Environmental Pollution 176 (2013) 106–113

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Direct and indirect effects of roads and road vehicles on the plant community composition of calcareous grasslands

Mark A. Lee*, Sally A. Power[1]

Department of Life Sciences, Division of Ecology and Evolution, Imperial College London, Silwood Park Campus, Ascot, Berkshire SL5 7PY, UK

ARTICLE INFO

Article history:
Received 10 August 2012
Received in revised form
14 January 2013
Accepted 18 January 2013

Keywords:
Calcareous grassland
Nitrogen deposition
Nitrogen dioxide
Ammonia
Vehicle emissions

ABSTRACT

Exposure of plants to vehicle exhaust emissions and road-induced changes to soil biogeochemistry and hydrology can lead to shifts in plant composition in calcareous grasslands. Mixed effects models were used to identify relationships between plant community composition and a suite of measured and modelled environmental variables along transects away from roads at eight calcareous grasslands. Ellenberg pH, moisture and nitrogen (N) scores increased nearer roadsides, however, only Ellenberg N scores were associated with their respective measured or modelled values highlighting NO_2 deposition as a likely driver of change. Forb abundance and diversity increases nearer roadsides were also associated with NO_2 deposition, with increases seen in the abundance and diversity of typical edge species rather than species characteristic of calcareous grasslands. Grazing, removal of invasive species and the use of barriers to intercept transport-derived air pollution may help to reduce the detrimental effects of roads across these diverse but threatened landscapes.

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1. Introduction

Calcareous grasslands are among the most species-rich ecosystems in Western Europe and are important habitats for a diverse flora and fauna (Mortimer et al., 1998). Calcareous grassland and roadside verges supporting calcareous plant communities are priority habitats for the protection of biodiversity in the UK (UKBAP, 2007) and across Europe (Pedro Silva et al., 2008). Whilst species-rich grasslands are important from a conservation perspective, they are reducing in area. Calcareous grasslands have declined by 18,000 ha in the UK (1984–2007) and semi-natural grasslands have declined by 180,000 ha across Europe (1990–2006), as a result of road building, pollution, urbanisation, afforestation and conversion to agricultural land (Countryside-Survey, 2008; EEA, 2010).

Roads currently extend 400,000 km in the UK (DfT, 2011) and 5 million km across Europe (ERF, 2010). Plants growing alongside roads can be directly exposed to elevated concentrations of several pollutants emitted from vehicle exhausts and engine degradation, including nitric oxide (NO), nitrogen dioxide (NO_2), ammonia (NH_3), potentially toxic metals (TM), poly-aromatic hydrocarbons (PAH) and carbon dioxide (CO_2) (Wallington et al., 2008). Roads also have the potential to influence adjacent vegetation indirectly via run-off of surface water and associated increases in soil moisture content (Boivin et al., 2008), transportation of alkaline road surface chemicals which raise soil pH (DfT, 2008), and deposition of suspended TMs and dissolved salts to roadside soils (Li et al., 2007; Zechmeister et al., 2005). Rapidly moving traffic can also increase roadside disturbances e.g. wind turbulence (Truscott et al., 2005).

Fumigation studies have demonstrated changes in plant phenology, growth rates, flower development and rates of leaf senescence following exposure to vehicle exhaust gases (e.g. Viskari et al., 2000; Honour et al., 2009). Similarly, changes in plant species composition alongside roads have been correlated with local gradients of N enrichment in heathland (Angold, 1997), in the ground flora of coniferous forests (Bernhardt-Römermann et al., 2006), at a blanket bog (Bignal et al., 2007) and within roadside verge plant communities (Truscott et al., 2005). Roadside studies are supported by observed declines in plant species richness in acidic grasslands, and reduced Shannon diversity (and evenness) indices in calcareous grasslands across gradients of N deposition (Stevens et al., 2004; Van den Berg et al., 2011).

Calcareous grasslands may be particularly sensitive to the suite of environmental changes associated with roads because associated plant species are typically adapted to a relatively narrow range of ecological conditions, particularly alkaline soils, exposure to frequent drought events and low nutrient availability (Bennie et al.,

* Corresponding author.
E-mail address: mark.lee07@imperial.ac.uk (M.A. Lee).
[1] Current address: Hawkesbury Institute for the Environment, University of Western Sydney, Locked Bag 1797, Penrith NSW 2751, Australia.

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http://dx.doi.org/10.1016/j.envpol.2013.01.018

2006; Critchley et al., 2002). Critical levels (CLE) relating to N concentrations in the atmosphere and critical loads (CLO) relating to N deposition are set in order to prevent ecological changes from occurring. Higher plant CLEs for NO_x and NH_3 are annual mean concentrations of not more than 30 $\mu g\ m^{-3}$ and 3 $\mu g\ m^{-3}$, respectively (Cape et al., 2009; DEFRA, 2007; WHO, 2000). CLOs vary according to ecosystem type, with the CLO for total N deposition in calcareous grasslands being 15–25 kg N $ha^{-1}\ yr^{-1}$ (Bobbink and Hettelingh, 2011). However, it should be noted that there is emerging evidence that current CLOs and CLEs may be too high for some sensitive grasslands (Bobbink et al., 2010).

Land managers use grazing livestock or mowing to prevent soil nutrient accumulation, to remove small populations of invading plant species and to inhibit successional changes in calcareous habitats (Kahmen et al., 2002). Management of ecosystems near roads may also include physical barriers (e.g. trees) which can impede the dispersal of vehicle exhaust-derived pollution, buffer zones to intercept road run-off and/or active filters which remove pollutants in transit (for a review see Spellerberg, 1998). Quantifying the region of influence of roads within calcareous grassland ecosystems is important if land managers are to use these management tools to protect the structure and functioning of these diverse, species-rich ecosystems.

Roadside plant communities provide an opportunity to assess the effects of long-term exposure across spatial gradients of environmental change, including gradients of N enrichment. Roadside N enrichment and elevated soil moisture content has previously been associated with localised increases in the abundance of N tolerant plants, particularly grasses and reductions in forbs in three calcareous grasslands (Lee et al., 2012). The current study builds upon that of Lee et al. (2012), adding data describing hydrology, biogeochemistry and air quality at a further five calcareous grasslands located adjacent to roads of varying traffic densities, to investigate relationships between plant species composition and roadside proximity. The aims of the study were to: (1) test the ubiquity of relationships observed in the earlier three site study, (2) identify which plant species and groups of species are increasing and decreasing at roadsides, (3) establish the likely environmental drivers of observed relationships and (4) provide data which can inform management decisions aimed at reducing the influence of roads on calcareous grasslands.

2. Materials and methods

2.1. Sites

Eight grass dominated ecosystems growing on chalk substrate in the UK were selected to represent species rich calcareous grassland communities with high conservation value (Rodwell, 1992) at sites with a range of slopes and aspects (for site details see Table 1). Three parallel transects were set up approximately 50–75 m apart at each site, perpendicular to the road. Sites were Aston Rowant (AR), Butser Hill (BH), Lewes Down (LD), Martins Down (MD), Newlands Corner (NC), Stockbridge Down (SBD), St Catherine's Hill (SCH) and Seale Chalk Pit (SCP). Locations on transects began as near to the road as possible within the fenced boundaries of each site and then continued a further 2.5, 5, 7.5, 10, 20, 50, and 100 m. There were, therefore, 24 location markers at each site and a total of 192 survey locations. Study sites were located in close proximity to roads (mean distance from road edge to site = 6 m, precise distances given in Table 1) with a range of traffic flow rates. This value represents the distance between fenced site boundaries and the road; all sample locations within a site were, therefore, subject to the same grazing and/or mowing regime.

2.2. Soil toxic metal (TM) concentrations

Soil samples were collected at each of the 192 survey locations using 2.5 cm diameter, 15 cm length polyvinyl chloride (PVC) tubes in March 2011 for all sites except AR, BH and MD which were collected in March 2010. Samples were homogenised, dried in a drying oven (80°C ± 10 °C) and refluxed with 1:1 65% nitric acid and deionised water, 30% hydrogen peroxide and hydrochloric acid at 95 °C, following the methods outlined in van der Wiel (2003). TM content was determined using inductively coupled plasma atomic emission spectrometry (ICP AES, Agilent Technologies, UK). Metals measured were lead (Pb), copper (Cu), zinc (Zn), vanadium (V), nickel (Ni), chromium (Cr), cobalt (Co), cadmium (Cd) and arsenic (As).

2.3. Soil pH, salinity and moisture content

Soil pH was measured at all sites in June 2011 using a PHH-200 pH probe which was calibrated prior to use with two pre-mixed pH calibration solutions (pH 7.00 and 10.01, Omega, UK). Soil moisture was also measured at all sites using a ThetaProbe soil moisture sensor (Delta-T, UK) in April 2011. Soil moisture and pH were measured at 5 cm soil depths with three replicates at each of the 192 sampling locations. Single soil surveys allowed data from multiple sites to be collected (for information on seasonal fluctuations in soil parameters see Lee et al., 2012). For salinity measurements, soil samples were collected to a depth of 15 cm in February 2011 from each site and oven dried for 48 h (80°C ± 10 °C). Soil was homogenised, mixed with water in a 1:1 ratio and salinity was measured using a PHR-986 sodium-selective electrode (Thermo-Scientific, UK) calibrated with prepared standards (Zhang et al., 2005).

2.4. Modelling NO_2 concentrations and N deposition

NO_2 concentrations were modelled at each site using Equation (1) (D = distance from the roadside (m) and T = mean monthly traffic volume) which was derived

Table 1
Details of study sites including: annual traffic volume (million vehicles, T), management type (grazing, G and/or cutting, C), background total (dry + wet) nitrogen (N) deposition, background NO_2 deposition (DEFRA, 2011), elevation of the first location marker above (+) or below (−) the road (m), distance of the first location marker from the road edge (m), slope away from the road (incline, ↑, decline, ↓ or none, 0), location and rainfall. Conservation designations are: National Nature Reserve (NNR), Site of Special Scientific Interest (SSSI) and Area of Outstanding Natural Beauty (AONB). Mean temperatures range from 9 °C to 10 °C with annual rainfall given (MetOffice, 2011). Grazing rates are given as the number of sheep per hectare (cattle per hectare at NC).

Site	T[a]	Management (grazing density)	N (NO_2) dep kg N $ha^{-1}\ yr^{-1}$	Elevation (Distance)	Slope	Location		Rainfall mm yr^{-1}
						N	E	
Aston Rowant NNR	35.0	G[b] (2.5–2.7)	10.9 (0.5)	0 (3)	↑	51.688	−0.949	500–600
Butser Hill NNR	17.1	G[c] (1.1–2.1)	13.6 (0.4)	10 (3)	↑	50.979	−0.975	800–1000
Lewes Down NNR	8.3	na[d]	11.4 (0.3)	0 (1)	↑	50.876	0.021	800–1000
Martins Down NNR	2.4	G[e] (0.9–1.9)	14.6 (0.6)	0 (1)	0	50.968	−1.536	600–800
Newlands Corner AONB	5.3	G[f] (1.0–1.2)	10.3 (0.4)	−2 (3)	↓	51.232	−0.506	600–800
St Catherine's Hill SSSI	38.2	G[g] (3.4–3.7)	15.5 (0.7)	38 (32)	↓	51.044	−1.310	600–800
Seale Chalk Pit SSSI	17.9	C[h] (n/a)	9.2 (0.4)	0 (2)	↓	51.224	−0.714	600–800
Stockbridge Down AONB	3.2	GC[i] (1. 0–1.5)	11.6 (0.6)	0 (2)	0	51.098	−1.409	600–800

[a] DfT, 2011.
[b] R.Silverwood, *pers comm.*
[c] T.Speller, *pers comm.*
[d] S.Tillman, *pers comm.*
[e] L.Smith, *pers comm.*
[f] C.Williams, *pers comm.*
[g] A.Watson, *pers comm.*
[h] M.Allen, *pers comm.*
[i] estimated from observations on-site.

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