Agriculture, Ecosystems and Environment 192 (2014) 61–66

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Opposing effects of agricultural intensification on two ecologically similar species

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ARTICLE INFO

Article history:
Received 5 November 2013
Received in revised form 21 March 2014
Accepted 25 March 2014
Available online 24 April 2014

Keywords:
Agricultural intensification
Biodiversity
Brown hare
Livestock grazing
Pasture
Rabbit

ABSTRACT

Brown hares and rabbits are widely distributed in agricultural landscapes across the UK, occupy similar habitats and have considerable dietary overlap. However, as agriculture in the UK has intensified, hares have declined and become a species of conservation concern while rabbits have become an increasing pest. An intensive study of hares, rabbits and the dynamics of pastures over two grazing seasons was undertaken, in order to understand the environmental factors associated with hare and rabbit abundance at field level. Linear mixed models were used to assess the environmental variables, in terms of the structure, nutritional components and effects of livestock grazing that are associated with the abundance of the two species. The models revealed that hares were negatively associated with grazing intensity and plant diversity, whereas rabbits showed the strongest associations with nutritional content of pastures, in particular fat, nitrogen and fibre content in forage, as well as a positive association with short grass swards. The data suggest that, at the field-scale intensification of pasture use may have contributed to declines in hares and increases in rabbits.

1. Introduction

Agricultural land accounts for 70% of the UK land area with 46% consisting of permanent grassland, some of which is grazed by approximately 9.9 million cattle (*Bos taurus* Linnaeus) and 32 million sheep (*Ovis aries* Linnaeus) (DEFRA, 2012). Sheep grazing has increased from around 19.7 million sheep in the 1950s (Fuller and Gough, 1999), whilst cattle grazing has experienced a decline from 10.6 million (Hood, 1982). The increase in sheep grazing and reduction in cattle grazing has resulted in shorter more uniform sward structures across the landscape, as sheep are able to graze to 3 cm, whereas cattle graze to around 5 cm and create patchy tussocks around dung, which increases habitat heterogeneity (Vickery et al., 2001).

Brown hares (*Lepus europaeus* Pallas) suffered a dramatic population decline in the UK, with numbers falling from an estimated 4 million in 1880 to just over 800 000 in 1993 (Hutchings and Harris, 1996). In contrast the population of the European rabbit (*Oryctolagus cuniculus* Linnaeus) in the UK has increased significantly in recent decades and was estimated to be growing at around 2% each year (Trout, 2003). Numbers still remain relatively high despite the spread of myxomatosis (Lees and Bell, 2008) and rabbit haemorrhagic disease virus (RHDV) that caused initial declines (Wright et al., 2013). Damage to UK crops caused by rabbits has been valued at £115 million each year (Smith et al., 2007).

Livestock grazing and pasture management affect the nutritional quality of forage and intensification of grazing has been shown to increase levels of protein, nitrogen and reduce fibre (Bakker et al., 1983; Pavlů et al., 2006). The amount of fat in forage has been shown to affect the condition of hares (Hackländer et al., 2002), although Smith et al. (2005b) found no link between broad habitat selection and forage quality, in terms of protein, fat or energy content for hares. Both fibre and higher amounts of nitrogen have been linked to foraging patch selection by rabbits (Bakker et al., 2005; Iason et al., 2002), whereas Hewson (1977) found hares were negatively associated with nitrogen content in forage.

At the landscape scale hares have been found to be negatively associated with low habitat diversity, hedgerow removal and loss of unfarmed habitat (Tapper and Barnes, 1986; Vaughan et al., 2003; Smith et al., 2004, 2005a; Pépin and Angibault, 2007). Conversely, rabbits have demonstrated mixed responses to landscape-scale intensification and shown positive associations with aspects of less intensively managed landscapes, such as the presence of woodland

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http://dx.doi.org/10.1016/j.agee.2014.03.048
0167-8809/

and field boundaries, as well as with more intensive practices such as predator control and high levels of sheep grazing (Petrovan et al., 2011; Trout et al., 2000). However, since agricultural landscapes are typically managed at the field-scale, an understanding of how intensification of farming practices is associated with the two species' distribution at this scale could help in the development of practical solutions to hare conservation and rabbit control.

The study aimed to assess the effects of intensification of livestock grazing on field-scale habitat associations of brown hares and rabbits in pastures. The effects of livestock grazing type on pasture forage diversity, height and nutritional composition were examined and related to hare and rabbit distribution.

Specifically the study assessed the following hypotheses:

(1) Sheep and cattle grazing have different effects on forage diversity, height and nutritional composition.
(2) Hare and rabbit distribution is associated with pasture management, forage height and nutritional composition.

2. Material and methods

The study was carried out in a lowland, mixed arable and pasture landscape in North Yorkshire, UK, with average field sizes of 6.4 ha (SD = 4.63 ha). Eighteen fields were intensively studied that were grazed by either dairy/beef cattle (n = 11; mean field size = 8.66 ha, SD = 5.07 ha) or sheep (n = 7; mean field size = 3.41 ha, SD = 1.66 ha), and were either continuously or rotationally grazed. The pasture management between cattle grazed fields was similar during the study, and had an annual application of manure and were cut for silage. Sheep grazed fields were also cut for hay when left ungrazed for a period of time. Although all fields were subject to grazing during the study, fields were described as 'grazed' if, at the time of survey they had livestock actively grazing them. A field surveyed either before grazing had commenced or after livestock had been removed was classified as 'ungrazed'. Data were collected between March 2011 and July 2011 from the start of the grazing season when the cattle were let out into the fields following winter housing and repeated again from February 2012 until July 2012.

2.1. Survey methods

Data were collected on plant diversity, forage nutrition and grass heights before and after grazing in order to assess the effects of grazing on these variables and relate them to lagomorph distribution. During 2011 habitat surveys were carried out before and after grazing of cattle and sheep. In 2012 data were collected twice before the grazing season started and five times during the grazing season (every two weeks). ArcGIS 9.2 (ESRI, USA) was used to calculate the area of each field from Ordnance Survey maps acquired through the Edina Digimap service (http://edina.ac.uk/digimap). The percentage of arable, semi-improved, improved, unimproved grasslands and woodland within a 1 km radius from the centre of each study field was also calculated. The presence and number of cattle and sheep and the number of days the field was grazed for were also recorded to measure livestock density and grazing intensity. Livestock were counted exactly unless large numbers were present, in which case they were estimated to the nearest 10 animals. Livestock units (LU) were used to calculate the livestock density, using the ratio 1 cow = 0.11 sheep (DEFRA, 2010).

To account for within-field variation, three transects were walked per field, one along the edge, one in the middle and an intermediate transect between the edge and middle of the field, 20–30 m from the field boundary. Plant samples were taken to analyse the nutritional composition of forage within fields, and between grazed and ungrazed pastures, by cutting all above ground green plant material from three 1 × 0.1 m plots per transect (Bakker et al., 2005).

Vegetation was surveyed in 1 m^2 quadrats along the transects. Quadrats were placed at intervals of 30 or 50 m depending on the size of the field, with a minimum of 6 quadrats per transect. The mean number of quadrats surveyed over the two years was 222 per field (SD = 15). Ten grass height measurements were taken per quadrat using the direct method, which is suitable for use in measuring grass of varying heights, in particular short swards (Stewart et al., 2001). Percentage cover of all grass and herb species within each quadrat was recorded to the nearest 1% to assess plant species diversity and richness. Inverse Simpson's diversity index was chosen as it accounts for evenness, is less affected by sample size and is easier to interpret than other diversity indexes (Magurran, 2004).

One visit per week to all the fields was made at least 1 h after sunset during 2011. This was increased to three visits per week of all study fields during 2012. Each field was scanned using a 1 mega candlepower spotlight (Clubman CB2, Cluson Engineering Ltd, Hampshire, UK) and 8 × 42 binoculars, and the number of hares and rabbits was counted.

2.2. Forage analysis

Plant cuttings collected from each field were oven dried at 100 °C for 36 h, finely ground and mixed using a Retsch rotor mill. The Kjeldahl method was used to determine the amount of protein and nitrogen (AOAC, 2006a) and the Soxtherm method to determine crude fat levels within the grass (AOAC, 2006b). Energy content was calculated using a bomb calorimeter and ash was obtained by placing samples in the furnace for 4 h at 400 °C (AOAC, 2005). Crude fibre was ascertained through a process of boiling fat-free samples, using the filter bag method, in sulphuric acid solution for 30 min followed by boiling in a solution of sodium hydroxide for a further 30 min. The remaining residue was oven dried at 100 °C for 4 h, then placed in a furnace at 600 °C and ashed for a further 4 h (AOAC, 2006a).

2.3. Data analysis

A multivariate ANOVA was used to test if there was a difference between the amount of different types of habitat surrounding sheep and cattle fields on logit transformed percentages (Warton and Hui, 2011). Moran's I was calculated using the *ape* package in R 3.0.1 (R Development Core Team, 2013) to test for spatial autocorrelation in the numbers of hares and rabbits across the landscape.

Differences in plant diversity, forage nutrition and grass heights between livestock types and before and after grazing were assessed using two-way analyses of variance. Pearson correlations were used to assess relationships between grazing intensity (stocking density × days grazed) and nutritional composition between fields. Normality and homogeneity were tested to ensure assumptions were met.

Linear mixed models were used to assess the environmental variables that were associated with hare and rabbit abundance. Data were checked for outliers in each variable and collinearity between the explanatory variables was tested. Those where $r > 0.7$ were either removed or combined (Dormann et al., 2012). This process resulted in variables for livestock density and number of days grazed being combined to create a 'grazing intensity' variable by multiplying the two variables together and log transforming to remove significant outliers. Protein values for forage were also removed as these values are derived from the measured nitrogen value with which they are highly correlated (r = 1.000, P = 0.001).