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Short communication

Modeling herbaceous productivity considering tree-grass interactions in drylands savannah: The case study of Yatir farm in the Negev drylands

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ABSTRACT

Savanization is an efficient strategy to confront desertification by increasing herbaceous productivity in drylands providing income to local population relying on grazing. Hence, to assess successful savanization herbaceous production must be estimated accurately. The conventional technique uses random sampling, which might misestimate productivity underneath the canopies due to tree-grass interactions. Here we present an improved model to assess biomass production accounting for tree-grass effects using a stratified sampling technique. Our model calculates biomass underneath the canopy in two configurations: (a) a cone shape, accounting for gradual changes along the bole-to-drip line with radiuses representing topographic aspects, and (b) a cylindrical shape, accounting for biomass underneath the canopy not affected by the tree. We tested our model in the *Acacia victoriae* savannah of Yatir at the Northern Negev drylands, Israel. Results showed that biomass underneath the canopy were up to 3-fold higher than the measured in between trees. Although the total canopied area was only 4.4% of the savannah, biomass underneath canopies constituted 7% of the total savannah production. Thus, conventional sampling might significantly underestimate biomass production in denser savannah. Our model was adjusted to multi-species savannah and different geographic aspects and could be used in drylands systems elsewhere.

1. Introduction

Savanization (i.e. planting of less than 200 trees ha^{-1}) is an efficient way for increasing the biomass of native herbaceous vegetation in arid and semiarid drylands (MAP < 550 mm y^{-1}) (Helman et al., 2014a,b; Malagnoux et al., 2008). It provides sustainable supply of forage for grazing management that the local population in these areas rely upon (Asner et al., 2004; Oba et al., 2000; Verwijmeren et al., 2014). Hence, to assess successful savanization herbaceous production must be estimated accurately without damaging the low-productivity ecosystem. Therefor, usually random sampling is conducted (Belsky et al., 1993).

Former studies have treated the area underneath the trees as one unit and as such suggested to simply sample it randomly in order to assess its contribution to total herbaceous biomass (Ludwig et al., 2004). However, herbaceous vegetation seems to be affected by trees in dry and temperate savannah sites, showing gradual changes in herbaceous biomass from the tree bole to the canopy edges (Dohn et al., 2013; Moustakas et al., 2013).

In general, trees interact with grasses through positive (facilitative) or negative (competition) mechanisms. The net effect will be facilitative or competitive depending on many factors that are difficult to model (Scholes and Archer, 1997). Specific environmental conditions regulate such interactions. For example, in semiarid regions (MAP < 550 mm y^{-1}) trees were found to have net facilitative effects on the local herbaceous vegetation (Moustakas et al., 2013). Dense herbaceous layers would develop underneath the canopy benefiting from the tree shade and water uplift in these dry places. Such interactions become competitive in more mesic sites ($550 \leq$ MAP < 750 mm y^{-1}) (Dohn et al., 2013).

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Because of these tree-grass interactions, using conventional random sampling technique (i.e. unstratified sampling) might misestimate the total herbaceous production of the savannah. The magnitude of under/over-estimation will depend on the intensity of the net facilitative/competitive effect and the stand density of the savannah.

Here we present a model to estimate biomass accounting for tree-grass interactions using a stratified sampling approach with minimum damage to the ecosystem. We present our model as mathematical equations suitable for single and multi-tree species savannah elsewhere and compare it with the conventional random technique in a drylands savannah at the Northern Negev. For that purpose, we chose the Yatir farm *Acacia victoriae* savannah (Fig. 1). A net facilitative effect was previously observed in this area (Helman et al., 2014a,b; Mor-Mussery et al., 2013) (Fig. 1). We examined the constancy of these observations and present the way it should be used to assess total productivity in drylands savannah elsewhere.

2. Model description

To properly estimate herbaceous biomass (*HB*) underneath the canopy we used a stratified sampling technique in two distinct configurations: (i) as a constant configuration that calculates total production underneath the tree (in g) assuming no tree-grass interactions, and (ii) as a gradual one, accounting for *HB* added due to facilitative effects (Fig. 2).

(i) The constant configuration (cylinder type):

The constant configuration was modelled as the volume of a cylinder. The base of the cylinder represents the projected area of the canopy perpendicular to the ground (Tr_{Area} and black lines in Fig. 2). Its height is the assumed *HB* (g m^{-2}) if no tree-grass interactions occurs, which is equal to the *HB* between the trees in open areas (HB_{Open}). Accordingly, Tr_{Area} (m^2) was calculated from the canopy radiuses measured in downhill, (Tr^D_{Rad}), uphill (Tr^U_{Rad}) and perpendicular to slope directions (Tr^P_{Rad}- i.e. the average of the right and left directions) (Fig. 2):

$$Tr_{Area} = \pi\left(\frac{Tr^D_{Rad} + Tr^U_{Rad}}{2}\right)Tr^P_{Rad} \qquad [1]$$

Then, the total *HB* underneath the canopy area for the constant configuration (HB_{Cons}) is:

$$HB_{Cons} = HB_{Open} \cdot Tr_{Area} \qquad [2]$$

Note that HB_{Cons} is in grams for the canopied area of a single tree.

(ii) The gradual configuration (cone type):

The gradual configuration was modelled as the volume of an elliptical cone with the centre at the bole (red lines in Fig. 2) (in the web version). Here, the area of the cone represents the area where *HB* changes gradually from the bole and is different from that of between the trees. The radiuses of the cone are the distances from the bole to where *HB* equals to that of between the trees (Fig. 2). These distances will be referred here as ‘changing points’. Changing points are measured from the bole in downhill, (Tr^D_{Effect}), uphill (Tr^U_{Effect}) and perpendicular to slope directions (Tr^P_{Effect} − i.e. the average of the right and left directions), and the area is:

$$Tr_{Effect} = \pi\left(\frac{Tr^D_{Effect} + Tr^U_{Effect}}{2}\right)Tr^P_{Effect} \qquad [3]$$

HB in the area underneath a single canopy where gradual changes occur (HB_{Grad}, in g) is calculated from *HB* measured at the

Fig. 1. A general view of Yatir farm (Upper), and the gradual change in herbaceous biomass from tree bole to drip line (Lower). Photos credit: A. Mor-Mussery (Febraury, 2014).

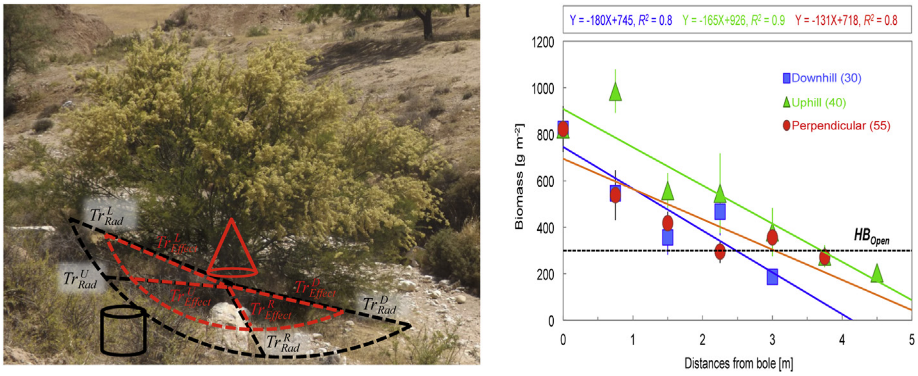

Fig. 2. Geometric scheme demonstrating distances from the bole in ‘constant’ (cylinder-black) and ‘gradual’ (cone-red) configurations (Left). The linear functions fitted to biomass measured from the bole in downhill (blue), uphill (green), and perpendicular to hill slope (red) directions, where the horizontal dashed line (black) was the biomass measured between trees (HB_{Open}) with intersections as the ‘changing points’ (Right). Error bars denote standard errors and number of samples are indicated in parenthesis.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

bole (HB_{Bole}) minus HB where no gradual change occur (i.e. between trees – HB_{Open}) (both in g m^{-2}):

$$HB_{Grad} = \frac{1}{3}\left(HB_{Bole} - HB_{Open}\right)Tr_{Effect} \quad [4]$$

Finally, Eqs. (2) and (4) are combined to calculate total HB underneath the projected canopy area of a single tree (HB_{Canopy}, in g):

$$HB_{Canopy} = HB_{Cons} + HB_{Grad} \quad [5]$$

Total HB (in tons) for the entire savannah area is then calculated in three steps:

(a) For the open area of the savannah between the trees (HB^{Total}_{Open}):

$$HB^{Total}_{Open} = \frac{Area(1 - \mathrm{N}\cdot Tr_{Area})}{10^6} HB_{Open} \quad [6]$$

where $Area$ is the total area of the savannah (m^2) and N is the stand density (trees m^{-2}) (HB_{Open} and Tr_{Area} are in g m^{-2} and m^2, respectively).

(b) For the under-canopied area of the savannah (HB^{Total}_{Canopy}):

$$HB^{Total}_{Canopy} = \frac{\mathrm{N}\cdot Area}{10^6} HB_{Canopy} \quad [7]$$

(c) The total HB in the savannah (HB_{Sav}, in tons):

$$HB_{Sav} = HB^{Total}_{Open} + HB^{Total}_{Canopy} \quad [8]$$

Because most savannah systems encompass different tree species, the following adjustments where made to Eqs. (6) and (7):

$$HB^{Total}_{Open} = \frac{HB_{Open}\left(Area - \sum_{m}^{i=1} Area^{i}\cdot \mathrm{N}^{i}\cdot Tr^{i}_{Area}\right)}{10^6} \quad [9]$$

$$HB^{Total}_{Canopy} = \frac{\sum_{m}^{i=1} Area^{i}\cdot \mathrm{N}^{i}\cdot HB^{i}_{Canopy}}{10^6} \quad [10]$$

where m is the number of tree species in the savannah (i is the specific tree species). N^i is the stand density of species i (trees m^{-2}) and $Area^i$ its total area (m^2). Tr^{i}_{Area} and HB^{i}_{Canopy} are canopy area (m^2) of species i and total biomass underneath this canopy (in g), respectively.

In case of trees located on hills with different geographic aspects, and to account for slope-effects on HB (Osem et al., 2004), Eqs. (9) and (10) can be used by replacing tree species by aspects. Thus, i would be the same species trees on geographic aspect i (e.g. northern aspect), and m would be the four main aspects.

3. Yatir site and sampling schemes

We selected the site of Yatir to implement our model. Yatir farm is a 5.5 ha of savannah area located at the Chiran region (34°59′04″E, 31°19′34″N), with elevation between 450 and 500 m. The area is hilly with all slopes facing southwest. The mean annual precipitation amount is 230 ± 54 mm y^{-1} (for 2000–2013, Israel Meteorological Services), and the total amount during the year of sampling was 220 mm. Soil is sandy clay loam.

The Jewish National Found (JNF) planted 55 *A. victoriae* trees (10 trees ha^{-1}) in this area in 1993 for rehabilitation purposes (Fig. 1). Native herbaceous vegetation includes mainly *Graminae* species with dominance of *Stipa capensis* L. and *Hordeum spontaneum* K. Koc. (Danin and Orshan, 1990). Supervision ensures that grazing during spring is less than one livestock unit per ha.

Herbaceous biomass (HB) was collected in March 2013 after it reached its peak density (Osem et al., 2004), and before grazing took place. Sampling was carried out using 0.2 × 0.3 m quadrats from: (a) underneath the canopy, and (b) between the trees in open spaces. Due to this low-productivity area, number of samples had to be representative enough for analysis but minimize possible ecosystem damage.

Underneath the canopy, samples were collected using quadrats at intervals of 0.75 m from the bole toward the drip line (i.e. projected drip line perpendicular to the ground) in four directions: downhill, uphill and to the right and left-perpendicular (90°) to hill slope. Because canopy size might affect the magnitude of HB underneath the canopy (Ludwig et al., 2004), representative trees with closest canopy area to the mean (44 ± 14 m^2, ±SE) were selected. Ellipse formula was used to calculate the projected canopy area, while radiuses were measured on the ground using a tape measure. A total of seven trees were chosen for representative analysis (ca. 13% of the savannah's trees).

In between trees, 10 samples were randomly collected with a minimal distance of 2 m from tree canopies. Distances between trees ranged from 20 to 80 m. All samples were dried for 48 h at

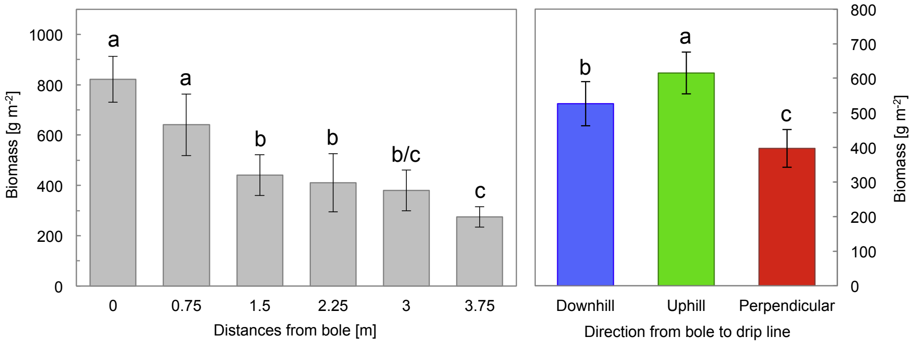

Fig. 3. Herbaceous biomass (g m^{-2}) measured at different distances from the bole (Left), and in different directions (Right). The perpendicular direction is the average between right and left sides. Error bars are standard errors. Letters denote significance levels using one-way ANOVA test at $\alpha = 0.1$.

60° C, weighted and converted to g m^{-2} (Sava, 1994). Differences in *HB* between directions and distances where assessed through one-way ANOVA test at $\alpha = 0.1$ (JMP® ver. 5.3 of SAS® co.).

4. Results

Herbaceous biomass (*HB*) was high underneath *A. victoriae* with up to 800 g m^{-2} (mean = 500 g m^{-2}), which is more typical for subhumid grassland ecosystems (Dohn et al., 2013; Golodets et al., 2015). Such high productivity, though, was previously reported in Wadi sites (up to 700 g m^{-2}) at the Northern Negev (Osem et al., 2004). Between trees, which constitute the major area of the savannah, *HB* was typical for the region (MAP = 230 mm y^{-1}) with productivity up to 250 g m^{-2} (Osem et al., 2004; Tadmor et al., 1974). The large difference between under and in between trees productivity was due to the net facilitative effects of trees on herbaceous vegetation (Moustakas et al., 2013).

In average, *HB* had a significant gradual decline from bole to the canopy edges ($p < 0.1$, Fig. 3). The gradual change was significant in all seven trees ($p < 0.1$). Differences between right and left directions were not significant ($p > 0.1$) and were therefore averaged and referred as perpendicular to hill slope. Between uphill, downhill and perpendicular to the hill slope directions, *HB* was significantly different with highest *HB* in the uphill direction ($p < 0.05$, Fig. 3). Higher *HB* in uphill direction was probably due to the southern facing slopes, whereas trees create shade toward uphill direction facilitating herbaceous growth (Dohn et al., 2013).

The 'changing points' (i.e. distances from bole toward where *HB* equals that of between trees) for downhill, uphill, and perpendicular to the hill slope directions were 2.7, 4 and 3.4 m, respectively (dashed line in Fig. 2). However, slopes were not significantly different ($p > 0.1$), so the mean distance (3.4 ± 0.7 m) was used to calculate Tr_{Effect} as a circular cone instead of elliptical one (in Eq. (3)).

Using Eqs. (1)–(7), HB^{Total}_{Open}, HB^{Total}_{Canopy} and HB_{Sav} were calculated. The total herbaceous biomass underneath the canopies in the entire savannah area (HB^{Total}_{Canopy}) was estimated at ca. 1 t (0.2 t ha^{-1}), which was 7% of the entire production of the savannah (HB_{Sav}) during 2013 (ca. 14 t or 2.6 t ha^{-1}).

The total area underneath the *A. victoriae* canopies is only 4.4% of the savannah's area. Yet, it held a ratio of 1.6 between percentage of under-canopied biomass from savannah production ($HB^{Total}_{Canopy}/HB_{Sav}$) to relative area (under-canopied area/total area). Or in other words, random sampling in this case would underestimate biomass production underneath the canopies by 40%. This could lead to significant underestimation in denser savannah sites.

It was shown that *A. victoriae* has significant effects on productivity of native herbaceous vegetation in this region (Helman et al., 2014a). However, such effects depend much on stand density, and techniques used for their planting (Helman et al., 2014b; Materechera, 2014; Mussery et al., 2013). This study showed that using a stratified sampling is more appropriate in drylands savannah than conventional random sampling alone, especially in dense savannah (Scholes and Archer, 1997). The presented method will help improving biomass assessment in drylands savannah, allowing better between-site comparisons.

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