoid cover (*Eriophorum* species in bogs and *Deschampsia flexuosa* in heaths) were strong in heathlands and bogs. In lowland heaths oxidised N deposition was associated with a reduction in overall species richness and a change in species composition; however, climate and changing soil type over the lowland heath sites explained more variation.

Change in species composition

In all habitats except sand dunes a form of N deposition was a key variable associated with change in species community composition. In upland heaths, reduced N deposition appeared to be the most significant driver of change in the cover of many species. As expected, significant variance in the data was also explained by climate (growing degree days) and the organic matter content of soil, which is linked to increased rainfall. Similar variables came through the analysis of lowland heath data with climate (growing degree days and precipitation), and dry-oxidised N in lowland heaths explaining the most change in species composition. In lowland heaths the soil type (pH) was also significant. In bogs, the 1986-1988 S deposition was also significantly related to species composition (marginally better than dry oxidised N) alongside dry-reduced N deposition and hydrological index.

Biogeochemical indicators

The performance of a number of chemical indicators as predictors of modelled N deposition was tested. Most consistent across habitats was moss phosphatase enzyme activity, indicating P limitation as available N increased. A reduction in soil pH as a function of increasing N deposition occurred in all habitats except sand dunes, demonstrating the acidification potential of N. Moss chlorophyll fluorescence (Fv/Fm) both rose and fell with increasing N deposition, depending upon habitat, but the relationship was only statistically significant in *Hypnum cupressiforme* in sand dunes. Soil mineralisation potential also showed some increase in response to N and was also negatively correlated with moss species richness within heathlands. Specific heathland indicators, *Calluna* tissue N%, *Calluna* litter phenol oxidase enzyme activity and KCl exchangeable N, all increased with increasing N deposition, but only in upland heaths (whilst in related field experiments responses were also seen in lowland heaths and bogs).

Nitrogen indicator plant species

The presence or absence of particular plant species towards the lower and higher end of the N deposition range in the survey suggested their value as indicator species. The preferred indicator species differed across the habitats. The best overall examples of N-eutrophication indicators were: *Brachythecium rutabulum*, *Deschampsia flexuosa*, *Eriophorum vaginatum*, *Sphagnum fimbriatum*, *Sphagnum subnitens*, while good indicators of low N condition were *Hylocomium splendens, Pleurozium schreberi* and *Cladonia* spp lichens.

DISCUSSION

This multi-habitat UK survey found new evidence of ecological change across landscapes that could be attributed to air pollution. The strength of this research is that it covered five distinct habitat types in one co-ordinated study, using common methods in surveying and laboratory analyses. The main factors that appeared to influence plant communities were pollution, climate, and soil properties (pH, water table, organic matter). The reduction in species richness and changes in plant communities that were linked to nitrogen pollution were seen in addition to climate induced changes in species composition and richness. Climate has an acknowledged influence on global patterns of vegetation and this was also detected in this study, where increasing warmth (GDD) was correlated with lower species richness in contrast with typical latitudinal patterns of species diversity across the globe.

In most habitats, a form of nitrogen deposition was the principal factor influencing species richness or composition, but frequently sulphur pollution or total acidity explained more of the variation. Isolating the separate impacts of sulphur and nitrogen deposition is difficult due to the strong spatial co-correlation between sulphur and nitrogen air pollutants across the UK landscape. However, atmospheric SO_2 concentrations across the survey sites were much lower than the critical level threshold; on the other hand, the total N deposition was often above habitat specific critical loads and levels. Therefore, it is proposed that while S may have contributed to the degradation of polluted ecosystems, the current poor condition is maintained by pollutant N.

A further outcome of the survey was identification of potential indicators of N deposition and N impact. Plant species (some increasing, others decreasing) emerged as stronger and more reliable indicators of N impacts than changes in plant and soil biogeochemistry. In general, biogeochemical indicators (e.g. %N in moss and C/N in soil) have performed better at experimental sites and in smaller surveys (e.g. Edmondson et al., 2010; Phoenix et al., 2011) where the period of sampling can be shorter and other factors such as climate have less influence.

Supporting evidence for the view that nitrogen deposition has influenced the ecology of peatlands of the UK comes from long term nitrogen addition field experiments on bogs (Sheppard et al., 2011), moorlands (Edmondson et al., 2010; Pilkington et al., 2007) alpine heaths (Britton et al., 2007) and lowland heaths (Power et al., 2006). These experiments and others summarised by Phoenix et al., (2011) found that responses to N addition in experiments, where climate and soil type were approximately constant, were broadly similar to changes observed along N gradients in the field.

The mechanisms by which air pollution has caused ecological change in the habitats are uncertain and require further study. Furthermore we do not know if ecological change observed now is the result of recent pollution or the gradual impact of nitrogen accumulation over several decades or even the centuries since the intensification of farming and industry. If, as seems likely, the impacts result from long term build up of N in ecosystems (Phoenix et al., 2011), then the benefits of reducing emissions and deposition may only become evident over a lengthy period of time unless nitrogen is, by some means, removed from ecosystems.

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