Monitoring Spatial Heterogeneity of Pasture within Paddock Scale using a Small Unmanned Aerial Vehicle (sUAV)

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Abstract

Site-specific management strategies in a grazing ecosystem increase management efficiency. Due to the complex interrelationship among the soil-plant-animal-environment in a grazing ecosystem, site-specific grazing management requires a high measurement density to reflect their spatial patterns within a paddock rather than an inter-paddock scale. Recently, small unmanned aerial vehicles (sUAV) have been introduced into agricultural research. Their images offer a potential alternative for pasture monitoring given by their low cost of operation, high spatial and temporal resolution, and their high flexibility in image acquisition programming. In this study, we reviewed current developments of sUAVs and photogrammetric algorithms, and we highlight the applications for pasture managements using results obtained mainly at Hiroshima University farm, which included; (1) seasonal changes in a number of species and the nutrient status of plants, (2) the spatial distribution of herbage biomass from sUAVs, and (3) the spatial distribution of GPS collars attached to cows.

1. Introduction

Site-specific grazing management by assessing plant productivity and species richness in a grazing ecosystem is regarded as a central task for the efficient management and conservation of the ecosystem. Species richness generally promotes ecosystem productivity, and the species richness-productivity relationship has been of interest in grassland ecosystems (Wang *et al.*, 2016). Moreover, a species-rich ecosystem creates rich variations of nutrient composition for large herbivores to feed on (Mizuno *et al.* 2014; Takamizawa *et al.* 2016b). The species rich conditions may also affect their diet selection and foraging behavior (Ogura *et al.* 2011).

Meanwhile, grazing by large herbivores also affects herbage productivity and plant species richness in grassland ecosystems. The grazing activities influence the availability of essential resources, such as light and soil nutrients (Bakker *et al.*, 2003). The activity of grazers may also lead to a greater spatial heterogeneity of resources due to trampling or patchy removal of the herbage biomass (Bakker *et al.*, 2003) and excretion events (Betteridge *et al.*, 2010a). To date, many tools or methodologies have been developed to monitor the activities of animals (Betteridge *et al.*, 2010b; Tani *et al.*, 2013; Yoshitoshi *et al.*, 2013) and to predict their spatial distributions (Yoshitoshi *et al.*, 2015). Local plant species richness is influenced by present-day variation in grazing intensity (Klimek *et al.*, 2007) and by the historical continuity of grazing management (Johansson *et al.*, 2008).

However, assessing the diversity in plant communities from field-based data is difficult and time-consuming. Site-specific grazing management needs a high measurement density to reflect their spatial patterns within a paddock rather than an inter-paddock scale. Remote sensing is a promising tool to estimate plant productivity over large areas, and has been used to estimate grassland production. Recently, small unmanned aerial vehicles (sUAV) or drones have been introduced into agricultural researches and have become useful for monitoring plant or soil parameters on a field scale (Zhang and Kovacs, 2012). The sUAVs provide ultra-high resolution images of the plant canopy due to their low flight altitude. In contrast to satellite imagery and airborne-based remote sensing, sUAVs can be used frequently during the entire plant growing season. The main benefits are simple mission planning, instantaneous operation with low man power and imaging below the cloud cover (Floreano and Wood, 2015).

Moreover, recent advances in 3D modeling using structure-from-motion(SfM) photogrammetry have allowed researchers to utilize sUAV for initially geosciences (Smith and Vericat, 2015; Woodget *et al.*, 2015), and these methods have been expanded to various applications (Zahawi *et al.*, 2015; Cunliffe *et al.*, 2016). Although fine-grain 3D structures can be produced using sUAV-acquired image data with SfM photogrammetry (Westoby *et al.*, 2012), there have been limited applications for using this approach to characterize the biophysical structures of vegetation. Zahawi *et al.* (2015) suggested that SfM modelling of sUAV-acquired image data was not yet suitable for measuring the structure of small plants, such as grasses, due to the limitations with the accuracy of the derived canopy height models. Further refinement of the technique was needed to improve the measurement accuracy of sUAV-SfM approaches to support applications in grassland ecosystems dominated by shorter vegetation.

The aim of this review was to highlight the potential of sUAVs for monitoring spatial heterogeneity of species richness and herbage production in a grazing pasture as a case study at the Setouchi Field Science Center, Saijo Station, Graduate School of Biosphere Science, Hiroshima University, Japan (hereafter, Hiroshima University farm). The Hiroshima University farm (N34º23’, E132º43’) is located in a temperate zone with a warm, humid summer and a cool, dry winter (Lim *et al.*, 2015). The area is a boundary zone where cool-season grass or warm-season grass is grown in the recommended region. To ensure the pasture production for feeding grazing cows, the farm was using a unique strategy to combine cool-season grass (tall fescue [*Festuca arundinacea* Schreb.]) and warm-season grass (bahiagrass [*Paspalum notatum* Flűgge]) with white clover (*Trifolium repens* L.).

2. Relationship between species richness and plant productivity or nutrient status

Several studies have investigated the plant species richness–productivity relationships (Waide *et al.*, 1999; Mittelbach *et al.*, 2001; Fraser *et al.*, 2015). At Hiroshima University farm, the monthly changes in the number of species (*n*) and nutrient status data from our field survey in 2015 are shown in Fig.1, which were obtained using 0.5 m × 0.5 m quadrats on a 100 m line transect during a grazing period. Although the plant species richness (number of species) showed less or a negative relationship to herbage biomass (Kawamura *et al*. unpublished), the total digestible nutrient (TDN) concentrations tended to link the number of species.

In some cases, highly productive sites are known to be rich in resource and poor in species (Fraser *et al.*, 2015). Such high-productivity and low-diversity sites are typically highly managed via irrigation or fertilizer application and often lead to declines in the species richness relationships at high productivity. It is fact that variation in the relationship between biodiversity and ecosystem function depended on the resource availability and environmental factors (Isbell *et al.*, 2015). Particularly in grazing ecosystems, like Hiroshima University farm, grazing by large herbivores may have influenced the plant species richness–productivity. Another potential factor in Hiroshima University farm is renovation –the number of species and TDN values increased after renovation in July 13, 2015 (Fig. 1a,b).

3. Spatial distributions of herbage biomass and grazing cattle

Low-cost sUAV imagery based on an RGB consumer-level camera can compute ultra-high resolution orthoimages and surface models. There has been an increase in the use of sUAV images for estimating biophysical parameters, *e.g.*, leaf area index (LAI) (Hunt *et al.*, 2011), aboveground biomass

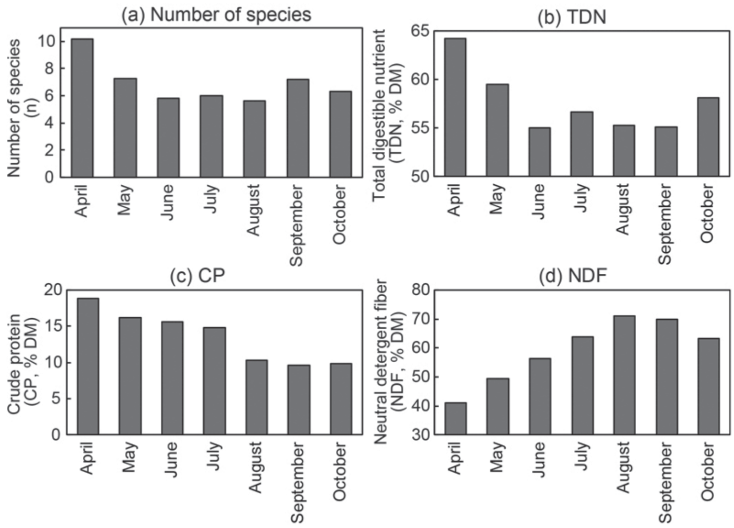

Fig. 1. Monthly changes in the number of species (*n*), total digestible nutrient (TDN), crude protein (CP) and neutral detergent fiber (NDF) concentrations of herbage from a field survey 2015 using 0.5 m × 0.5 m quadrats.

(BM) (Honkavaara *et al.*, 2013; Bendig et al., 2014) and plant height (Bendig *et al.*, 2014), as well as nitrogen (N) concentration (Lelong et al., 2008; Schirrmann *et al.*, 2016). At the Hiroshima University farm, Kawamura *et al.* (unpublished) investigated the relationship between herbage BM and the green normalized difference index (GNDVI) from sUAV images (R^2 = 0.68, p < 0.001) during grazing season. Using the relationship between herbage BM and the GNDVI, spatial distribution maps of BM were estimated in ultra-high spatial resolution (5 cm or more less). For example, Fig.2 shows the spatial distributions of herbage BM in prior- and post-grazing, and their differences (ΔBM) with 5 cm spatial resolution in a short-term grazing trial from 2013 (grazing period June 1–12, 2013) at Hiroshima University farm (Kawamura et al. unpublished). The spatial distributions showed that the herbage BM decreased in the southern area, while the northern areas did not change. In grazing ecosystems, large herbivores played an important role in spatial heterogeneity (Hirata *et al.*, 2011), and promoted the increase of more nutritious and palatable species. To evaluate the grazing effects, the locations of four cows fitted with GPS collars are also shown in Fig. 3. Cows were mainly grazed in the southern areas, and this approach may have also reflected the decrease in herbage BM.

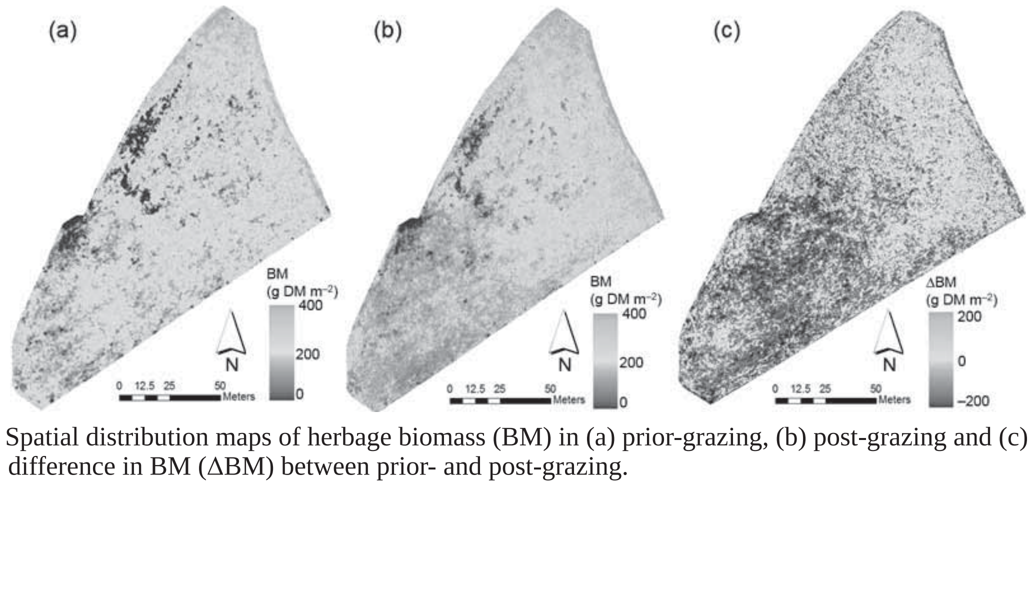

Fig. 2. Spatial distribution maps of herbage biomass (BM) in (a) prior-grazing, (b) post-grazing and (c) the difference in BM (ΔBM) between prior- and post-grazing.

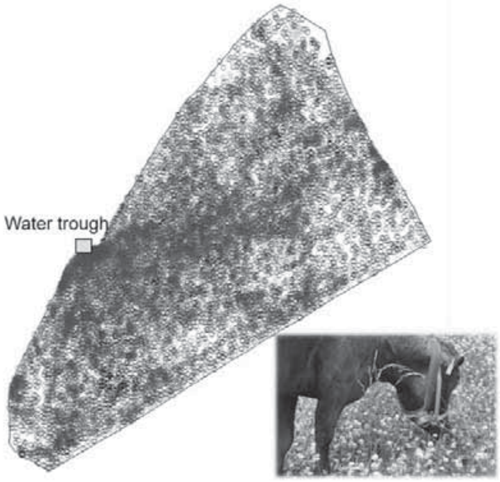

Fig. 3. Spatial distributions of the locations of four cows fitted with GPS collars.

4. Potential and limitation for an sUAV

The sUAV can be expected to be an efficient and inexpensive way to assess the productivity and the biodiversity at a paddock scale in a grazing ecosystem. This paper demonstrated (1) species richness and a productivity relationship in an artificial grassland, and (2) the potential use of an sUAV for assessing spatial distribution of herbage BM with cows' location as a case study in Hiroshima University farm.

However, similar to most technologies, an sUAV has some limitations and technical issues, including (i) payload size and weight are critical limitation factors and have trade-offs with the sensor system on an sUAV (Hunt *et al.*, 2011), (ii) stabilization may not be constant at high flight altitudes (*e.g* ., > 100 m) due to the wind being more noticeable, (iii) the battery determines the duration of the flight, and (iv) flight altitude in many countries is restricted to 120–150 m by the regulations for an sUAV (Borra-Serrano *et al.*, 2015). These limitations affect the operation planning. For example, the flight course and its altitude decide the pixel size and dimensions of the surface covered by each flight because the lower the flight altitude is, the higher the spatial resolution is but with lower surface coverage. Further research should be conducted to increase the number of potential applications for an sUAV in biodiversity and conservation studies as well as more efficient grazing management.

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