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Changes in plant species richness and productivity in response to decreased nitrogen inputs in grassland in southern England

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ABSTRACT

Biomass production and plant species diversity in grassland in southern England was monitored before and after a change from conventional to organic farming. Our 18-year study, part of the UK's Environmental Change Network long-term monitoring programme, showed that the cessation of artificial fertiliser use on grassland after conversion to organic farming resulted in a decrease in biomass production and an increase in plant species richness. Grassland productivity decreased immediately after fertiliser application ceased, and after two years the annual total biomass production had fallen by over 50%. In the subsequent decade, total annual grassland productivity did not change significantly, and yields reached 31–66% of the levels recorded pre-management change. Plant species richness that had remained stable during the first 5 years of our study under conventional farming, increased by 300% over the following 13 years under organic farm management. We suggest that the change in productivity is due to the altered composition of species within the plots. In the first few years after the change in farming practice, high yielding, nitrogen-loving plants were outcompeted by lower yielding grasses and forbs, and these species remained in the plots in the following years. This study shows that grassland can be converted from an environment lacking in plant species diversity to a relatively species-rich pasture within 10–15 years, simply by stopping or suspending nitrogen additions. We demonstrate that the trade-off for increasing species richness is a decrease in productivity. Grassland in the UK is often not only managed from a conservation perspective, but to also produce a profitable yield. By considering the species composition and encouraging specific beneficial species such as legumes, it may be possible to improve biomass productivity and reduce the trade-off.

1. Introduction

In 1939 the British parliament removed covenants protecting old grasslands from ploughing restrictions (Duffey et al., 1974). This, coupled with a desire for self-sufficiency, accentuated by the onset of the Second World War, marked the start of intensive agriculture in the United Kingdom. This intensification substantially increased between the 1940s, when two thirds of Britain's food was imported (Lloyd and Wibberley, 1977), and the 1980s when overproduction and subsequent detrimental effects on the environment were causing concern. By 1984 production of cereals was 10 million tonnes more than the population of the UK could utilise (Marren, 2002). Increased mechanisation and inorganic fertiliser use, as well as new strains of pasture species, including ryegrass and clover, created highly productive but species-poor swards.

In response to the loss of wildlife and degradation of landscape associated with this agricultural intensification (Ratcliffe, 1984; Hopkins et al., 2000), agri-environment schemes (AES) were introduced into the UK. Over the past 20 years three types of schemes have been introduced: Environmentally Sensitive Areas (ESAs), Countryside Stewardship (CSS) and Environmental Stewardship (ESS). The uptake of these schemes has substantially increased in the last 10 years: in 2005, 13% of the UK (Defra, 2007) was covered by AES, and by 2009 this had reached 66%, in excess of 6 million ha. In 2013 the area of land enrolled in entry level AES had risen to 7.4 million ha, compared to just under 2 million ha in 2005 (Defra, 2014).

Little is known about how the change from intensive to extensive farming methods affects land and biodiversity. Taylor and Morecroft (2009) followed and described plant and insect diversity trends at our study site in southern England for five years after the farmland was converted from conventional to organic agriculture. Those authors showed that above-ground biomass production in the pasture decreased rapidly after the management

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change, and that plant species richness had increased within two years. Although other authors have compared the effect of organic farming on plant species biodiversity and biomass production with that of conventional farming as paired comparisons, they do not detail – or have not assessed – the direct effect of the change in one area over time (Hole et al., 2005). There is some disagreement about the effect of nitrogen addition in agricultural systems. It has been shown that long-term nitrogen inputs increase standing crop biomass and decrease plant species richness, shifting plant composition to a few dominant species (Bakelaar and Odum, 1978; Tilman, 1987; Hunneke et al., 1990; Inouye and Tilman, 1995). However, other studies have shown that low species richness resulted in low above-ground biomass (Hector et al., 1999; Palmborg et al., 2005), although a recent re-analysis of one of these experiments has demonstrated that species richness and composition are likely to be of similar importance for productivity (Hector et al., 2011).

In this study, which forms part of the Environmental Change Network (ECN), a long-term monitoring programme started in 1992, we followed changes in vegetation in permanent pasture on the Wytham estate in Oxfordshire, UK, prior to and following the adoption of agri-environment measures under an ESA agreement. Building on the work of Taylor and Morecroft (2009), we assessed continued impacts on above-ground productivity and plant species richness for eight years beyond the original study, using data collected as part of additional ECN vegetation surveys in other parts of the study area.

2. Materials and methods

All experimental plots were situated on the Wytham estate (51.77 N, 1.34 W), as described by Taylor and Morecroft (2009). The estate, owned by Oxford University, is situated five km northwest of Oxford, and currently consists of approximately 670 ha of organic farmland, leased to FAI Farms Ltd, and 390 ha of woodland. The woodland consists of a variety of types, including ancient semi-natural woodland, secondary woodland and plantations. Until September 2001 the farmland was managed as a commercial mixed farm. In 2002 organic management was adopted, and by 2005 the farm had obtained organic status certification.

2.1. Plot description

The experimental plots in this study were of two types: grazing 'exclusion plots' in permanent pasture and 'vegetation plots' in grassland within the woods.

Ten exclusion plots were first set up on Lower Seeds permanent pasture (British grid reference: SP46720847) in 1996 to prevent grazing from livestock or wild herbivores (Fig. 1). Each exclusion plot measured 1.5 m × 2.5 m, was positioned randomly within a subplot (750 m^2) of a single main plot of 7500 m^2 and was covered with a wire mesh cage. The plots remained in the same position throughout the year and were relocated annually in March.

Six 10 m × 10 m vegetation plots were established between 1994 and 1998 in grassland within Wytham woods and in the surrounding farmland on the Wytham estate. Within these plots, ten 40 cm × 40 cm quadrats were randomly located and permanently marked with aluminium pegs, thus allowing the exact plots to be revisited annually.

Three of the six grassland plots, U1 (SP45710812), U2 (SP460008309), and U3 (SP46540762) were left 'unmanaged', other than for sporadic grazing and the ensuing natural fertilisation by sheep (Fig. 1). The remaining three plots, M1 (SP46710923), M2 (SP46570839) and M3 (SP46620770) were classified as 'managed' plots. They were all grazed by sheep and/or cattle, and were fertilised with nitrogen compounds prior to 2002; the nitrogen

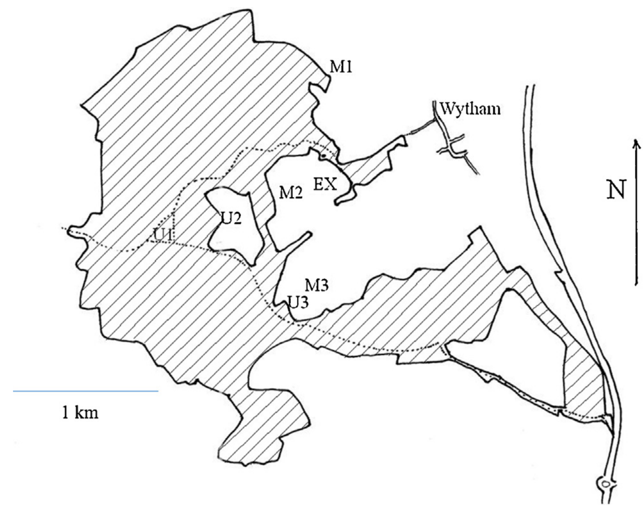

Fig. 1. Location of plots on the Wytham estate. U1–U3 are unmanaged plots on areas of rough grassland within the boundary of the woods. M1–M3 are managed plots on farmland and EX are the exclusion plots. Shaded area indicates woodland, clear areas indicate large areas of grassland.

applications stopped in 2001. Between 1993 and 2000 (we do not have farm records for 2001) nitrogen was applied to the exclusion plots and the managed plots at a mean rate of 225 kg ha^{-1} $year^{-1}$. In addition, plot M3 was managed as historic grassland under the Higher Level Stewardship (HLS; Natural England, 2013) scheme.

2.2. Biomass production in permanent pasture

The pasture in the exclusion plots was cut four times during each year in May, July, September, and October, using a power scythe (Alpina, Global Garden Products Italy S.p.A. Veneto, Italy). A 10 cm strip was cut around the edge of each plot, raked off and discarded. The remaining uncut area was measured and the vegetation was then cut, collected and bagged for further processing and biomass calculation. The mesh cage was replaced in the exact spot it had been removed from (two opposite corners had been marked with aluminium tent pegs) and firmly pegged down to prevent accidental movement by grazing livestock. The vegetation removed from each plot was weighed and dried at 25 °C until the weight had stabilised and no more water was being lost. If the cut was large (>1 kg), a subsample of 100 g was used. Biomass was calculated and expressed as g m^{-2} $year^{-1}$.

2.3. Plant species diversity in the permanent pasture and grassland within Wytham woods

Between June and August, the six vegetation plots were surveyed annually as part of the ECN vegetation survey. Prior to the July cut the exclusion plots were also surveyed. The presence of all plants (graminoids, forbs, woody species and mosses) rooted in the soil within the small quadrats and in the exclusion plots were recorded. Species names follow Stace (2010) for vascular plants and Smith (2004) for bryophytes.

2.4. Data analysis

Data analysis was carried out in R version 3.2.2 (R Core Team, 2015). All analyses addressed the central hypothesis of whether a measured outcome (i.e. biomass, species richness or species frequency, depending on the experiment and model) exhibited a change significantly different from zero across the temporal shift from conventional to organic farming, here represented by the