Spatial variation in vegetation height as an indicator of aboveground carbon stocks in grazed grasslands

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Abstract

Spatial heterogeneity in plant and soil properties is known to influence ecosystem functions, but the linkages between spatial variation and ecosystem services in grasslands are unclear. Here we examine within-field variation in sward structure (vegetation height) and test whether indices of spatial heterogeneity can be used as a simple indicator of aboveground production services or carbon stocks over time in upland grasslands. Two upland pastures with continuous cattle grazing (high versus low stocking rate and N inputs) were studied over a six-year period using a spatially explicit sampling scheme, as part of a long-term field management trial in central France. We found that grassland height showed significant spatial and temporal variation during the study period in both grazing management treatments. Contrary to expectations, stocking rate did not affect the degree of within-field variation in vegetation height recorded during the study. Mean annual biomass in both grazed paddocks showed a positive relationship with variation in end-of-season vegetation height, but was unrelated to vegetation properties at the start of the growing season. Simple metrics of height variation appear to be a useful proxy of grassland standing biomass, and hence carbon stocks, at broader spatial and temporal scales, and could improve the prediction of field-scale function in a changing environment.

Keywords: biomass production, vegetation height, upland grassland, management

Introduction

Within-field variability and spatial patterns in plant and soil properties reflect the interplay between geology, topography and biotic processes, both past and present. Studies at small spatial scales suggest that spatial heterogeneity plays a key role for ecosystem functions (i.e. biomass production, biogeochemical cycling, nutrient losses), with significant implications for the provision of ecosystem services in managed systems (Bloor and Pottier, 2014). This is of particular relevance for grazed grasslands where large herbivores promote within-field variation in plant biomass and soil nutrients due to their grazing activities (non-uniform activities of defoliation, animal returns). Indeed, grazed paddocks encompass a range of grazed/ungrazed patches of differing sward height, and areas affected by animal returns and trampling. Impacts of grazing herbivores on sward structure may vary depending on animal species and stocking rate, fertilizer inputs and vegetation composition, which modify patterns of defoliation and subsequent plant growth. However, the influence of spatial heterogeneity on field-scale processes is poorly understood, and the description of within-field variation in vegetation and soil resources in relation to grazing management remains limited (Bloor *et al.*, 2020). Improved understanding of the linkages between within-field variation and field-scale ecosystem functions is required to establish whether the enhancement (or reduction) of spatial heterogeneity should be considered in the elaboration of management strategies (Dronova, 2017), and could have significant implications for biodiversity and sustainable agriculture. In order to address this issue, we examined within-field variation in vegetation structure (height of green and senescent biomass) and tested whether indices of spatial variation could be used as a simple indicator of production services over time in upland grasslands.

Materials and methods

Measurements were carried out over a six-year period (2016-2021) at the long-term French research platform (SOERE-ACBB, ICOS: Laqueuille; 45°64″ N, 02°73″ E; 1,100 m a.s.l.). The site is characterized by Andosol soil, with mean annual temperature of 8 °C and annual rainfall of 1000 mm. The field trial was established in 2002, and consists of two paddocks managed with continuous cattle grazing from May to October; the 'Intensive' management treatment is a 5.4 ha field with moderate stocking rate (1.1 LSU ha^{-1} y^{-1}) and N inputs (200 kg ha^{-1} y^{-1}), whereas the 'Extensive' treatment is a 3.4 ha field with low stocking rate (0.5 LSU ha^{-1} y^{-1}) and no N inputs. Both paddocks are dominated by grasses; species such as *Dactylis glomerata*, *Poa pratensis* and *Agrostis capillaris* are common across treatments, but *Trifolium repens* is present only in the 'Intensive' treatment, and forb species are more abundant in the 'Extensive' treatment (Klumpp *et al.*, 2011). Field-scale standing biomass during the growing season is assessed every year by harvesting aboveground samples at five dates at monthly intervals across each paddock. Potential productivity is assessed by grazing exclusion cages, and sampled at the same intervals as standing biomass. At each cut, biomass is sampled at a height of 5 cm above soil surface (70×70 cm quadrats), oven-dried (60 °C for 48 h) and weighed. Within-field variation was examined from 2016 onwards using a 30×20 m grid in the centre of each field (117 points per grid, regular 2.5 m distances). Permanent corner markers were installed in May 2016, and geographic coordinates of each sample point were established (precision 5 cm; Trimble R8 GPS Systems, Trimble Navigation Limited, USA) in order to repeatedly measure the same points at each subsequent sampling campaign. Maximum heights of both green and senescent shoots were determined using a sward stick at each grid point at the end of the grazing season each year (October – November depending on weather conditions and snow). This sampling period was chosen in order to capture the maximum effect of grazing on vegetation structure; effects of grazing on vegetation structure are known to become progressively more marked over the course of the plant growing-season (Rossignol *et al.*, 2011). Standard deviation (SD) and coefficients of variation (CV, standard deviation/ mean × 100) were used to assess the absolute and relative variation, respectively, of plant height within each treatment. Relationships between field-level biomass productivity and within-field variation were assessed using GLM models.

Results and discussion

During the study, mean annual productivity was greater in the 'Intensive' treatment than the 'Extensive' grazing treatment (mean of 7.2 and 3.3 Mg ha^{-1} for Intensive and Extensive treatments respectively; $F_{1,11}$=54.5, P<0.001; Figure 1A). This result is consistent with previous observations at this site (Klumpp *et al.*, 2011), and reflects higher N inputs in the Intensive treatment and increased nutrient cycling under high stocking rates (Bardgett and Wardle, 2003). In contrast, standing biomass ranged from 0.2 to 1.3 Mg ha^{-1} and showed no significant difference between grazing treatments (P>0.05, Figure 1B). We found there was a high degree of within-site variation for height measured for both green and senescent shoots irrespective of grazing treatment, and both absolute variation (SD) and relative variation (CV) showed interannual variation. Absolute variation in green vegetation height at the end of the growing season (green height SD) showed a positive relationship with mean annual field-scale standing biomass in both grazing treatments (R^2=0.65, P<0.001 across treatments), and showed some discrimination between treatments (Figure 1C). Green height SD was more closely linked to mean standing biomass than was mean vegetation height across years (mean green height range: 3.3-11.8 cm; R^2=0.46, P<0.001 across treatments). Neither mean green vegetation height nor any metrics of variation in green height were related to field-level productivity. Moreover, no significant relationship was found between metrics of variation in senescent height and either field-level productivity or standing biomass (P>0.05). Our results suggest that within-field variation in end-of-season green vegetation height may be an integrated indicator of biomass state during the year (i.e. quantity of standing biomass available for ingestion over time), with implications for the estimation of aboveground carbon stocks and carbon input into the soil. In contrast, these simple metrics of within-field variation do not appear to provide useful proxies of biomass fluxes, and hence production services, in the grazed grassland systems studied here.

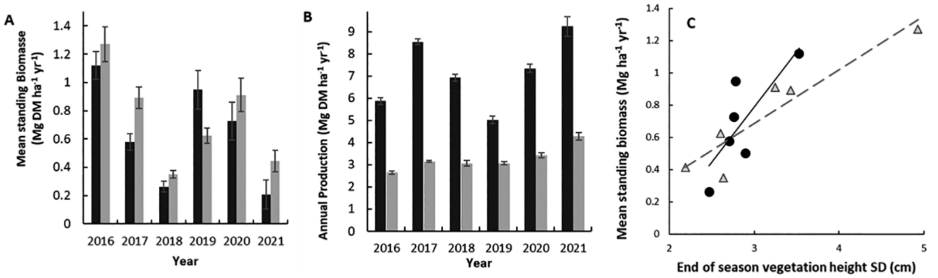

Figure 1. Interannual variation in field-scale annual biomass production (A) and mean standing biomass (B); data are means ± standard error. Graph C shows relationship between within-field variation in green vegetation height (standard deviation) and estimations of mean annual field-scale standing biomass during the study. Grazing treatments are given by: Intensive, black-filled bars/circles; Extensive, grey-filled bars/triangles.

Conclusions

Metrics of within-field variation in vegetation height at the end of the growing season were more closely linked to mean annual standing biomass than grassland productivity, and showed some evidence of treatment-induced changes in ecosystem function. These results suggest that simple measurements of grassland heterogeneity could be useful for model validations and the prediction of field-scale carbon stocks in a changing environment.

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