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Change in propagule banks during prescribed burning: A tale of two contrasting moorlands

Hyohyemi Lee [a,1], Josu G. Alday [a,1], Angus Rosenburgh [a,b], Michael Harris [a], Hugh McAllister [a], Rob H. Marrs [a,*]

[a] School of Environmental Sciences, University of Liverpool, Liverpool L69 3GP, UK
[b] Department of Environmental & Geographical Sciences, Manchester Metropolitan University, Chester Street, Manchester M1 5GD, UK

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ABSTRACT

Moorlands on blanket bog are high-priority ecosystems from a conservation viewpoint in the British Isles; they are often managed through using prescribed burning to increase their productivity for sheep and Red grouse. However, there is an increasing demand to conserve these moorlands for other environmental services, e.g. carbon sequestration and water supplies. There is, therefore, a need for experimental evidence on the role that fire and fire-rotation intervals have on these moorlands ecosystems for the development of ecologically-sound management plans. Here, the impact of prescribed burning on the propagule banks was evaluated at two contrasting geographical moorland locations differing in productivity, climate and past pollution history. Two different approaches were used; chronosequences of elapsed time since burning and a long-term replicated grazing and burning experiment (1954–2010) where different burning rotations were applied. The propagule banks in both moorlands were very species-poor and the species present were mainly common ones. The chronosequences showed that few species had significant effects with elapsed time since burning; the dominant *Calluna vulgaris* increased in the above-ground litter fraction which acted as a barrier to seed transfer to the underlying peat. Within the experiment, the seed bank of *C. vulgaris* and the frequency of occurrence of *Sphagnum* species increased as rotation-interval increased. It is suggested that prescribed burning rotations simultaneously at two temporal scales within a moorland landscape may be needed to conserve *Sphagnum* species, short-rotation burns (every 10-years) to enhance its abundance in the vegetation and long-rotations (>55 years) to maintain *Sphagnum* propagules in the surface peat.

1. Introduction

Moorlands dominated mainly by *Calluna vulgaris* with *Eriophorum* spp. and a range of bryophytes are very important ecosystems from a conservation view point in the British Isles (Bain et al., 2011). Many of them occur on Blanket Bog (ombrotrophic mires) which occur in areas of high rainfall and low temperatures which together produced conditions that promotes peat formation (Rydin and Jeglum, 2006). Often the ecosystems have a high bryophyte component (especially *Sphagnum* spp.) which contributes to peat accumulation. These moorlands are now increasingly required to provide and maintain a range of other ecosystem services including carbon storage, recreation and the provision of potable water for human consumption (Bain et al., 2011). However, in Great Britain these moorlands are multi-functional ecosystems with respect to ecosystem services, and they are often managed through the use of prescribed burning mostly to increase plant productivity for sheep and Red grouse (*Lagopus lagopus scoticus* Latham). As a result, there is an increasing demand to conserve these moorlands as an important part of the natural and cultural heritage.

For many centuries Blanket Bog moorlands have been managed using prescribed burning in winter (Hester and Sydes, 1992). However, these fire-prone ecosystems are also often subject to wildfires, started accidentally or deliberately (Albertson et al., 2010); such fires are often outside the legal burning season (October–mid April; Anon, 2007), e.g. in summer, when effects can be very damaging, killing all surface vegetation and burning into the peat (Maltby et al., 1990). Damage can be exacerbated when summer wildfire is followed by exceptionally heavy autumn rainfall (Anderson, 1997). It has been predicted that such wildfires might increase in the future as a consequence of climate change (Albertson et al., 2010). Where damage to vegetation is extreme, then regeneration must be derived either from propagules in the surface peat or by colonisation from outside the damaged area. Therefore, in order to understand regeneration potential with respect to

* Corresponding author. Tel.: +44 (0) 1517955172.
E-mail address: calluna@liv.ac.uk (R.H. Marrs).
[1] Joint first authors.

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severe wildfire damage an understanding of the size and composition of the propagule bank is essential.

The propagule bank contains seeds and plant fragments and it represents a stock of regeneration potential which might aid restoration after perturbations (González-Alday et al., 2009). It is well known that vegetation restoration on damaged and degraded land is often hindered by a lack of available propagules within the soil bank (Bradshaw, 1983) and that a knowledge of the soil propagule bank (here surface peat) provides important information to guide land managers (Pakeman et al., 1998; González-Alday et al., 2009). Whilst, there is some knowledge of propagule banks in heathlands (Putwain and Gillham, 1990; Mitchell et al., 1998) and upland moorlands invaded by bracken (Ghorbani et al., 2003, 2006, 2007), almost nothing is known about propagule banks on deep blanket peats under *C. vulgaris-Eriophorum* moorland; and especially its composition under prescribed burning regimes.

A further factor that is likely to influence the propagule banks is geographical location. It has been well recorded that in certain places in the UK the species composition of Blanket Bog moorland vegetation has been damaged severely by, amongst other factors, past aerial pollution occurring since the industrial revolution (Tallis, 1998; Caporn and Emmett, 2008). Accordingly, we analysed propagule banks in two locations. The first encompassed three moorlands within the North Peak Environmentally Sensitive Area where chronosequences of elapsed time since burning were compared to assess the impacts of recovery after prescribed burning on the propagule banks. The second was within a replicated long-term grazing and burning experiment at Moor House National Nature Reserve; here effects of the treatments (grazing and burning rotations-fire intervals) on the propagule banks were assessed. This experiment, therefore, provided information on the cumulative effects of multiple fires (Hester and Sydes, 1992), identifying the fire return-intervals effects on formation and persistence of the propagule bank, and if the systems are likely to have the capacity to restore from propagule banks after repeated fires (Driscoll et al., 2010).

As far as moorland conservation management in Great Britain is concerned two important questions need to be considered: (1) What is the impact of prescribed burning and different burning rotations on the propagule banks within the system? (2) What is the potential for restoring the vegetation from the propagule bank assuming that a wildfire removes all surface vegetation and leaves at least some of the surface peat intact? Here we address these questions by quantifying the effects of prescribed burning and burning rotation on propagule banks on two contrasting moorlands in England during the prescribed burning/post-fire recovery cycle. Specifically, we consider both buried seeds and bryophyte propagules; it is well known that bryophytes including *Sphagnum* spp. can develop persistent propagule banks under some circumstances (Sundberg and Rydin 2000).

2. Methods

2.1. A comparison of the study areas

The two moorland areas North Peak and Moor House National Nature Reserve (hereafter referred as Peaks and Moor House, Table 1) are located at opposite ends of the Pennines, a range of hills that form the backbone of England (Fig. 1); both are situated on Blanket Bog (>50 cm peat, the widely-accepted definition for blanket peat in the UK; Costigan et al., 2005). The Peak moorlands are located in the centre of large industrial conurbations, Manchester to the west and Sheffield and Rotherham to the east, all active since the start of the industrial revolution. These moorlands were formed overlying millstone grit, are locally referred to as the ''Dark Peak'', and are managed by prescribed burning for grouse and to a lesser extent sheep production. The altitudinal range varies between 272 and 540 m across the three moors in the Peaks studied here (Table 1). Moor House is a National Nature Reserve and straddles the Pennines; the experimental site is on the eastern side and is on a gently-sloping, high-level plateau (Heal and Smith, 1978) at a higher altitude than the Peaks (600–650 m, Table 1) The underlying rock comprises a series of almost horizontal beds of limestone, sandstone and shale (Heal and Smith, 1978). Both sites are dissected by gullies but none of the study sites have been drained actively.

The climate at both sites can be described as severe by UK standards, oceanic/sub-arctic rather than temperate, i.e. cool, wet and windy (abridged for Heal and Smith's (1978) description of the Moor House climate). The January and July mean temperatures at Moor House are 2.7 °C and 14.4 °C respectively with the Peaks being slightly warmer at 3.2 °C and 15.6 °C; Moor House has almost double the annual precipitation at 1314 mm compared to 700 mm at Peaks (data derived from UK Meteorological Office 5-km monthly gridded climatic data averaged between 1961 and 2005, Perry and Hollis, 2005). Moor House precipitation was much greater in winter (January mean = 130 mm) compared to summer (July mean = 82 mm) whereas there was less difference at Peaks (January mean = 62 mm; July mean = 57 mm).

A further difference between the two sites is exposure to both past and present pollutants. The exposure to the Peak moors to past industrial pollution is well known and has been considered as one of the contributory causes of the very low plant species diversity in these sites; and this is especially true for bryophytes (Tallis, 1998; Caporn and Emmett, 2008). Moor House on the other hand has been exposed to mining activity in the historic past but is much further from industrial pollution sources. Whilst air quality has improved over the last 50 years there is still an impact of both sulphur and nitrogen at both these sites. Both sites are below the critical load (CL) for SO_2, but they exceed the CL for total Nitrogen (data from www.apis.ac.uk; Bealey et al., 2003). The CL range for moorland is between 5 and 10 kg N ha^{-1} yr^{-1} but deposition at Moor House is 19.5 kg N ha^{-1} yr^{-1} and 30 kg N ha^{-1} yr^{-1} at Peaks. Moor House is, therefore, much closer to the CL envelope than the Peaks with exceedance over the CL of 9.45–14.5 kg N ha^{-1} yr^{-1} compared to 20–25 kg N ha^{-1} yr^{-1} in the Peaks (www.apis.ceh.ac.uk).

The vegetation at the two sites reflects these past and current conditions. *Calluna vulgaris* and *Eriophorum vaginatum* are the most abundant species on both moorlands; the vegetation communities being described as M19/20 within the UK's National Vegetation Classification (Rodwell 1991). However, the species diversity differs considerably between the two locations. Over the last 60 years, 83 species have been recorded within the Hard Hill experiment at Moor House, including; 11 vascular plant species, 36 moss species (including 13 *Sphagnum* spp.), 17 liverworts and 18 lichen species (Lee et al. 2013). In contrast, a vegetation survey of the three Peak moors indicated a depauperate plant community with only 22 species detected: 13 vascular plants, 6 mosses and three lichens (Harris et al. 2011). *Sphagnum fallax* was the only *Sphagnum* species detected in extensive searches but it was present at a very low abundance/frequency. A species list for both moorland locations is presented in Supplementary Appendix I: Table 1.

Thus, on a comparative basis, Moor House is colder, wetter and less polluted than the Peaks and as such should have a lower productivity, more litter and peat accumulation than in the Peaks where productivity should be enhanced by the drier (less waterlogged), warmer conditions and a greater nitrogen loading. Moor House has also retained a substantive bryophyte component (Lee et al., 2013) including the peat-forming *Sphagnum* species, whereas Peak moorland vegetation is depauperate in bryophytes and *Sphagnum* species in particular (Tallis 1998; Harris et al. 2011).