Ecological Indicators xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Ecological Indicators

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

Winners and losers in a long-term study of vegetation change at Moor House NNR: Effects of sheep-grazing and its removal on British upland vegetation

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A R T I C L E I N F O

Article history:
Received 5 January 2015
Received in revised form 14 October 2015
Accepted 22 October 2015
Available online xxx

Keywords:
Moorland
Blanket bog
Upland grassland
Hurdle models
Ordination
Sheep grazing
Exclosures
Environmental Change Network

A B S T R A C T

We analysed data collected between 1954 and 2000 from nine long-term experiments designed to assess the effects of sheep-grazing versus no-sheep-grazing at Moor House NNR, an Environmental Change Network site. The experiments were set up between 1954 and 1972 across a range of vegetation types typical of much of upland Britain. Data from this type of experiment are often difficult to analyse and we describe the procedures undertaken to prepare the data for analysis. We fitted the resultant data to the British National Vegetation Classification and used ordination techniques to assess the relative positions of the experiments to each other. Finally, we used Generalized Linear Mixed-effects Modelling within a Bayesian framework to model change of species taxonomic/physiognomic groups through time in both sheep-grazed and ungrazed treatments across all nine experiments; variables included species diversity, Shannon–Weiner index and derived data on occurrence and abundance of species groups based on taxonomy and physiognomy. Hurdle analysis was used to model the species groups; this analysis separated the change through time in both probability of occurrence (binomial distribution) and abundance (Poisson distribution).

In the sheep-grazed plots (the “business-as-usual” treatment hence here designated the “control”) there was a reduction in species diversity and a decrease in abundance of vascular plants, grasses, lichens, liverworts and mosses; whereas herbs, sedges and shrubs increased. When probability of occurrence was considered, there was a reduction in number of presences of both lichens and liverworts. Thus, the status quo management of continuous sheep-grazing, even though reduced since 1972, has resulted in a marked change in species composition of these plant communities, with some winners and some losers, but overall they support the concept of biotic homogenization. It is likely that some of these changes were driven by external factors such as elevated atmospheric nutrient deposition. Removal of sheep grazing had some positive benefits; with the herbs, mosses, sedges and shrubs increasing, but faster reductions in grasses and liverworts. Sedges + rushes were stable. It suggested that future monitoring schemes might use either the probability of occurrence of liverworts and lichens, or the abundance of lichens, liverworts, grasses and mosses as sensitive indicators of change in upland Britain.

Moreover, during the period that Moor House has been protected as a nature reserve some key plant species groups have declined in spite of reductions in grazing pressure. To reverse this trend requires some form of interventionist management. In order to increase the diversity of vascular plants some form of disturbance will probably be needed, but for bryophytes and lichens this remains a research question. If the results from these small-scale experiments are replicated at the landscape scale a reduction of sheep grazing pressure, for example in rewilding schemes, will have little effect on species composition over a 28–44 year period.

1. Introduction

In order to manage our natural resources wisely, i.e. in a sustainable way, it is essential to have some understanding of how our ecosystems change through time, and how they respond to

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http://dx.doi.org/10.1016/j.ecolind.2015.10.053
1470-160X/

environmental drivers of change. Such drivers of change might include external factors such as climate change and pollutant loads and internal factors such as land management. Studies linking ecosystem change to environmental drivers are usually done using either a correlative approach, or by direct experimentation. The correlative approach is done most effectively when a large fraction of the available environmental resource has been surveyed and correlated directly to measured changes in the environmental drivers, or some proxy for them. A good example of this approach is the use of data from the Countryside Survey of Great Britain (Haines-Young et al., 2003; Firbank et al., 2003; Smart et al., 2003a; Maskell et al., 2010), where measures of species change indicated that productive species, known to respond to atmospheric nitrogen pollution, were favoured (Smart et al., 2003b; Maskell et al., 2010). The second approach is where vegetation is monitored through time within either permanent plots\transects (Thomas, 1960, 1963) or within experiments where management interventions are compared against an untreated control over a fairly long period; such long-term manipulative experiments are particularly valuable for testing ecological hypotheses (Silvertown et al., 2010). There are many examples of such experimental studies, but there are two main types: the first are experiments that measure the effects of applied treatments in a single location, well-known examples include the early Breckland grass-heath experiments of A.S. Watt (Watt, 1957, 1960a,b, 1962) and more recent ones such as the Buxton Climate Change Impacts Laboratory (Bates et al., 2005; Grime et al., 2008), Cedar Creek Ecosystem Science Reserve (Wilson and Tilman, 1993; Tilman, 1994; Tilman et al., 1994), and the Park Grass Experiment at Rothamsted Experimental Station (Tilman et al., 1994; Silvertown et al., 2006). This type of experiment provides detailed information about the effects of manipulated factors on species change and ecosystem properties. The second type are experiments that consider the effects of similar treatment interventions on the same ecosystem type in a range of locations, extending the assessment of impacts over a greater range of variation of that ecosystem, are particularly valuable. These multisite studies are less common than those on single sites and are more complex to analyse (Alday et al., 2013; Alday and Marrs, 2014).

The Environmental Change Network (ECN) site at Moor House National Nature Reserve (NNR) provides a third approach where a single treatment has been tested in a range of different plant communities over varying time periods from 28 to 44 years (Adamson and Kahl (2003). This approach was pioneered by A.S. Watt in his studies on grass-heath at Lakenheath Warren where he had similar experiments on a range of plant communities, although he analysed them separately (Watt, 1940). When Moor House was first designated for research work, it was perceived that there was a need for long-term information on the effects of both sheep grazing and its removal across the range of variation in plant communities found on the reserve (ca. 4000 ha). The vegetation comprised a mosaic of different upland plant communities dominated by dwarf-shrubs, grasses or sedges, occurring on soil types ranging from deep blanket peat through to brown-earth soils, and subject to different sheep grazing pressures (Eddy et al., 1969; Rawes and Welch, 1969; Heal and Smith, 1978). Accordingly, between 1954 and 1972 a series of nine experiments with similar designs, and monitored using the same methods (Marrs et al., 1986), were set up to compare the long-term effects on the vegetation of sheep grazing compared to sheep removal. In the early part of the time-series, detailed studies by Rawes and Welch (1969) estimated that there were 15,400 sheep on the Reserve in the summer months, assuming a grazing area of 3500 ha, this averaged 4.4 sheep ha^{-1} across all vegetation types. In 1972, after the formalization of grazing rights for Moor House under the Commons Registration Act (1965), grazing density was more than halved to 7000 sheep or 2 sheep ha^{-1}. From a conservation point of view, it was hoped this reduction would lead to an improvement in vegetation quality.

This suite of nine experiments covered the major moorland vegetation types that are found across the Moor House reserve, and are representative of many upland ecosystems found in much of upland Britain, although many less frequent or regional community-types are not covered (Averis et al., 2004). Some preliminary results have been published on species change in individual experiments, for example the high-level grasslands (Rawes, 1981), two of the blanket bog experiments (Rawes, 1983) and a *Juncus squarrosus*-dominated community (Marrs et al., 1988) but no attempt has been made to produce an holistic analysis. There are several problems in doing such an analysis (Marrs et al., 1988). First, the data from all the individual experiments are unreplicated, with only one sheep-grazed plot and an equivalent ungrazed exclosure in each location. Second, the experiments have been monitored irregularly (between 3 and 8 times), but over a fairly long time period, 28–44 years (Adamson and Kahl, 2003). One way to add power to the analysis is to assess change based on the combined data from all experiments; this approach should provide an overview of change with any significant result being a function of measured change across all experiments. Here, therefore, we provide a combined analysis of change across all nine experiments at Moor House. There are three further complications. The first is that the grazed treatment is the "business-as-usual" condition and hence must be treated as "the control" and the removal of sheep grazing is the applied "intervention" treatment. Clearly, there will be changes in species composition in these "control" plots through time caused by other environmental factors and there have been changes in sheep grazing pressure because of the deliberate reduction in grazing pressure in the early 1970s. The second is that some of the experiments were not monitored from the outset, rather they were set up on "similar, visually identical vegetation". The third issue is that to provide a rigorous assessment we can only assess significant directional change within the grazed plots, i.e. the "controls", and then measure any additional significant change associated with grazing removal, the "intervention-treatment".

There were three parts to this study. The first was to provide a descriptive context for the vegetation in each experiment so that managers could use the results in other locations. We did this by allocating the vegetation in each experiment to a community type within the British National Vegetation Classification (NVC; Rodwell, 1991, 1992). Second, we analysed the data using multivariate analysis so that the relationships between experiments could be assessed. The third part considered the change in abundance of selected taxonomic/physiognomic groups (hereafter termed Groups) through time; these groups were used rather than functional traits, because they are more easily recognizable by conservation managers. We tested the following hypotheses: (1) the null hypothesis was that there would be no directional change in the sheep-grazed plots through time, i.e. there would either be a steady-state or any change could be described as a fluctuation, a change in individual species abundance around a notional mean; (sensu Miles, 1979), (2) if this hypothesis was rejected and a directional change detected this would provide evidence for either (a) conservation enhancement (+ve relationship), or a conservation loss (−ve relationship). If a loss was detected this would support the hypothesis of biotic homogenization that has been reported in upland areas with losses in sub-dominant vascular plants, lichens and bryophytes (Smart et al., 2006; Britton et al., 2009; Ross et al., 2012). Moreover, identification of groups that changed through time in the sheep-grazed plots would provide sensitive indicators that might be used elsewhere to monitor for damaging change. Hypothesis 3 tested whether there was an effect (+ve or −ve) with respect to the removal of sheep-grazing. This might provide indicator groups to inform future conservation policy involving reducing