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ECOIND-2842; No. of Pages 11
ARTICLE IN PRESS
Ecological Indicators xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Ecological Indicators
journal homepage: www.elsevier.com/locate/ecolind

Evidence for increases in vegetation species richness across UK Environmental Change Network sites linked to changes in air pollution and weather patterns

Rob Rose[a,*], Don T. Monteith[a], Peter Henrys[a], Simon Smart[a], Claire Wood[a], Mike Morecroft[b], Chris Andrews[c], Deborah Beaumont[d], Sue Benham[e], Victoria Bowmaker[f], Stuart Corbett[h], Jan Dick[g], Bev Dodd[a], Nikki Dodd[g], Mel Flexen[i], Colm McKenna[i], Simon McMillan[j], Denise Pallett[k], Sue Rennie[a], Stefanie Schäfer[k], Tony Scott[l], Lorna Sherrin[a], Alex Turner[f], Helen Watson[h]

[a] NERC Centre for Ecology and Hydrology, Lancaster Environment Centre, Library Avenue, Bailrigg, Lancaster LA1 4AP, United Kingdom
[b] Natural England, 2nd Floor, Cromwell House, 15 Andover Road, Winchester, Hampshire SO23 7BT, United Kingdom
[c] NERC Centre for Ecology and Hydrology, Bush Estate, Penicuik EH26 0QB, United Kingdom
[d] Rothamsted Research, North Wyke, Okehampton, Devon EX20 2SB, United Kingdom
[e] Forest Research, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH, United Kingdom
[f] Natural Resources Wales, Maes-Y-Ffynnon, Ffordd Penrhos, Bangor, Gwynedd LL57 2DW, United Kingdom
[g] Dstl, Porton Down, Salisbury, Wiltshire SP4 0JQ, United Kingdom
[h] James Hutton Institute, Craigiebuckler, Aberdeen AB15 8QH, United Kingdom
[i] AFBINI, Large Park, Hillsborough, Down BT26 6DR, United Kingdom
[j] ADAS UK Ltd., Drayton, Alcester Road, Stratford-Upon-Avon, Warwickshire CV37 9RQ, United Kingdom
[k] NERC Centre for Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB, United Kingdom
[l] Rothamsted Research, Harpenden, Hertfordshire AL5 2JQ, United Kingdom

ARTICLE INFO

Article history:
Received 24 July 2015
Received in revised form
22 December 2015
Accepted 5 January 2016
Available online xxx

Keywords:
Environmental Change Network
Vegetation
Soils
Nitrogen
Acidification
Weather
Atmospheric deposition

ABSTRACT

We analysed trends in vegetation monitored at regular intervals over the past two decades (1993–2012) at the twelve terrestrial Environmental Change Network (ECN) sites. We sought to determine the extent to which flora had changed and link any such changes to potential environmental drivers. We observed significant increases in species richness, both at a whole network level, and when data were analysed within Broad Habitat groupings representing the open uplands, open lowlands and woodlands. We also found comparable increases in an indicator of vegetation response to soil pH, Ellenberg R. Species characteristic of less acid soils tended to show more consistent increases in frequency across sites relative to species with a known tolerance for strongly acidic soils. These changes are, therefore, broadly consistent with a response to increases in soil solution pH observed for the majority of ECN sites that, in turn, are likely to be driven by large reductions in acid deposition in recent decades. Increases in species richness in certain habitat groupings could also be linked to increased soil moisture availability in drier lowland sites that are likely to have been influenced by a trend towards wetter summers in recent years, and possibly also to a reduction in soil nitrogen availability in some upland locations. Changes in site management are also likely to have influenced trends at certain sites, particularly with respect to agricultural practices. Our results are therefore indicative of widescale responses to major regional-scale changes in air pollution and recent weather patterns, modified by local management effects. The relative consistency of management of ECN sites over time is atypical of much of the wider countryside and it is therefore not appropriate to scale up these observations to infer national scale trends. Nevertheless the results provide an important insight into processes that may be operating nationally. It will now be necessary to test for the ubiquity of these changes using appropriate broader spatial scale survey data.

1. Introduction

Vegetation underpins the biogeochemical and ecological functioning of most environments on Earth and often provides the

* Corresponding author. Tel.: +44 01524595833.
E-mail address: rjr@ceh.ac.uk (R. Rose).

http://dx.doi.org/10.1016/j.ecolind.2016.01.005
1470-160X/© 2016 Published by Elsevier Ltd.

basis for ecosystem classification. Vegetation species composition and structure are particularly sensitive to local effects of habitat management, but are also vulnerable to regional-scale forcing by atmospheric pollution and climate, particularly in less intensively managed environments. Quantification of the importance of these wider-scale drivers in influencing vegetation is clearly vital for the assessment of the efficacy of national and international air pollutant emission policy on natural environments, but is also highly desirable at the local scale for the informed management of vulnerable habitats.

Air pollution may influence vegetation assemblages through both acidification and eutrophication. Since the onset of the industrial revolution, acid deposition, predominantly from compounds of sulphur and nitrogen (Fowler et al., 2007; RoTAP, 2012), has contributed to widespread soil acidification, but damage to soils has been clearest in high rainfall upland areas (www.apis.ac.uk) and this has been linked to upland water acidification (Curtis et al., 2014). Spatial surveys and experiments that have also experienced widespread surface water acidification suggest that the resulting combination of low pH and depleted base cation levels and a concomitant increase in the availability of inorganic aluminium (Al^{3+}) has had a negative influence on a range of plant species, and several are rarely found in soils with a pH below 4.5, the approximate threshold for increased Al^{3+} availability (Andersson, 1988). Nitrogen (N), is also a common limiting nutrient for plant productivity in unimproved environments and as ecosystem demand is often considerable it is likely that these habitats have been accumulating N over the industrial period (Bobbink et al., 2010; Shibata et al., 2015). Elevated levels of nitrogen favour nutrient demanding species with relatively rapid growth rates that outcompete slower growing taxa (Bobbink et al., 2010). Significant reductions in N might eventually be expected to favour species adapted to low N availability, e.g. low growth rates, ectomycorrhizal associations and insectivory (e.g. *Drosera* spp.), over nitrogen demanding species, although the tight cycling of N within terrestrial ecosystems is likely to impose a considerable lag between reductions in inputs, reductions in soil N availability and plant species composition (McGovern et al., 2011). Furthermore, biogeographic constraints on many species reflect adaptation to particular combinations of moisture availability and temperature, and there is increasing concern that rising air temperatures in Europe are leading to the outcompeting of some slow growing montane taxa by more aggressive thermophilic taxa (Harald et al., 2012). Species also show varying levels of resilience with respect to drought events that are expected to become more frequent as a consequence of global warming (Morecroft et al., 2009).

A number of studies in recent years have sought to examine evidence for widespread changes in vegetation. Among these, the UK Countryside Survey has been the most comprehensive and spatially extensive (Carey et al., 2008), with a wide range of vegetation assemblages surveyed at hundreds of locations across the UK in 1978, 1990, 1998 and 2007. A recent assessment of vegetation trends based on data from these surveys concluded that overall plant diversity in Great Britain had decreased by 8% between 1978 and 2007 but that there had been no significant decrease between 1998 and 2007.

More commonly, however, vegetation survey data lack the methodological consistency necessary to chart what may be very subtle long term trends in community composition in response to these regional-scale pressures. Spatial surveys are sometimes collated retrospectively for the purpose, but are rarely initiated with a long term monitoring strategy in mind. Their value in discerning patterns of long-term change may be limited, therefore, for a variety of reasons including: paucity of time points, problems of accurate plot re-location, changes in methodology between surveys, seasonal variation in the timing of surveys, lack of documentation regarding local site management changes or variation in surveyor skill level between surveys.

The UK Environmental Change Network (ECN) vegetation monitoring protocols were designed to minimise these sources of potential error. Monitoring has been conducted at a regular frequency and to a common set of protocols at all ECN sites since the advent of the network. Furthermore, ECN sites are well suited to the assessment of regional-scale influences of environmental change, as land use tends to remain relatively stable, although management practices inevitably change over time in response to changing economic and policy drivers (see Dick et al., in this issue).

Previously, a broad cross-habitat analysis of the first 12 years of ECN vegetation data (Morecroft et al., 2009) showed that stress tolerating species (as determined by higher values for the Grime Stress tolerator (or S) index, see (Grime, 1974)) increased in abundance relative to more ruderal species (R), with high Grime R scores. The authors proposed that this was consistent with an observed shift away from drier conditions during the growing season that had caused gaps in grassland swards favouring more opportunistic species. While soil solution pH was found to have increased at several ECN sites in an apparent response to reductions in sulphur (S) deposition, Morecroft et al. (2009) found no consistent evidence for a response in an indicator of vegetation response to changing acidity (Ellenberg R), see Hill et al. (1999). Furthermore, no changes were observed in the Ellenberg N metric, an indicator of nutrient enrichment that has been used to identify impacts of nitrogen deposition on sensitive habitats.

Now, an updated assessment of trends in the physical and chemical environment over the first 20 years of monitoring (Monteith et al., this issue) demonstrates even more clearly than before that large reductions in acid pollutant deposition and concomitant increase in soil solution pH have occurred over much of the UK since ECN monitoring began. In contrast, there has been little evidence for change in air temperatures, although summers have become progressively wetter. While management has remained relatively constant at most ECN sites, some have also undergone potentially important changes. Improved grassland habitats at both the Wytham and Drayton sites, for example, received marked reductions in chemical fertiliser input after around a decade of monitoring, while there has been a reduction in upland grazing intensity at Moor House and Snowdon. There is a clear need, therefore, to re-appraise vegetation status across the network to determine whether responses to these observed shifts in the ambient environment are beginning to emerge.

In this study we restricted our analysis to vascular plants only to minimise potential taxonomic discrepancies. By blending results from two compatible ECN survey methodologies, i.e. the 9 year "Coarse Grain" and 3 year "Fine Grain" surveys (see Methods), drawn from the first twenty years of monitoring, we created a much larger dataset covering a considerably longer timescale than had been available for the earlier analysis (i.e. Morecroft et al., 2009). This extended dataset enabled us to assess changes in key metrics, e.g. species richness and Ellenberg and Grime Indices at a Broad Habitat level at each site, and consider the extent to which these could be linked to dominant trends in the physical and chemical environment in addition to other site-specific management related effects. We focussed particularly on identifying consistent patterns of change in metrics across all sites and subgroups of Broad Habitats, and also considered how the direction of change in the frequency of individual taxa relate to their indicator value with respect to metrics representative of primary regional scale pressures of interest, namely Ellenberg acidity, nutrient and soil wetness indices.

Please cite this article in press as: Rose, R., et al., Evidence for increases in vegetation species richness across UK Environmental Change Network sites linked to changes in air pollution and weather patterns. Ecol. Indicat. (2016), http://dx.doi.org/10.1016/j.ecolind.2016.01.005