Method Article

The use of UAV-based remote sensing to estimate biomass and carbon stock for native desert shrubs

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Abstract

Unmanned Aerial Vehicles (UAVs) have started to receive more attention in the ecological field in the past 15 years, as they provide very high-resolution imagery that ranges from meters to millimeters. Very high-resolution multispectral imagery obtained from UAVs can help in assessing and monitoring native desert vegetation. Thus, this study use UAVs to develop a method to estimate the biomass and carbon stock of native desert shrubs. The method integrates different techniques and software to monitor native plants’ coverage, biomass, and carbon stock. The techniques used in this work are also applicable for other native desert shrubs in the region and could support ecosystem managers in assessing and monitoring arid ecosystems and restoration and revegetation programs. A three-stage image and data management are discussed, including: (1) fieldwork and image acquisition using UAVs, (2) image pre-processing, and (3) image processing using different techniques and software.

• Determining shrub biomass is not restricted to multispectral data only but could be applicable for RGB data since it mainly depends on the DSM and DTM.
• Allometric parameters could help in estimating desert shrub biomass which could be measured easily and rapidly using UAV imagery.
• SVM Supervised classification could help in distinguishing between native shrubs and grasses.

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Specifications table

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| More specific subject area: | Monitoring native desert plants using UAVs |
| Method name: | UAV image processing to estimate desert shrubs biomass and carbon stock |
| Name and reference of original method and Resource availability: | Estimating desert shrub biomass and carbon stock Brown, G. (2003) Species richness, diversity and biomass production of desert annuals in an ungrazed Rhanterium epapposum community over three growth seasons in Kuwait. Plant Ecology, 165, 53-68. Rundel, P.W. & Nobel, P.S. (1991) Structure and function in desert root systems. Plant root growth: an ecological perspective. Blackwell Scientific Publications, Oxford. Ludwig, J.A., Reynolds, J.F. & Whitson, P.D. (1975) Size-biomass relationships of several Chihuahuan desert shrubs. American Midland Naturalist, 451-461. IPCC (2006) 2006 IPCC guidelines for national greenhouse gas inventories. Agriculture, Forestry and Other Land Use, Chapter 4, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan. UNDP (2014) Grassland Carbon Stock Calculation and Preparation of Water Balance Model for Vashlovani Protected Areas. United Nations Development Programme. UAVs (Drones) and classification Agudo, P.U., Pajas, J.A., Pérez-Cabello, F., Redón, J.V. & Lebrón, B.E. (2018) The potential of drones and sensors to enhance detection of archaeological cropmarks: A comparative study between multi-spectral and thermal imagery. Drones, 2, 29. Mavroforakis, M.E. & Theodoridis, S. (2006) A geometric approach to support vector machine (SVM) classification. IEEE transactions on neural networks, 17, 671-682. |

Method details

The presented methodology in this paper integrates field base experiment and spatial analysis using UAV-based remote sensing and GIS to estimate biomass and carbon stock of native desert shrub. Fig. 1 presents a flow chart summarizing the main steps of estimating biomass and carbon stock of native desert shrubs.

Image data acquisition

UAV Platform

This study used Parrot Disco-Pro AG (ready to fly kit) fixed-wing UAV, accompanied by Parrot Sequoia multispectral sensor. The sensor contains multispectral bands including Green (550 BP 40), Red (660 BP 40), Red Edge (735 BP 10), and Near-infrared (790 BP 40), as well as the sunshine sensors (Fig. 2) [14] to collect the imagery data. The UAV size is 1150 × 580 × 120 mm (45 × 22 × 5 in) with a wingspan of 1150 mm (45 in). The UAV covers 80 ha (200 ac) in a single flight at a flight altitude of 120 m (400 ft) [13]. The multispectral bands were used to generate the NDVI layer, which helps analyze the vegetation by capturing the amount of light they absorb and reflect. The sensor's ground resolution is 11.3 cm/px at 120 m flight altitude [14]. Decreasing the flight altitude will provide better resolution, but the flight time will increase, which might require extra-flights.
Image data collection and processing

Image data collection

In this work, we examined ground resolution of 7.2 cm/px at 80 m flight altitude for our experiment on 20th of January 2019 at 9:30 AM using automatic flight plan using the Pix4Dcapture mobile application (www.pix4d.com). RGB and multispectral bands, including Green, Red, Red Edge, and Near-infrared, were captured from the study area. One flight was implemented to cover the study areas (a total area of 1 km$^2$). Around 2400 images were captured during the flight to cover the entire area with 80% imagery overlap. A high overlap percentage is recommended to prevent any corrupted images affected by the wind speed, especially for fixed-wing UAVs. They are more sensitive to wind speed than the multirotor UAVs, which have better wind resistance. All captured images were georeferenced and radiometrically corrected, and mosaicked using the Pix4Dmapper software (version 4.3).
Image classification

The Normalized Difference Vegetation Index (NDVI) was utilized to distinguish between healthy vegetation and bare ground. NDVI is widely used in monitoring and assessing vegetation coverage and distribution. The index can separate green vegetation from its background soil brightness and is identified as the difference between the Near-Infrared (NIR) and the Red (RED) bands normalized by the sum of those bands [10], as shown in the following equation:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}$$

Afterword, the ENVI software was used to stack the generated multispectral bands and the NDVI layer, and the training regions of interest (ROIs) were defined from the stacked layer for three major classes of interest, including (1) shrubs, (2) grasses, and (3) bare ground. The NDVI was utilized to select the ROIs, as the NDVI helps identify healthy green vegetation. The Support Vector Machine (SVM) classifier in ENVI was then used to classify the image due to its high accuracy in detecting desert vegetation in previous works [1,3,18]. The SVM classifier is a binary machine-learning algorithm that classifies pixels by locating the optimal statistical boundaries between classes [7].

Shrub maximum height analysis

The major step in estimating native desert shrub maximum height using 2D imagery is by subtracting the Digital Surface Model (DSM) from the Digital Terrain Model (DTM). Therefore, the Pix4Dmapper was used to generate the DSM and DTM and the spectral bands for the UAV image. The processing steps included aligning images, building a dense point cloud, building a 3D mesh, and building a field geometry. The DSM layer represents the height of all objectives in the image, including shrubs, fences, buildings, and ground. However, the DTM represents the ground elevation used to separate the vegetation heights from the ground elevation. The shrub classified class generated in the classification section (Section 2.4.3) was then extracted from the DSM to determine the surface height of the shrub class using GIS-ArcMap. The DSM for the shrub layer was then subtracted by the DTM to determine the shrub height.
Shrub heights model validation

A field experiment was designed to quantitatively measure the heights of the *Rhanterium* shrubs in the field to validate the accuracy and reliability of the estimated plant maximum heights using UAV imagery. The maximum shrub height refers to the main stem's length above the ground surface to the maximum plant height. In this work, 70 *Rhanterium* shrub sample points were selected randomly using the very high-resolution UAV image in ArcMap. The sample points were then transferred to the ArcPad GPS to ground truth each point using a measuring tape to record each selected sample's maximum height. The results of the estimated shrub heights were then compared with the ground-truthing points measured in the field. The regression analysis test, which includes the coefficient of determination ($R^2$), and Root Mean Square Error (RMSE), was implemented using JMP statistical software (version 13.0) to validate the results. The results illustrated a reasonable correlation between the estimated shrub heights and the ground-truth measurements ($R^2 = 0.66$, $p$-value $<0.01$).

Estimation of above ground biomass (AGB)

In this study, AGB for *Rhanterium epapposum* shrub was determined based on an actual field experiment and laboratory analysis accomplished by [4], as shown in Eq. (1). He used a 1 x 3 m quadrats for the same type of plant community in Kuwait during the growing seasons (winter/spring) in three years (1997, 1998, 2000). In our work, we implemented the same experiment using the spatial analysis tools in ArcMap software (10.5) by developing a grid map for the entire study area using the fishnet method with the same size of the plot dimension (1 x 3 m) used by [4]. These plots were then used to estimate shrub coverage (%) was calculated for each plot (quadrate), as shown in Fig. 3. Next, coverage (%) of 76 shrubs were selected randomly and used to estimate the AGB was estimated according to the following equation:

$$AGB = 1.169 \times VC$$

where AGB: Above Ground Biomass (g/m2) and VC: estimated vegetation coverage (%)
Define the allometric parameters influencing AGB

At this stage of the work, we investigated the influence of allometric parameters on the AGB of desert shrubs. Regression analysis was used to develop a model to determine the relationship between the allometric parameters and AGB. The following allometric parameters were investigated in this study, including the crown area (CA) [6], vegetation heights (VH), and Shrub Volume (SV) [9]. The parameters were then measured for the 76 shrub samples using ArcMap software before implementing them in the allometric equations. We used the following equations to calculate the CA and SV (Fig. 4).

\[ CA = R1 \times R2 \times \pi \]  
where CA: crown area (m²), R1: radius of the longest crown diameter (m), R2: radius of the crown diameter perpendicular to R1 (m) and \( \pi \): 3.14.

\[ SV = \frac{4}{3} \pi a^2 b \]  
where SV: shrub volume (m³), a: shrub radius (m), b: shrub height (m) and \( \pi \): 3.14

However, we used the shrub heights, which were generated in the previous section. Finally, the regression analysis was implemented to determine the relationship between the AGB and the three examined allometric parameters using the JMP statistical software (Version 11, SAS Institute Inc.). We found that the obtained AGB were significantly correlated with the allometric parameters, including the CA \( (R^2 = 0.81) \), SV \( (R^2 = 0.74) \), however, the SH showed a lower correlation \( (R^2 = 0.24) \) (Fig. 5).

Estimation of below ground biomass (BGB)

Root extraction is the traditional method of estimating BGB, which is considered a destructive method as it impacts the uprooting of shrubs and disturbs soils. It is also costly, especially when implemented in a large-scale landscape. Thus, we used the root to shoot ratio (R/S) method to estimate the BGB [15], which depends on multiplying the AGB (which was estimated in the previous section) by R/S [11]. However, since this ratio mainly depends on the type of species and biomass, we used the R/S designed for desert landscapes, ranging from 0.5 to 1, with an average of 0.75 [11,16,17]. The mean of the R/S of arid lands was implemented to estimate the BGB, as shown in the following Eq. (4).

\[ BGB = AGB \times 0.75 \]
where BGB: Below Ground Biomass (g/m²), AGB: Above Ground Biomass (g/m²), R/S conversion factor: 0.75

Finally, total biomass (TB) was calculated using the following equation:

$$TB = AGB + BGB$$  \hspace{1cm} (5)

where TB: Total Biomass (g/m²), AGB: Above Ground Biomass (g/m²), BGB: Below Ground Biomass (g/m²).

**Quantification of carbon stock in the desert shrub biomass**

The TB results were used to estimate the carbon stock due to the robust relationship between biomass and carbon storage [5]. The TB was converted to carbon stocks using the IPCC conversion factor of 0.47 [8,19], using equations (6). Then, the carbon stock was converted into CO₂ equivalent (CO₂-eq) using Eq. (7) [12].

$$TC = TB \times 0.47$$  \hspace{1cm} (6)

where TC: Total Carbon stocks (g/m²), TB: Total Biomass (AGB+BGB) (g/m²) and IPCC conversion factor: 0.47

$$CO₂_{-eq} \text{ in the shrub} = TC \times 3.6663$$  \hspace{1cm} (7)

where CO₂-eq: Carbon dioxide sequestered in the shrub (g/m²), TC: Total Carbon stocks (g/m²), conversion factor: 3.6663, which is the ratio of carbon atom in the molecular weight of CO₂.
Conclusion

This paper presents an integrated method to assess and evaluate native desert plants using UAVs. The work gives clear evidence on the effectiveness of using UAVs to estimate the above-ground biomass of desert shrubs. It was found that the use of very high-resolution imagery can provide a rapid and accurate assessment of native desert vegetation. The methods used in this work provide a useful guideline on integrating different techniques and software for monitoring native plant’s coverage, biomass, and carbon stock. The methods are also applicable for other native desert shrubs in the region and could support ecosystem managers in assessing and monitoring arid ecosystems and restoration and revegetation programs. However, even though UAVs could provide detailed ecological information, including plant monitoring ecological assessment, they are not always beneficial. They mainly depend on the scale and purpose of the study, making it applicable for small-scale studies, which is one of the major limitations of utilizing UAVs. Thus, the integration of aerial and satellite imagery could help in developing biological indicators that could provide ecological information for large-scale studies.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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