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Unmanned aerial vehicle methods makes species composition monitoring easier in grasslands

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ABSTRACT

Species composition plays a critical role in environmental conservation, ecosystem functioning and health of grasslands. However, there is no efficient and long-term monitoring method. In this study, we developed a practical method with unmanned aerial vehicles (UAVs), and tested it along a range of grazing intensities in alpine meadow of the Qinghai-Tibetan Plateau. We found that 1) there were significant linear relationships of widely used species composition indices between this and traditional methods ($P < 0.01$); 2) along increasing grazing density, there were similar tendencies of these indices estimated by the two methods; 3) the new method was more representative than the traditional one though some specific species were difficult to identify. We concluded that this method is suitable for long-term repeated monitoring of grassland species composition, which will be useful for grassland conservation and management.

1. Introduction

Species composition plays a critical role in environmental conservation, ecosystem functioning and health of grasslands (Lu and He, 2017; Reich et al., 2012; Van et al., 2018). It is essential to investigate the spatio-temporal variations of species composition to understand grassland vegetation growth dynamics and ecosystem evolutionary processes, and for managing grasslands (Gould, 2000; Lu and He, 2017; Price et al., 2001).

In previous studies, space-borne imagery has been applied to study grassland species composition at different spatial levels, ranging from regional level, landscape level, to community level using MODIS, Landsat and Quickbird imagery (Hall et al., 2010; Huang et al., 2009; Langley et al., 2001). However, all these imageries cannot resolve grassland species composition at species level (centimeters), because species in grasslands are typically small in size and highly mixed (Lu and He, 2017). Hence, up to date, traditional field survey (quadrat or belt) is still employed in studies of species composition of grasslands. To depict characteristics of species composition, various indices have been implemented in previous studies (Bello et al., 2006; Spellerberg and Fedor, 2003). These indices generally refer to the number of species (e.g. species richness), heterogeneity or diversity (e.g. Shannon index and Simpson index) (Bello et al., 2006; Spellerberg and Fedor, 2003; Wesuls et al., 2013), and evenness of species abundances (e.g. Pielou's J index) (Karen et al., 2004). However, traditional methods of measuring these indices have several drawbacks: 1) they require large amounts of time, labor, cost, and resources (Arif et al., 2016); 2) their results are not comparable among different spatio-temporal sampling schemes (e.g. different sampling plot sizes that have been applied to balance sample size and investment of resources) (Bonham, 2013; Chillo et al., 2015); and 3) they are difficult to measure frequently due to destructive sampling. Therefore, a new efficient, repeatable and comparable monitoring method is urgently needed.

In recent years, unmanned aerial vehicles (UAVs) have been applied in a few species composition studies (Baena et al., 2017; Lu and He, 2017; Laliberte et al., 2011; Rango et al., 2009). However, only specific species were the focus in these studies. For example, Baena et al. (2017) identified keystone tree species in a forest ecosystem, and Lu and He (2017) focused on six dominant species in a grassland ecosystem. Furthermore, previous monitor methods based on UAV were not compared to traditional monitoring and analysis methods. For instance, a high fly height (70 m) and low spatial resolution (5 cm) (Lu and He, 2017) are not conducive for species-level fixed-point monitoring. Therefore, in the present study, we propose and test (along a range of grazing intensities in alpine meadows of the Qinghai-Tibetan Plateau, QTP) a new plant species composition monitoring method, which can

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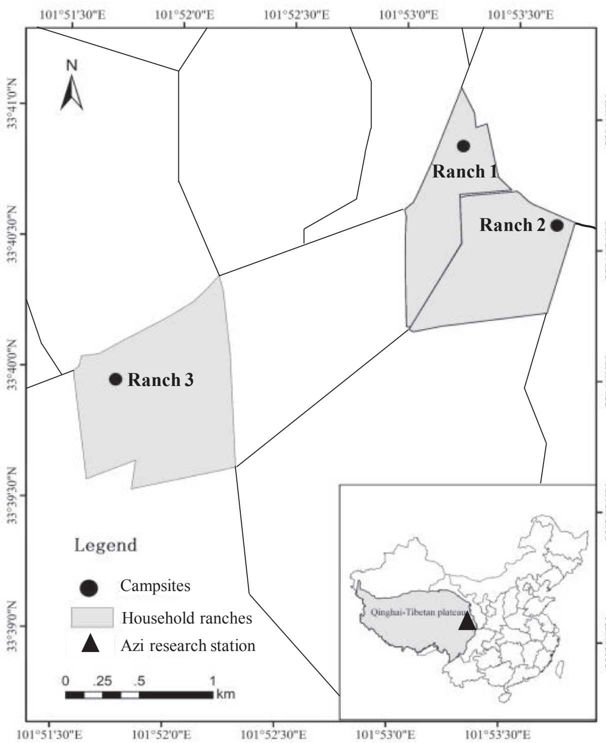

Fig. 1. Study area in the east of the Qinghai-Tibetan Plateau (the triangle in the insert) including sampling ranches. Lines indicate ranch borders; Black circles represent campsites.

monitor species composition dynamics at fixed points on a large scale and is comparable to traditional field-based monitoring methods.

2. Methods

2.1. Study area

This study was conducted during August of 2017, at Azi, Gansu Province, China (101°52′07.9″E, 33°24′24.1″N; 3547 m a.s.l.) (Fig. 1). Azi is in a humid region with a mean annual precipitation > 600 mm and mean annual air temperature of 1.1 °C (Sun et al., 2015; Sun et al., 2018). The soil type at the study site is alpine meadow soil, primarily Mat-Cryic Cambisols (Gao and Li, 1995). The plant community type is mainly alpine meadow which is dominated by monocotyledonous species, primarily Poaceae and Cyperaceae. Various dicotyledonous species are also common: *Ranunculaceae, Polygonaceae, Saxifragaceae, Asteraceae, Scrophulariaceae* and *Gentianaceae* (Ma et al., 2010).

The study area consisted of three typical household ranches with 48.53–113.64 ha areas of gentle topography (slope < 5°), which are primarily used for warm season grazing (Fig. 1). The current number of yaks is 278–335 in each pasture. Yaks are penned each night and released for grazing during the daytime. There are 3–4 neighbouring night pens employed for rotation around each campsite (Fig. 2). The pastures have been continually grazed in this way for more than 30 years. This practice generates a radial gradient of grazing intensity from the concentrator (i.e. the campsite in this study) (Chillo et al., 2015), which provide suitable research fields to study the response of species composition to grazing intensity and test the feasibility of the new method.

Three sampling points were set up along transect from campsites to the margin in each ranch. The distances of each sampling point from campsites were random and identified based on a geographic information system (the ground sampling distance was ~0.09 cm) (e.g. Fig. 2). Grazing densities were represented according to the proxy parameter of inverse distance (in m^{-1}) from the campsite (Chillo et al., 2015; Wesuls et al., 2013). A fencing paddock (control treatment in this study, 50 m × 50 m) was set up as one component of multi-stocking rates and grazing system experiments since 2010 (Sun et al., 2015). All the sampling points were within 4 km radius of each campsite (Fig. 1). The flight missions were conducted with permissions from both the airspace authority and the landowner.

2.2. Field sampling and data collection

Field sampling methods are depicted in Fig. 2. At each sampling point, a UAV flew along "belt" and took 16 photos using the FragMAP system (Yi, 2017) (Fig. 2b). In this study, we used a DJI drone (MAVIC Pro, DJI Innovation Company, China) with 3000 × 4000 pixels, and the height was set as 2 m to take photos (2.6 m × 2.0 m on ground) suitable for identifying each species accurately (Fig. 2b and c). We identified species visually and recorded all the species occurring within each aerial photograph. Then we calculated indices as Eqs. (1)–(4) at each sampling point based on the information from the 16 aerial photographs (see Section 2.3 for details). The terrain following function of Mavic Pro maintains similar areas of each photo so that the photos are comparable. To explore relationships between UAV_{Belt} and $Traditional_{Quadrat}$ methods, 3 quadrats were sampled around the centers of 3 aerial photographs randomly (Fig. 2c), and average values were used in statistical analyses.

2.3. Calculation of indices

Usually, several measures are used in combination for an in-depth description of vegetation (Bonham, 2013). We selected four common indices to assess feasibility of using the UAV_{Belt} method to quantify species composition of rangelands. Species richness is a simple and widely used index that indicates diversity of a study area (Karen et al., 2004). The Shannon index and Simpson index are widely used indices to quantify the diversity of communities, while Pielou's J index is commonly used to quantify the evenness of species abundances (Karen et al., 2004; Spellerberg and Fedor, 2003). Species richness was calculated using Eq. (1) (Bonham, 2013).

$$N = \text{number of species appeared in unit area} \quad (1)$$

where N is total number of species per sampling point (16 photographs, UAV_{Belt}) or quadrat (3 quadrats, $Traditional_{Quadrat}$).

The Shannon (H) and Simpson (D) diversity indices were calculated using Eqs. (2) and (3), respectively (Bello et al., 2006; Spellerberg and Fedor, 2003; Wesuls et al., 2013).

$$H = -\sum p_i \ln p_i \quad (2)$$

$$D = 1 - \sum p_i^2 \quad (3)$$

where pi is proportion of species in each quadrat ($Traditional_{Quadrat}$), or frequency of species i in 16 photographs of each sampling point (UAV_{Belt}).

Pielou's J index was calculated using Eq. (4) (Karen et al., 2004).

$$P = H/\ln N \quad (4)$$

2.4. Data analysis

The coefficient of determination (R2) and its P values were used to evaluate the performance of different sampling methods (UAV_{Belt} and $Traditional_{Quadrat}$). Analyses of indices were performed utilizing the VEGAN package in R (R Core Team, 2013). To select the final regression models, which indicated the effect of grazing intensity on species composition, the likelihood ratio tests were used to compare the simple linear regression and polynomial regression models (n = 10, ggplot2 package in R). The statistical analyses were performed with R version