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Fine spatial scale assessment of structure and configuration of vegetation cover for northern bobwhites in grazed pastures

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Abstract

Background Monitoring forage in livestock operations is critical to sustainable rangeland management of soil and ecological processes that provide both livestock and wildlife habitat. Traditional ground-based sampling methods have been widely used and provide valuable information; however, they are time-consuming, labor-intensive, and limited in their ability to capture larger extents of the spatial and temporal dynamics of rangeland ecosystems. Drones provide a solution to collect data to larger extents than field-based methods and with higher-resolution than traditional remote sensing platforms. Our objectives were to (1) assess the accuracy of vegetation cover height in grasses using drones, (2) quantify the spatial distribution of vegetation cover height in grazed and non-grazed pastures during the dormant (fall–winter) and growing seasons (spring–summer), and (3) evaluate the spatial distribution of vegetation cover height as a proxy for northern bobwhite (*Colinus virginianus*) habitat in South Texas. We achieved this by very fine scale drone-derived imagery and using class level landscape metrics to assess vegetation cover height configuration.

Results Estimated heights from drone imagery had a significant relationship with the field height measurements in September ($r^2=0.83$; growing season) and February ($r^2=0.77$; dormant season). Growing season pasture maintained residual landscape habitat configuration adequate for bobwhites throughout the fall and winter of 2022–2023 following grazing. Dormant season pasture had an increase in bare ground cover, and a shift from many large patches of tall herbaceous cover (40–120 cm) to few large patches of low herbaceous cover (5–30 cm) ($p<0.05$).

Conclusions Drones provided high-resolution imagery that allowed us to assess the spatial and temporal changes of vertical herbaceous vegetation structure in a semi-arid rangeland subject to grazing. This study shows how drone imagery can be beneficial for wildlife conservation and management by providing insights into changes in fine-scale vegetation spatial and temporal heterogeneity from livestock grazing.

Keywords Spatial heterogeneity, Landscape metrics, Image height classification, Canopy height model, Normalized digital surface model

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Introduction

Approximately 308 million hectares (36%) of the land in the United States of America are considered rangelands. These rangelands provide habitat for the declining populations of upland gamebirds (Holechek 1981; Bureau of Land Management 1992), which hold significant ecological, economic, and cultural significance. People are drawn to these avian species for observation, hunting, or their value for ecosystems services (Warner 1992; Brennan et al. 2007, 2017, 2022). Nonetheless, over the past two centuries, the extent and quality of rangelands have experienced a steady decline (Reeves and Mitchell 2012; Cady et al. 2023). One potential reason for this decline can be attributed to the disruption of historical patterns of native grazers, which play a pivotal role in rangeland dynamics (Holechek et al. 2011; Teague and Kreuter 2020). Livestock grazing has replaced free ranging grazing patterns with significant changes in ecological processes (Luoto et al. 2003; Mysterud 2006; Weir et al. 2013). The impacts of domestic livestock overgrazing have been recognized and well documented for the last century (Sampson 1923; Fuls 1992; Mysterud 2006). However, with adequate management and forage monitoring, livestock grazing can promote habitat for upland game bird species [e.g., Rio Grande Wild Turkey (*Mealeagris gallopavo intermedia*), Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*), and Northern Bobwhite [(*Colinus virginianus*), hereafter 'bobwhite'] (Bock et al. 1984; Campbell-Kissock et al. 1984; Schulz and Guthery 1987; Hall 2005; Litton and Harwell 1995; Hernandez and Guthery 2012; Schieltz and Rubenstein 2016; Fritts et al. 2018; Gary et al. 2022).

Monitoring forage in livestock operations is critical to improve or maintain rangeland sustainability of basic soil and ecological processes that provide both livestock and wildlife habitat and ecosystem services (Herrick et al 2005). Traditionally, rangeland monitoring sampling methods have relied on ground-based techniques to collect data through direct observation and manual measurements (National Research Council 1994; Brummer et al. 1994; Stohlgren et al. 1998). While these traditional sampling methods have been widely used and provided valuable information, they are time-consuming, labor-intensive, and limited in their ability to capture large extents of the spatial and temporal dynamics of rangeland ecosystems (Booth and Tueller 2003; Tsutsumi et al. 2007; Reeves and Baggett 2014; Paltsyn et al. 2019). Technological approaches used to monitor rangelands have improved in the last 50 years, and remote sensing has provided opportunities to monitor rangelands at multiple scales (Allred et al. 2021; Rhodes et al. 2022; Schroeder et al. 2022).

Remote sensing provides a broad scale understanding of these ecosystems (Booth and Tueller 2003), and it has allowed us to map and monitor rangeland vegetation types, assess rangeland health, biomass estimation, vegetation disturbances, and spatiotemporal analyses (Pettorelli et al. 2005; Muraoka and Koizumi 2009; Zhao et al. 2012; Mata et al. 2018). For example, the Rangeland Analysis Platform provides significant information on vegetation cover and production for U.S. rangelands (Allred et al. 2021; Schroeder et al. 2022). However, satellite remote sensing is limited to the spatial and temporal resolution of the sensor platform (Woodcock and Strahler 1987; Fassnacht et al. 2006; Williamson et al. 2019). Due to the spatial and temporal dynamics of herbaceous vegetation, fine-scale changes across the landscape such as those occurring after disturbances at the pasture scale (e.g., grazing, fire, chemical, and mechanical treatments), require finer scale measurements (Marceau and Hay 1999; Fassnacht et al. 2006; Lechner et al. 2020).

New remote sensing platforms such as Planet imagery (daily imagery with 3-m resolution) have improved spatial and temporal resolution of rangeland observation (Frazier and Hemingway 2021). Drones can provide information at much finer resolution than satellite sensors and most aerial photography platforms (Ruwaimana et al. 2018; Lechner et al. 2020). At the same time, drones provide a solution to collect data at larger extents than field-based methods and with greater-resolution than traditional remote sensing (Booth and Tueller 2003; Rango et al. 2006; Laliberte et al. 2010; Perez-Luque et al. 2022). Drone imagery and remote sensing have been used in rangelands to describe and quantify landscape features (Page et al. 2022), estimate forage mass (DiMaggio et al. 2020; Page 2021; Perotto-Baldivieso et al. 2021), vegetation spatiotemporal analysis (Perez-Luque et al. 2022), rangeland health condition (Amputu et al. 2023), and to monitor wildlife species and their habitat (Hodgson et al. 2016; Mazumdar 2022; Fust and Loos 2023; Friesenhahn et al. 2023; Zabel et al. 2023). With very fine spatial resolution and significant image overlap we can use structure for motion to generate 3D vegetation cover models (Küng et al. 2011; James and Robson 2012; Díaz-Varela et al. 2015; Otero et al. 2018). The combination of 2D orthomosaic and 3D models from drone imagery can help quantify the amount and spatial distribution of vegetation cover height in the landscape (Küng et al. 2011; James and Robson 2012; Díaz-Varela et al. 2015; Cunliffe et al. 2016). The addition of spatial configuration in the vertical dimension of vegetation cover in rangelands at the landscape level has not been assessed yet, and could provide new insights to monitor larger extents of the spatial-temporal changes in herbaceous vegetation cover than current field-based vegetation monitoring techniques.

The spatial configuration of vegetation cover height can be used to assess spatial heterogeneity which is important for the distribution of resources in the landscape. Spatial heterogeneity plays in important role in wildlife demographic variability, species dispersal, as well as plant species richness, community structure, and ecosystem processes (Miller et al. 1995; Wijesinghe et al. 2005; McGranahan et al. 2012; Dubois et al. 2015; Perotto-Baldivieso 2021). In rangelands, herbivory and grazing play an important role in shaping spatial heterogeneity (Otieno et al. 2011). Changes in vegetation composition are regulated by herbivory and grazing with impacts on soil structure that feedback to plant productivity. This has a direct effect on resource availability over space and time for wildlife species and can modify abundance and presence particularly for upland game birds. Prairie chickens (*Tympanuchus pallidicinctus* and *T. cupido*), northern bobwhites and ring-necked pheasants (*Phasianus colchicus*) are economically important species that have declined in the North American Great Plains (Hernandez et al. 2013; Sauer et al. 2013; Schindler et al. 2020). Upland game birds such as the bobwhite require a grassland mosaic configuration of different herbaceous vegetation cover heights that is beneficial for roosting, traversability, and food finding during the covey season (Taylor et al. 1999; Lusk et al. 2006; Edwards et al. 2022). Previous studies have addressed herbaceous configuration for bobwhites using remote sensing imagery with pixel resolutions ranging 1–30 m (Mata 2017; Edwards et al. 2022). To our knowledge this is one of the first studies that addressed spatial configuration of bobwhite habitat at a very fine resolution.

The goal of this study was to quantify the amount and distribution of vegetation cover and vegetation cover height using high-resolution drone imagery. We assessed the spatial configuration of herbaceous cover heights through landscape metrics analyses using remotely sensed data acquired with drones. We did this as part of a study in South Texas that used an adaptive grazing management approach to improve bobwhite habitat, which consisted of adapting stocking rates throughout the grazing season to leave a residual goal forage stubble height of 30 to 40 cm. We used the northern bobwhite as a model species because of its ecological, cultural, and economic importance throughout the United States (Lehmann 1984; Burger et al. 1999; Hernandez and Guthery 2012; Brennan and Kuvlesky 2005; Brennan 2015). Our specific objectives were (1) to assess the accuracy of measuring vegetation cover height in grasses using drones, (2) to quantify the spatial distribution of vertical structure in grazed and non-grazed pastures during dormant and growing season, and (3) to evaluate the spatial distribution of vertical vegetation cover as a proxy for bobwhite habitat. We hypothesized that: (1) there is a positive relationship between vegetation cover heights estimated using drone imagery and vegetation cover heights collected in the field and (2) changes in vertical vegetation cover configuration are modified through grazing and provide access to areas of usable space for bobwhites.

Methods

Study area

The project was conducted on the Sweden Ranch in Duval County, Texas. The study area is in the South Texas Plains ecoregion (Gould et al. 1960). The study site climate is categorized as semi-arid with a mean annual rainfall of 596 mm (mean annual normal from 1992–2022, PRISM 2023), rainfall distribution throughout the year is bimodal with peak rainfall from May to June and September to October (PRISM 2023). The mean annual temperature is 22.5 °C, the mean low temperature is 16.0 °C and the mean high temperature is 28.9 °C (PRISM 2023). The main ecological sites found in this study area are gray sandy loam, loamy bottomland, sandy loam, shallow sandy loam, and shallow ridge (Web Soil Survey 2021). The main soil types from these ecological sites are fine sandy loam and sandy clay loam. The warm-season grass community growth peak occurs from March to July (65% of the annual production) and a second smaller production peak during August to October (25% of the annual production) (Web Soil Survey 2021). The two peak growing season periods that elapse from March to October will be denoted as the growing season with 90% of the total annual production, while November to February will be denoted as the dormant season with 10% of the total annual production (Web Soil Survey 2021). The most common grasses on these ecological sites are four-flower trichloris (*Trichloris pluriflora*, hereafter 'trichloris'), buffelgrass (*Pennisetum ciliare* L.), tanglehead (*Heteropogon contortus* L. Beauv. ex Roem. & Schult), plains bristlegrass (*Setaria leucopila* (Scribn. & Merr.) K. Schum), Arizona cottontop (*Digitaria californica* (Benth.) Henr.), and silver bluestem (*Bothriochloa laguroides* (DC) Herter). The main forbs in this community are awnless bush sunflower (*Simsia calva* (Engelm. & A. Gray) A. Gray), orange zexmenia (*Wedelia texana* (A. Gray) B.L. Turner), daleas (*Daleas* spp.), American snoutbean (*Rhynchosia americana* (Houst. ex Mill.) M.C. Metz), and bundleflowers (*Desmanthus* spp.). Woody plant species composition is mostly composed of honey mesquite (*Prosopis glandulosa* Torr.), granjeno (*Celtis ehrenbergiana* (Klotzsch) Liebm.), guajillo (*Senegalia berlandieri* Britton & Rose), cenizo

(*Leucophyllum frutescens* (Berl.) I.M. Jonst.), wolfberry (*Lycium berlandieri* Dunal), blackbrush acacia (*Vachellia rigidula* (Benth.) Seigler and Ebinger) and lime prickly ash (*Zanthoxylum fagara* (L.) Sarg.) (Web Soil Survey 2021).

The study site is comprised of two adjacent fenced pastures that are divided by a single fence line totaling 1790 hectares (Fig. 1). We used an adaptive grazing management approach (Derner et al. 2022). Our specific approach focused on forage cover structure as our most important outcome. Our primary focus was not to test stocking rate, number of grazing days, and/or pasture size. With our approach we focused on monitoring forage cover structure throughout the grazing period and move cattle to a different pasture once the forage outcomes have been met. For this research, the target was to achieve a forage stubble height of grasses around 30 cm to improve wildlife habitat, more specifically northern bobwhite habitat (Schulz and Guthery 1988; Hernandez et al. 2007). The grazing height goal of 30 to 40 cm included a 5 cm buffer to match the 25–30 cm cover height recommended for bobwhites. One pasture of 960 hectares had been previously grazed from 2020 to 2022 during the predominant growing season (May to October) (hereafter 'growing season pasture'). The growing season pasture has been grazed following the adaptive grazing management principles and had already met the criteria for northern bobwhite habitat in terms of forage cover structure and distribution. The second pasture of 830 hectares had not been

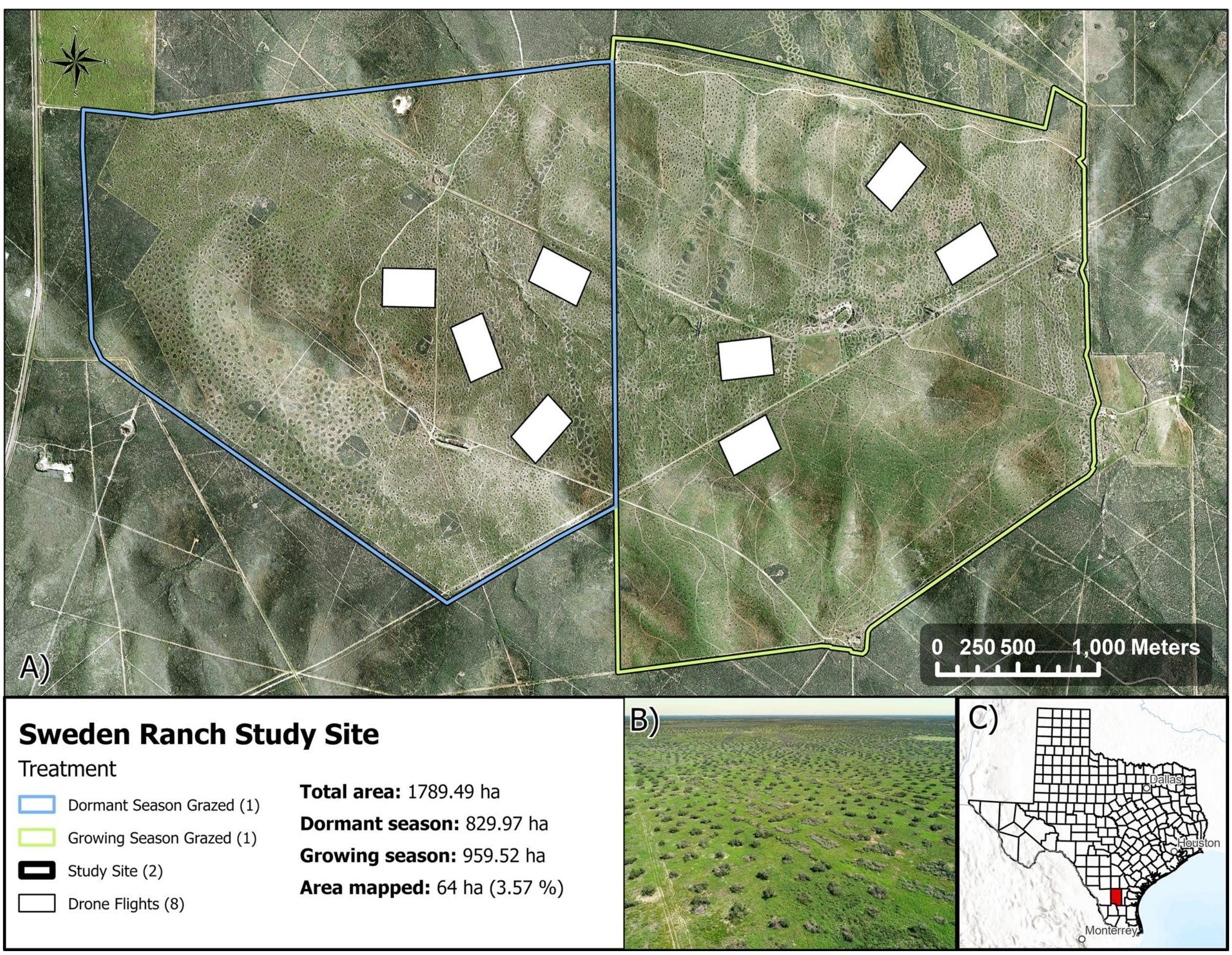

Fig. 1 Study area in Duval County, Texas. **A** The two pastures flown are separated outlined in green (growing season pasture) and outlined in blue (dormant season pasture). White squares are the drone flight plots. Aerial imagery is from the United States Department of Agriculture (USDA), Texas National Agriculture Imagery Program (NAIP), 2020-04-01 in RGB color with a pixel spatial resolution of 60 cm (0.6 m) overlayed with a digital elevation model (DEM) from the United States Geological Survey (USGS), South Texas Lidar, 2018-02-23, with a spatial resolution of 1 m. **B** Oblique aerial photograph of the study site captured with DJI Phantom 4 RTK drone. **C** The inset provides the location of the Sweden Ranch study site within Duval County in the state of Texas. The map was generated in ArcPro 2.9.5 (www.esri.com)

previously grazed prior to 2022 and was grazed during the dormant season (November to February) of 2022–2023 (hereafter 'dormant season pasture'). In May of 2022, 400 cows (*Bos taurus*) with an average weight of 545 kg (1.86 ha AU^{-1}) were introduced into the growing season pasture. When the target forage stubble height of 30 to 40 cm was met, cattle were transferred from the growing season pasture into the dormant season pasture in November of 2022 (1.61 ha AU^{-1}). At the time of transfer, the 400 mother cows had been in the growing season pasture for 173 days (May to October 2022), and by the end of the study, the cows had been present in the dormant season pasture for 94 days (November 2022–February 2023).

Due to the size of the pasture, grazing distribution is often uneven (Hart et al. 1993), we addressed and influenced cattle grazing distribution by rotating the access to water sources and minerals (mineral tubs) throughout the pasture (Bailey et al. 1996, 1998). Water trough valves were shut off and on, and ponds would be fenced in to disable or give cattle access to the water source and forced to locate to a different location in the pasture (Bailey 2004).

Data collection

We acquired drone imagery for eight plots of eight ha each (four plots/treatment) in September 2022 and repeated the flights in February 2023 for a total of 16 flights (Fig. 2). In September 2022, we flew when the growing season pasture had been grazed for 173 days and the dormant season pasture was not grazed. In February 2023, we flew when the dormant season pasture had been grazed for 94 days after cattle was moved from the growing season pasture to the dormant season pasture (Fig. 1).

We used a DJI enterprise Phantom 4 Real-Time Kinematics (RTK) drone (SZ DJI Technology Co. Shenzhen, China) to collect red, green, blue (RGB) imagery (Table 1). The drone is a quadcopter weighing 1.39 kg at takeoff including a battery and camera sensor with an approximate flight time of 22 min per battery. The drone platform includes a RTK enabled

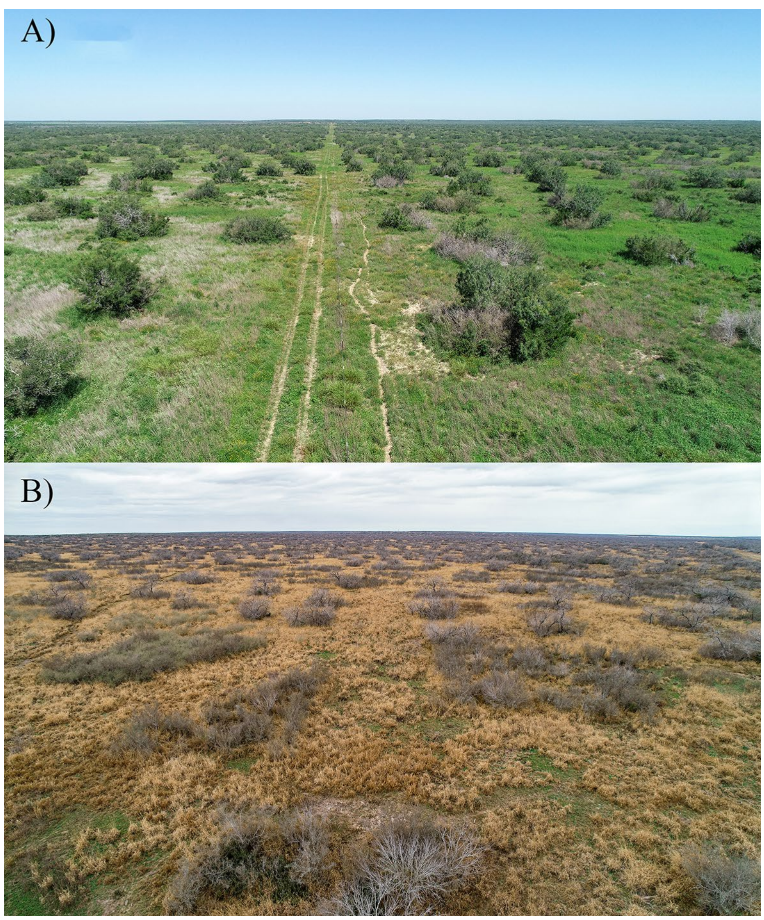

Fig. 2 Oblique (~ 35°) drone images captured of the general area of the study site in September 2022 (**A**) and February 2023 (**B**)

Table 1 Drone, flight, and image acquisition specifications for the data collected during September 2022 and February 2023, table format followed Gillan et al. (2021) to continue standardization of flight mission and data acquisition specifications

Category	Specification
Aircraft	DJI Phantom 4 RTK
Sensor	2.5 cm CMOS sensor; 20 mp; Global shutter
Aperture and shutter	Automatic
Image format	JPEG
Acquisition pattern	Single grid; 70° oblique
Image forward and side overlap	80%
Flying height	50 m; Terrain follow
Flying time/mission	~24 min
Ground sampling distance (m)	0.0248
Images per flight	580–640
Images per hectare	~76
Total area imaged	64 ha (×2 flight periods = 128)
No. flying days	< 2 days per flight period

Global Navigation Satellite System (GNSS) system which connects to a DJI RTK base station during flights. RTK uses dynamic differential technology to provide centimeter positioning (1.2 cm relative horizontal accuracy). We captured images using a natural color (RGB) 2.5 cm Complementary Metal-Oxide Semiconductor (CMOS) sensor of 20 MP, which produced a JPEG image with 3:2 ratio and 5472 × 3648 size. Flight missions were 8-ha rectangular-shaped grids that were flown at a set altitude of 50 m above ground level (AGL) (DiMaggio et al. 2020; Page 2021). The flights were a single grid pattern with an 80% vertical and horizontal overlap. The camera was stabilized with an onboard gimbal and set to capture images at a 70° angle during flight with auto-focus enabled (Table 1). The drone was always kept within line of sight and had a minimum of 1 visual observer at each flight mission.

Image processing

After images were acquired, we used structure-from-motion (SfM) and Pix4D Mapper software (Pix4D Inc., San Francisco, CA, USA) to stitch overlapping images captured from the drone to create 2D orthomosaic, 3D photogrammetric mesh, and 3D point cloud dataset models (Cunliffe et al. 2016; Sanz-Ablanedo et al. 2018). We processed digital surface models (DSM) and digital terrain models (DTM) using structured algorithms within Pix4D. The DSM raster pixel data obtains the height of each pixel including the elevation (m) of the terrain, and the DTM raster pixel data obtains the elevation of the terrain. We used raster calculator in ArcGIS® Pro (v. 2.9; ESRI, Redlands, CA, USA) to model vegetation height by subtracting the DTM from the DSM and created a canopy height model (CHM) that generates an output raster with the vegetation height in cm (Gillan et al. 2020). Pixel resolution from the CHM of herbaceous vegetation using drone imagery ranged from 11.91 to 12.70 cm.

Height data validation

Before conducting the drone flights, we measured field herbaceous plant height to validate the height data from the drone imagery. We used a similar approach to Forsmoo et al. (2018) to measure sward height. We walked throughout the plots selecting random points in herbaceous cover and measured plant heights to the nearest centimeter using a combination of the sward stick and the drop disc method (Stewart et al. 2001). We ensured that a variety of vegetation heights were collected as we selected the random locations. We collected 100 GPS point locations measured with a Geode GNSS Receiver (60 cm horizontal accuracy) (Juniper Systems, Logan, Utah) per pasture during each flight period, totaling 198 locations (The data from two locations were not stored correctly) for September 2022 and 200 locations for February 2023. For each point we spray-painted the point orange to later georeference the points in the orthomosaic drone imagery. We downloaded all GPS points captured in the field, georeferenced, and located the spray-painted points on the orthomosaic imagery. We generated a 20 cm buffer on the points to capture the circumference measured at the field and clipped the CHM raster. For each point we calculated the average value of pixel height (Forsmoo et al. 2018). To assess the degree of relationship between these two variables, we regressed the CHM average pixel height values to field heights using simple linear regression ($\alpha = 0.05$) (Wester 2019) in NCSS software v. 22.0.5 (NCSS Statistical Software, Kaysville, Utah).

Image classification

We classified the CHM raster pixel values into five different height classes: bare ground (0 to < 5 cm), low herbaceous vegetation (5 to < 30 cm), grazing target height herbaceous vegetation (30 to < 40 cm), tall herbaceous vegetation (40 to < 120 cm), and brush and shrubs (> 120 cm) (Figs. 3 and 4). Classes were selected based on previous bobwhite habitat use research (Spears et al. 1993; Guthery 2002; Hernandez et al. 2007; Hernandez and Guthery 2012). We classified brush and shrub cover over 120 cm because the tallest height of herbaceous vegetation did not exceed 120 cm and we excluded it from the analysis.

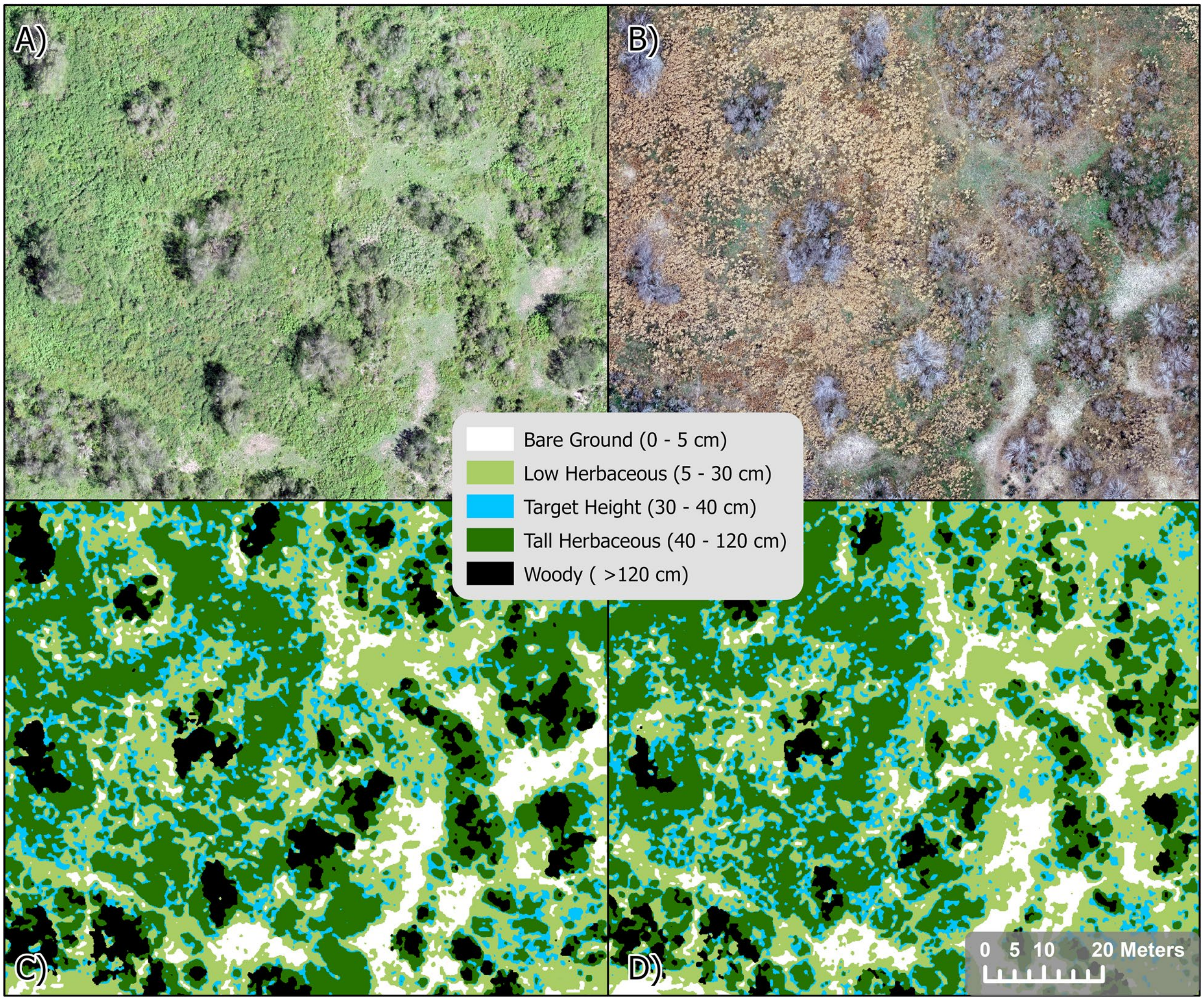

Fig. 3 Drone-based imagery collected using a DJI Phantom 4 RTK. Natural color (RGB) orthomosaic from the growing season pasture in September 2022 (**A**) and February 2023 (**B**). Classified canopy height (cm) model from the growing season pasture in September 2022 (**C**) and February 2023 (**D**)

Landscape metrics and statistical analysis

We used the classified CHM raster to quantify the amount and spatial distribution of the different vegetation height classes in Fragstats v.4.2 (McGarigal et al. 2023) using class-level landscape metrics. We calculated percent land cover (PLAND, %), patch density (PD, number of patches per unit area), and mean patch area (MPA, ha) (McGarigal et al. 2023). These landscape metrics were chosen because they have been used to characterize suitable habitat areas for bobwhite (Masters et al. 2009; Unger et al. 2015; Parent et al. 2016; Brooke et al. 2017; Mata 2017; Miller et al. 2019; Stewart 2020; McGarigal et al. 2023). Areas of high suitability for bobwhites require less than 39% of dense tall vegetation with small patches (low mean patch area and high patch density) and open areas to move across the landscape. Mata (2017) and Edwards et al. (2022) have shown that monocultures of invasive grasses (> 21% monoculture cover) can be detrimental to bobwhite habitat and grass diversity provides better areas for bobwhites. We analyzed each pasture between September and February separately with an Analysis of Variance (ANOVA) with Python programming language (Python Software Foundation, https://www.python.org/) in Google Colaboratory (Google Colaboratory, Mountainview, CA, USA) to examine the differences in PLAND, PD, and MPA between flights. We then repeated the ANOVA analysis and compared the pastures in September and then in February separately to look at the differences between pastures in each period. Treatments in this study were not

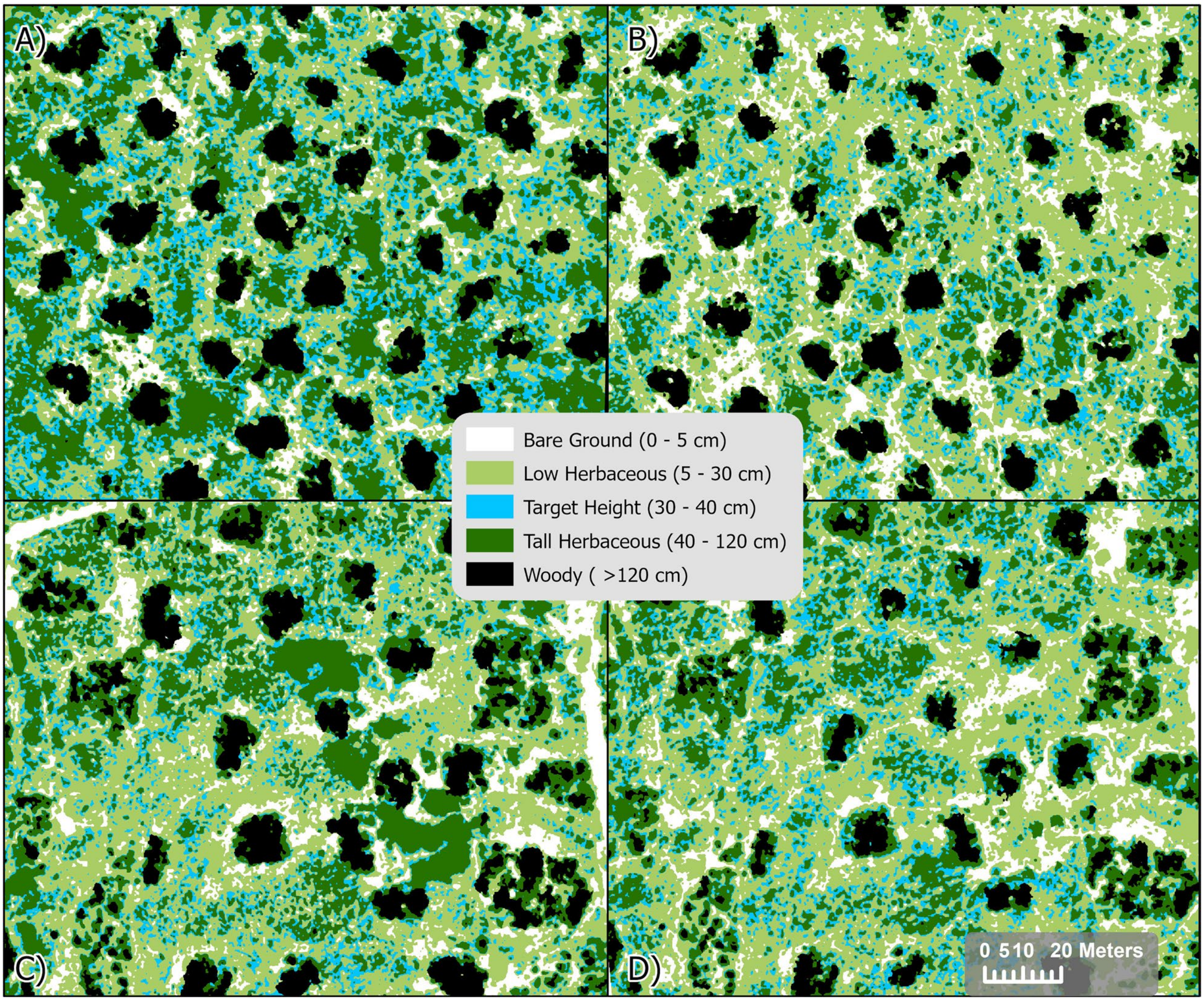

Fig. 4 Classified canopy height model from the dormant season pasture in September 2022 (**A**) and February 2023 (**B**). Classified canopy height model from the growing season pasture in September 2022 (**C**) and February 2023 (**D**)

replicated; it is often not feasible to allow replication of treatments at broad pasture scale following similar management techniques (Wester 1992).

Results

Herbaceous vegetation height from CHM had a positive relationship with the field height measurements in September and February; the coefficient of determination from the simple linear regression was $r^2=0.83$ ($p<0.05$) for the September flights, and an $r^2=0.77$ ($p<0.05$) for the February flights (Fig. 5).

We did not observe any statistically significant differences in PLAND, PD, and MPA from all vegetation height cover classes in the growing season pasture between September and February (Table 2; Fig. 6). However, significant changes ($p<0.05$) were observed in the dormant season pasture between the two time periods (Table 2; Fig. 6). Bare ground PLAND values increased from September ($\bar{x}=7.4\%$; SE = 0.91) to February ($\bar{x}=11\%$; SE = 0.91). Low herbaceous height PLAND increased from September ($\bar{x}=32.6\%$; SE = 3.13) to February ($\bar{x}=59.31\%$; SE = 3.13). PD decreased in low herbaceous height class from September ($\bar{x}=405.2$ patches ha^{-1}; SE = 55.2) to February ($\bar{x}=199.8$ patches ha^{-1}; SE = 55.2). The values of MPA were significantly smaller ($p<0.05$) in September ($\bar{x}=8$ m^2; SE = 2.62) than in February ($\bar{x}=32.75$ m^2; SE = 2.62). Target herbaceous height PLAND showed a decrease from September ($\bar{x}=15.3\%$; SE = 1.7) to February ($\bar{x}=8.8\%$; SE = 1.7). There was a significant decrease in tall herbaceous height class cover from September ($\bar{x}=32.2\%$; SE = 3.29) to February ($\bar{x}=11.7\%$; SE = 3.29). While the values of PD did not change for the tall herbaceous cover class, their mean patch size significantly decreased from September

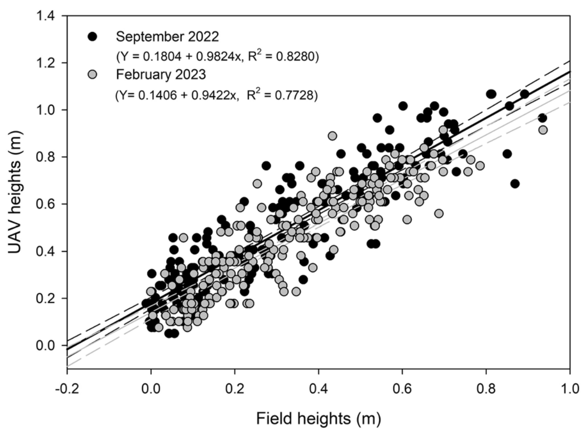

Fig. 5 Scatterplot and linear regression for drone heights and field heights for September 2022 (growing season; black dots) and February 2023 (dormant season; gray dots). The regression lines and 95% confidence intervals are continuous lines for September 2022 and dashed black lines for February 2023. NCSS software v. 22.0.5 (NCSS Statistical Software, Kaysville, Utah)

($\bar{x}$ = 5.00 m^2; SE = 0.81) to February ($\bar{x}$ = 1.75 m^2; SE = 0.81) (Table 2).

The values of PLAND for the target height class from the dormant season pasture ($\bar{x}$ = 15.3%; SE = 1.70) was significantly greater than that from the growing season pasture ($\bar{x}$ = 10.7%; SE = 1.70) (Table 2) in September 2022. The tall herbaceous PD in the dormant season pasture ($\bar{x}$ = 641.4 patches ha^{-1}; SE = 40.1) was greater than that in the growing season pasture ($\bar{x}$ = 576.0 patches ha^{-1}; SE = 40.1). The values of PLAND, PD, and MPA of bare ground and low herbaceous; PD and MPA of target height; and PLAND and MPA of tall herbaceous between dormant and growing season pastures did not show any differences in September 2022 (Table 2).

The PLAND values for the low herbaceous class in the dormant season pasture ($\bar{x}$ = 59.31%; SE = 3.13) was greater than that in the growing season pasture ($\bar{x}$ = 41.44%; SE = 3.13) in February 2023 (Table 2). Tall herbaceous PLAND was lower in the dormant season pasture ($\bar{x}$ = 11.7%; SE = 3.29) than that in the growing season pasture ($\bar{x}$ = 28.9%; SE = 3.29) (Table 2). The low herbaceous MPA in the dormant season pasture ($\bar{x}$ = 32.75 m^2; SE = 2.64) was greater than that in the growing season pasture ($\bar{x}$ = 13 m^2; SE = 2.64) (Table 2). Finally, the tall herbaceous MPA in the dormant season pasture ($\bar{x}$ = 1.75 m^2; SE = 0.81) was lower than that in the growing season pasture ($\bar{x}$ = 5 m^2; SE = 0.81) (Table 2). The values of PLAND, PD, and MPA of bare ground; PD of low herbaceous; PLAND, PD, and MPA of target height; and PD and MPA of tall herbaceous between dormant and growing season pastures from February 2023 did not show any differences (Table 2).

The increase of bare ground, low herbaceous, and target height cover areas in the dormant season are within the ranges of desired herbaceous vegetation cover reported for the species. The decrease of tall herbaceous vegetation cover, its increase in patch density, and decrease in mean patch area in the dormant season pasture (Fig. 6) showed increasing areas of the other herbaceous vegetation cover (Table 2). This indicates more open areas between patches of tall herbaceous vegetation cover (Fig. 2) that favor bobwhite habitat vegetation structure.

Discussion

Drones provided high-resolution imagery to assess the spatial and temporal changes of vegetation cover height in a grazed semi-arid South Texas pasture. The relationship between field herbaceous vegetation heights and CHM heights from September (r^2 = 0.83) and February (r^2 = 0.77) provided reliable estimates of herbaceous vegetation height (Fig. 5). These results supported our hypothesis of a positive relationship between field and drone-based data when estimating herbaceous heights. These results are consistent with previous studies on honey mesquite (*Prosopis glandulosa*) (r^2 = 0.95, Page et al. 2022), rangeland plants (r^2 = 0.78, Gillan et al. 2019), and hayfield forage height (r^2 = 0.78, Batistoti et al. 2019, r^2 = 0.80 to 0.96, Massey 2023). Our herbaceous vegetation height estimates using drones provide a robust framework to classify herbaceous vegetation into height classes that are relevant to livestock management and proxies for wildlife habitat. These classified datasets can be used to quantify the spatial configuration of the different herbaceous vegetation height classes and can be used to assess wildlife habitat at finer scales (Wheatley 2010; Bissonette 2012).

The use of landscape metrics to quantify changes in configuration of herbaceous vegetation cover height supported our hypothesis that grazing modifies the amount and spatial distribution of vegetation cover height and provides areas of usable space for bobwhites. Landscape metrics have been used to assess the relationship of wildlife species and their habitat preferences, mainly to perform habitat analysis (Schairer et al. 1999; Masters et al. 2009; Uuemaa et al. 2009), landscape patterns and changes (Perotto-Baldivieso et al. 2011; Rho et al. 2015), management (Perotto-Baldivieso 2021), and monitoring at broad scales (Roseberry and Sudkamp 1998; Holt et al. 2009; Miller et al. 2019; Smith et al. 2022). Several studies utilized landscape metrics to identify suitable areas for bobwhites over large extents and pixel resolutions ranging from 1 to 30 m (Roseberry and Sudkamp 1998; Parent et al. 2016; Miller et al. 2019). The use of fine-scale data (11.91 to 12.70 cm pixel resolution) to assess landscape configuration brings a

Table 2 Means and standard errors from analysis of variance for all landscape metrics between seasons of grazing and drone flights

	Percent land cover (%)			ANOVA ($F_{1,6}$)	Patch density (patches ha^{-1})			ANOVA ($F_{1,6}$)	Mean patch area (m^2)			ANOVA ($F_{1,6}$)
	September	February			September	February			September	February		
	$\overline{X}$	$\overline{X}$	SE		$\overline{X}$	$\overline{X}$	SE		$\overline{X}$	$\overline{X}$	SE	
Bare ground (0–5 cm)												
Dormant	7.4	11.0	0.91	**$P = 0.005$**	420.4	459.7	35.7	$P = 0.403$	2.0	2.5	0.45	$P = 0.134$
Growing	10.8	10.3	0.91	$P = 0.871$	354.6	368.3	35.7	$P = 0.816$	3.5	2.75	0.45	$P = 0.477$
Low herbaceous (5–30 cm)												
Dormant	32.6	59.31	3.13	**$P < 0.001$**	405.2	199.8	55.2	**$P = 0.002$**	8.00	32.75	2.62	**$P = 0.012$**
Growing	30.7	41.44	3.13	$P = 0.071$	416.8	373.6	55.2	$P = 0.722$	8.25	13.00	2.62	$P = 0.178$
		$P = 0.017$								**$P = 0.039$**		
Target height (30–40 cm)												
Dormant	15.3	8.8	1.70	**$P = 0.036$**	1,618.1	1,698.1	193	$P = 0.672$	1.25	0.50	0.21	$P = 0.097$
Growing	10.7	12.5	1.70	$P = 0.493$	2,167.9	1,930.4	193	$P = 0.600$	0.75	0.75	0.21	$P = 1.0$
	$P = 0.040$											
Tall herbaceous (40–120 cm)												
Dormant	32.2	11.7	3.29	**$P < 0.001$**	641.4	696.54	40.1	$P = 0.406$	5.00	1.75	0.81	**$P < 0.001$**
Growing	37.5	28.9	3.29	$P = 0.219$	481.6	576.0	40.1	$P = 0.111$	8.25	5.00	0.81	$P = 0.128$
		$P = 0.006$			**$P = 0.016$**					**$P = 0.005$**		

Horizontal p values are for the ANOVA between dates, and vertical for the ANOVA between pastures. Data captured from September 2022 to February 2023 at the Sweden Ranch, Duval County, Texas

Bold values denote statistical differences ($p < 0.05$)

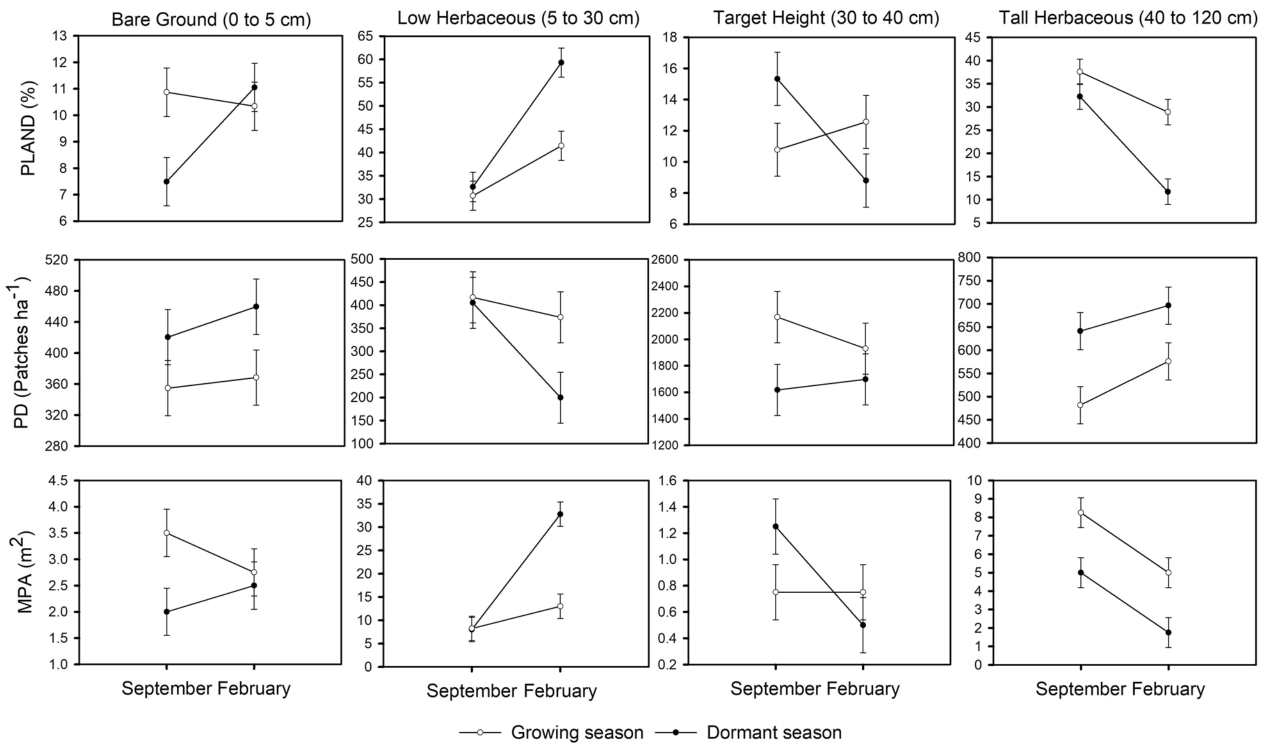

Fig. 6 Amount and spatial distribution of herbaceous vegetation cover height during the growing season pasture (growing season) and dormant season pasture (dormant season) in September 2022 and February 2023. Landscape metrics used for these analyses are: percent land cover, patch density, and mean patch area

new level of understanding of how vegetation structure can be used to assess wildlife habitat (Faye et al. 2016; Feagin et al. 2020; Chen et al. 2022). For example, Rutten et al. (2018) and Friesenhahn et al. (2023) used fine-scale data from drones to assess field crop damage caused by wild pigs (*Sus scrofa*). In addition, Wirsing et al. (2022) proposed that the use of drones can advance the understanding of wildlife habitat and distribution with fine-scale spatiotemporal data. This supports the idea proposed by Guthery (1997) that good understanding of landscape configuration can improve management efforts in areas that are potentially suitable for specific target wildlife species.

Grazing during the growing season and removing cattle during the dormant season can have a residual effect in the landscape structure that can be beneficial to wildlife in South Texas. Our results show that the growing season pasture did not have significant changes in composition and configuration of herbaceous cover between September (growing season) and February (dormant season) (Table 2). This residual configuration provides a grassland mosaic of different herbaceous vegetation cover heights that is beneficial for roosting, traversability, and food finding during the covey season (Taylor et al. 1999; Lusk et al. 2006; Edwards et al. 2022). Following grazing in the growing season allows bobwhites to use the pasture and benefit from the residual landscape configuration that remained throughout the dormant season, that otherwise would have not been available for bobwhites during the nesting and brooding season. However, we did not observe an increase in the target height cover, patch density, or decreased mean patch area in the dormant season pasture as expected. These changes in landscape configuration improved habitat conditions for bobwhites by providing different vegetation cover heights that allow them to use areas for escape cover, thermal regulation, brooding cover, and loafing cover (Guthery 1997, 1999; Cooper et al. 2020).

Changes in the dormant season pasture following grazing show that vegetation structure can also be changed during the dormant season. The dormant season pasture had not been grazed for 6 years prior to cattle being introduced. After 94 days of grazing, significant changes were observed including an increase in PLAND of bare ground, decrease in PLAND and MPA of tall herbaceous height class. By using the same stocking density used in the growing season pasture, we expected to observe in the dormant season pasture a decrease in tall herbaceous cover to shift into the target height class. However, forage utilization was greater during the dormant season pasture. During the dormant season, grasses are not actively growing (November to March, in our study site), therefore, forage utilization may be more sensitive to the grazing intensity if stocking rates are not adjusted to the forage supply and phenological stage of grasses (Ortega-Ochoa et al. 2008; Fulbright and Ortega-Santos 2013; Wyffels et al. 2019; Montalvo et al. 2020) (Fig. 2). However, changes in landscape structure could potentially provide an improvement of bobwhite habitat and increase of bobwhite densities. Based on our findings, we recommend the use of drones to assess fine-scale vegetation configuration based on heights for other upland gamebirds species in the Great Plains. The information obtained from drones can provide near real-time monitoring to evaluate changes in vegetation cover configuration and spatial heterogeneity to assess wildlife habitat and grazing objectives at the pasture scale.

Conclusions

Drones provided high-resolution data in 2D and 3D that can be used to assess the spatial and temporal fine-scale structure of vegetation height composition and configuration in a grazing system in South Texas. This study shows how the combination of drone imagery and landscape metrics combined with field results can provide evidence of the effect of grazing on bobwhite habitat. Our study shows that our approaches could be applied to other interactions between wildlife and domestic livestock by assessing very fine-scale spatial and temporal vegetation cover heterogeneity. The residual effect of grazing in a South Texas pasture shows that changes in landscape structure go beyond the grazing period which can be beneficial to wildlife species using these areas. Future applications of these approaches combined with broader-scale remote sensing could provide opportunities to understand the dynamics between livestock and wildlife and adjust management practices to maintain or enhance rangeland ecological functions and ecosystem services.

Abbreviations

AGL	Above ground level
ANOVA	Analysis of variance
CHM	Canopy height model
DSM	Digital surface model
DTM	Digital terrain model
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MPA	Mean patch area
PD	Patch density
PLAND	Percent land cover
RGB	Red–green–blue imagery
RTK	Real-Time Kinematics

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Author contributions

All authors made substantial contributions to the conception, design, and acquisition of data, and made significant contributions to the analysis and interpretation of the data. All authors were involved in drafting the manuscript and revising it critically for important intellectual content. HLP-B, JSA-S, JAO-S, LAB, FH, and LDM have given final approval of the version to be published; they take public responsibility for appropriate portions of the content; and they have agreed to be accountable for all aspects of the work in ensuring that questions associated with the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Availability of data and materials

Please contact the authors for data requests.

Declarations

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Competing interests

The authors declare that they have no competing interests.

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