

Effects of Shrub Identity and Abiotic Factors on Understory Richness and Occurrence in Mediterranean Arid Pseudo Savanna of South Tunisia

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Abstract

This research was carried out in the national park of Bou-Hedma, South Tunisia. The purpose of the study was to determine whether shrub variety characteristics and abiotic factors were relevant in predicting the distribution of understory species. To evaluate the relative roles of shrubs in vegetation composition and diversity patterns under pseudo-savanna conditions, soil water content and nutrient concentrations were collected from various shrub canopies and open spaces. Herbaceous similarity (species density, richness, and biomass) and soil attributes were sampled using the quadrat method beneath and between different shrubs and in open areas. The results show that all studied shrubs enhance soil water availability as well as the nutrient status of the soil. It is expected that *Retama raetam* has the greatest positive impact on soil fertility and understory vegetation, given the findings that it was the most effective shrub among those studied. In this pseudo-savanna, environmental management strategies should encourage the preservation of surviving shrubs and promote their restoration through targeted efforts. The study recommends using *Retama raetam* as a key restoration species in Tunisia's arid ecosystems.

Keywords: Arid areas, Plant-plant *interactions*, Shrubs, Soil enrichment, Water availability

1. Introduction

Perennial vegetation, which significantly influences the geographical distribution of microclimates, soil qualities, and organisms, is a fundamental feature of dryland ecology (Varela et al., 2017). Nurse plants, as defined by Callaway (1995), are plant species that facilitate the establishment of other plants by providing shelter under their canopy or protecting them from herbivores. Woody plants benefit other plant species through two mechanisms: an edaphic effect, which includes nutrient enhancement, and a physical influence from their canopy, leading to moderated light and temperature conditions (López-Pintor et al., 2006). Furthermore, Variations in vegetation have been observed on a small scale under trees or bushes (Michalet et al., 2015; Noumi et al., 2015). These differences in vegetation beneath shrubs may result from short-term effects rather than long-term processes (Noumi et al., 2016). The primary reason for differences among under-shrub species is competition for resources by dominant plants, particularly for water, nutrients, and light (Moro et al., 1997; Cui & Caldwell, 1997). The soil seed bank, seedling recruitment, and botanical composition of the understory in arid ecosystems are greatly influenced by attributes of shrub areas, such as their age, size, and density (Facelli & Brock, 2000; Pugnaire & Lázaro, 2000). Gómez-Aparicio et al. (2004) and Michalet

(2007) highlighted that differences in species traits and strategies between nurse plants and target plants could explain inconsistencies in previous studies (Gómez-Aparicio, 2009; Maestre et al., 2009b; Forey et al., 2010; Noumi et al., 2015, 2016; Noumi, 2020). For example, grasses may outcompete shrubs or forbs for water due to their high root allocation (Davis et al., 1998; Gómez-Aparicio, 2009). However, few studies have tested the impact of patch characteristics on understory abundance and diversity (Bascompte & Rodríguez, 2001; Gavilán et al., 2002). Additionally, the significance of shrub patch attributes relative to other abiotic factors that support understory plants is well recognized (Gavilán et al., 2002). In Tunisia, arid regions account for over 70% of the total land area (Noumi, 2010). These regions are characterized by dry conditions, high temperatures, and relatively high salinity levels. Shrub species such as *Periploca angustifolia*, *Rhus tripartita*, *Acacia raddiana*, *Ceratonia siliqua*, *Lycium shawii*, and *Retama raetam* play a critical role in stabilizing these ecosystems and mitigating desertification risks. Moreover, these shrubs contribute to the rehabilitation of degraded ecosystems (Maestre et al., 2001; Noumi, 2010).

The major goals of this research are: (i) to evaluate the importance of species identity and abiotic characteristics on the occurrence of understory species, and (ii) to identify the shrub species that can serve as a nurse plant to facilitate the establishment of other plant species in the arid regions of South Tunisia.

2. Materials and Methods

2.1 Study area and vegetation

The study was conducted in the Bou Hedma National Park in southern Tunisia, covering an area of approximately 5,114 hectares. The climate is characterized by a mean annual precipitation of less than 200 mm, a mean temperature of 19 °C, and an annual evapotranspiration of about 900 mm. These climatic features are typical of an arid-Mediterranean climate (Noumi, 2010). This ecosystem is notable for its high plant diversity, with dominant families such as Asteraceae, Fabaceae, Poaceae, and Brassicaceae, forming a pseudo-savanna dominated by the tree *Acacia tortilis* subsp. *raddiana* (Noumi, 2010).

2.2 Vegetation sampling

Ten individuals of the six most dominant shrub species were randomly selected within a uniform flat area of approximately 20 hectares. These species, commonly found in the arid and semi-arid environments of Tunisia (Noumi, 2010), included *Retama raetam*, *Lycium shawii*, *Rhantemum suaveolens*, *Rhus tripartita*, *Periploca angustifolia*, and *Hammada scoparia*. The height and canopy diameter of all selected shrubs were measured (Table 1). Additionally, annual plant communities were sampled at the peak of biomass production in April. Sampling was conducted at four aspects (N, S, E, and W) under the canopy of each shrub and in ten gaps using 30×30 cm quadrats. For the understory, quadrats were positioned midway between the shrub trunk and the projected edge of the canopy. Within each quadrat, aboveground biomass was clipped, and all samples were dried at 70 °C for two days. Plant density was calculated based on this data.

2.3 Soil sampling

We conducted soil water measurements and collected soil samples for chemical analyses, using five replicates per habitat. Soil volumetric water content was measured at a depth of 10 cm. Soil moisture was initially assessed during

the dry period and subsequently after 30 mm of rainfall at intervals of 5, 10, and 15 days. Soil fertility was evaluated using five samples per habitat (excluding litter and stones) taken from a depth of 10 cm during the dry period. The soil samples were air-dried and sieved (2 mm) for chemical analyses. Oxidizable soil organic matter was determined using the Walkley-Black procedure (Nelson and Sommers, 1982). Extractable phosphate and total nitrogen were measured using Olsen's bicarbonate extraction method (Olsen and Sommers, 1982) and the Kjeldahl method, respectively.

Shrub species	<i>H. scoparia</i>	<i>L. shawii</i>	<i>P. angustifolia</i>	<i>R. raetam</i>	<i>R. suaveolens</i>	<i>R. tripartita</i>
Height (m)	0,94 ± 0,15 ^d	1,23 ± 0,08 ^b	1,13 ± 0,07 ^c	1,55 ± 0,19 ^a	1,03 ± 0,07 ^d	1,26 ± 0,09 ^b
Crown diameter (m)	1,06 ± 0,08 ^d	1,86 ± 0,1 ^b	1,36 ± 0,11 ^c	2,31 ± 0,38 ^a	1,15 ± 0,09 ^d	1,66 ± 0,13 ^b

Table 1. Heights and crown diameters of the six shrub species (mean ± SE). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $P < 0.05$).

2.4 Data analysis

A one-way ANOVA was used to assess differences among sub-habitats (canopied vs. un-canopied sub-habitats) in aboveground biomass, species richness, individual density, dry matter, soil nutrients, and soil water content. When significant differences between group means were found, a multiple comparison of means test (post hoc Tukey's Honestly Significant Difference test) was performed. No transformations were required to meet the parametric assumptions of ANOVA. The SPSS program version 17.0 was applied for statistical analyses.

3. Results

3.1 Shrubs and plants characteristics

A significant effect of species identity on different vegetation parameters was observed (see Tukey test in Figures 1-3). The aboveground biomass of herbs, measured in spring, showed substantial variations between the open areas and the understory beneath the six shrubs (Figure 1). The lowest biomass values were observed in *Hammada scoparia* and *Rhanterium suaveolens*, which had a repressive influence on understory growth. The highest biomass values were recorded beneath *Retama raetam*. The other shrubs, *Rhus tripartita* and *Lycium shawii*, showed intermediate values, while the aboveground biomass ranged from a mean of 28 mg/m² in the open area to 25 mg/m² beneath *Retama raetam*.

The total number of plant species observed in open areas and beneath the canopy of the different bushes, as well as the mean number of plants per sample, differed significantly between the shrubs under study (Figure 2). Notably, the lowest values were observed in the open areas. Additionally, the analysis of plant density beneath each bush and in the open areas showed that the community under *Hammada scoparia* and *Rhanterium suaveolens* was similar to the community in open spaces, with no significant variations (Figure 2). The analysis also indicated that plant associations beneath *Retama raetam* were clearly distinct from those in open areas. It can be deduced that all other communities fall between these two boundaries.

Generally, the results revealed that the presence of shrubs enhanced all studied variables. Between shrub species, *R. raetam* shrubs were found to have elevated values of vegetation features compared to the other shrubs species (Fig. 1,2,3).

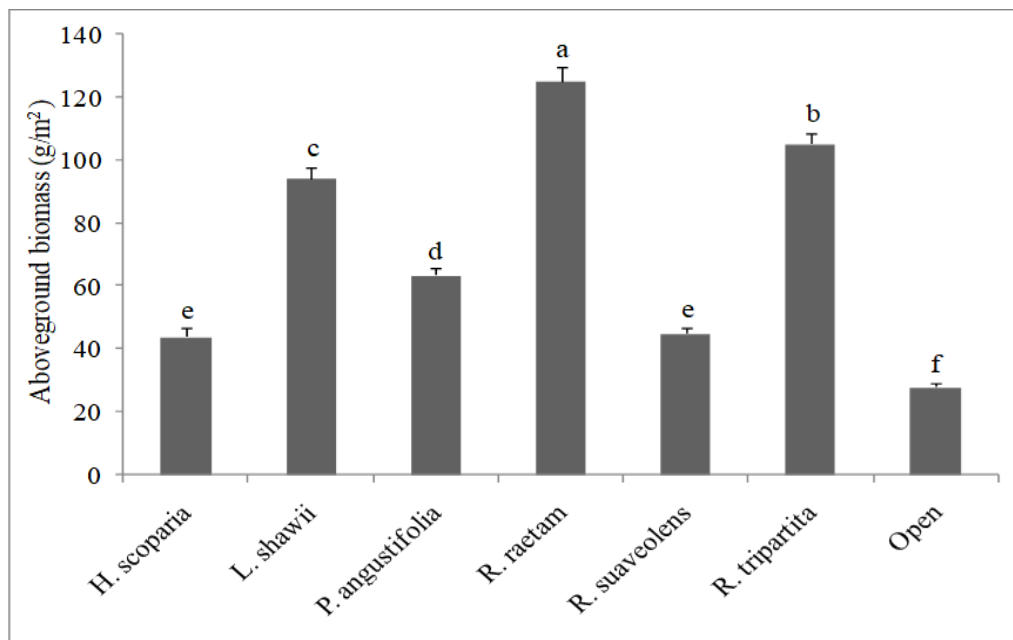


Figure 1. Aboveground biomass of species occurring under the six shrubs (mean $\pm$ SE). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $p < 0.05$).

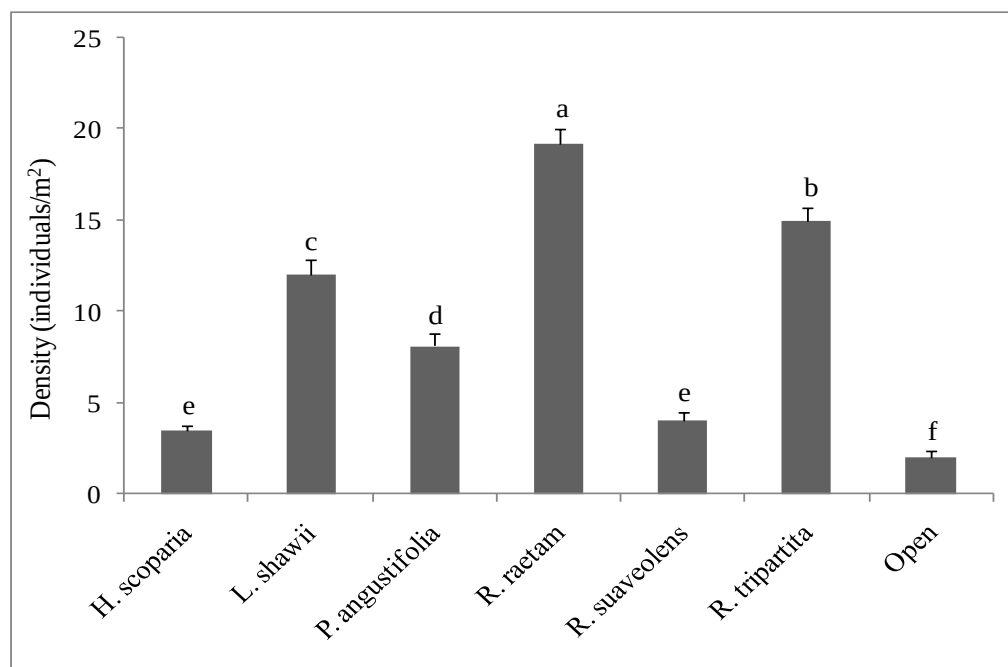


Figure 2. Density of species occurring under the six shrubs (mean $\pm$ SE). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $p < 0.05$).

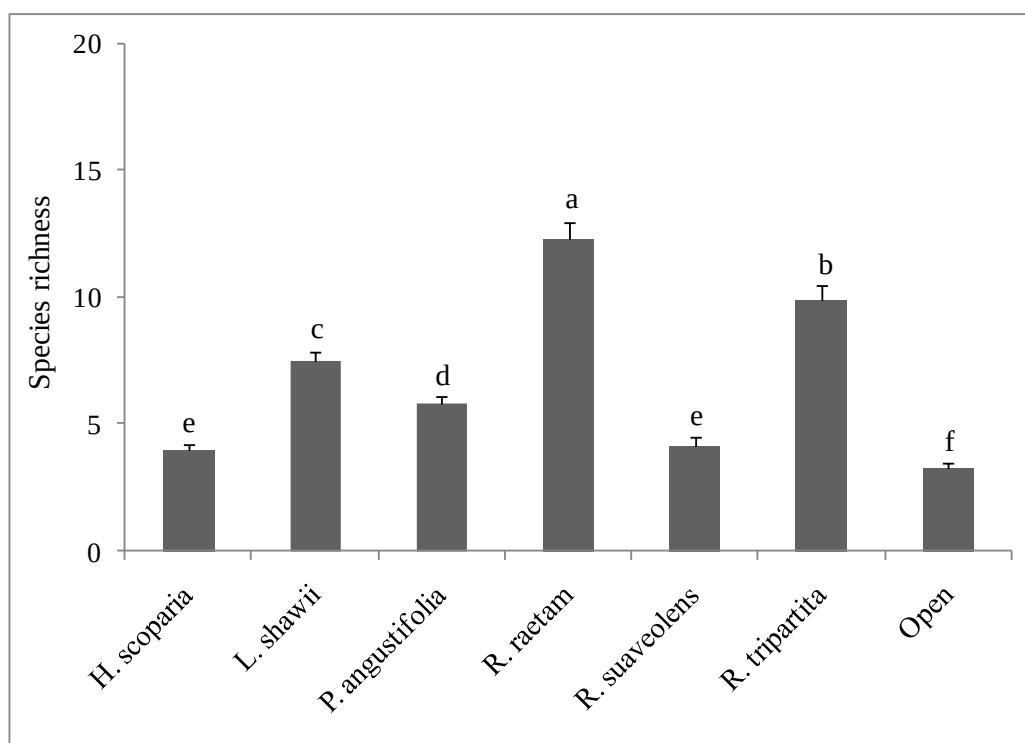


Figure 3. Species richness occurring under the six shrub species (mean ± SE). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $P < 0.05$).

3.2 Shrubs and soil properties

In general, the ANOVA of soil characteristics confirmed significantly higher concentrations of all nutrients in soils beneath shrubs compared to open areas (see Tukey test in Table 2). The greatest variations in soil properties were observed between shrub species (see Tukey test in Table 2). The organic matter (OM), nitrogen (N), and extractable phosphorus (P) contents were considerably higher under the canopy of the Fabaceae shrub (*Retama raetam*) compared to the other shrubs.

	<i>H. scoparia</i>	<i>L. shawii</i>	<i>P. angustifolia</i>	<i>R. raetam</i>	<i>R. suaveolens</i>	<i>R. tripartita</i>	Open
OM (g.kg⁻¹)	38.6 ± 8.37 ^a	38.6 ± 8.37 ^a	38.6 ± 8.37 ^a	38.6 ± 8.37 ^a	38.6 ± 8.37 ^a	38.6 ± 8.37 ^a	10.02 ± 1.1 ^e
N (g.kg⁻¹)	1.84 ± 0.34 ^a	1.84 ± 0.34 ^a	1.84 ± 0.34 ^a	1.84 ± 0.34 ^a	1.84 ± 0.34 ^a	1.84 ± 0.34 ^a	0.72 ± 0.13 ^e
P (g.kg⁻¹)	0.06 ± 0.01 ^a	0.06 ± 0.01 ^a	0.06 ± 0.01 ^a	0.06 ± 0.01 ^a	0.06 ± 0.01 ^a	0.06 ± 0.01 ^a	0.02 ± 0.01 ^e

Table 2. Organic matter (OM), total nitrogen (N) and extractable phosphorus (P) soils occurring under different shrubs canopies and in open areas. Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $P < 0.05$).

Before the rain, no significant differences were observed between the different treatments (Table 3). Five days after 30 mm of rainfall, significantly more soil moisture was found under the canopy of the different shrubs compared to the open areas, with the lowest values observed in the open patches (see Tukey test in Table 3, $P <$

0.05). This trend persisted steadily for 10 days following the rainfall. However, 15 days after the rainfall, no significant impact on soil moisture levels was observed in either the shrub communities or the open areas.

Overall, the findings supported that the presence of shrubs improved all the studied variables. Among the shrub species, *Retama raetam*, *Rhus tripartita*, and *Lycium shawii* showed the highest values for soil properties compared to the other shrubs.

Measures	Depth (cm)	<i>H. scoparia</i>	<i>L. shawii</i>	<i>P. angustifolia</i>	<i>R. raetam</i>	<i>R. suaveolens</i>	<i>R. tripartita</i>	Open
T1 (after 5 days)	0-20	0.16 ± 0.01 ^c	0.19 ± 0.01 ^b	0.18 ± 0.01 ^b	0.22 ± 0.02 ^a	0.16 ± 0.01 ^c	0.18 ± 0.02 ^b	0.13 ± 0.01 ^d
T2 (after 10 days)	0-20	0.08 ± 0.009 ^c	0.11 ± 0.007 ^b	0.11 ± 0.007 ^b	0.15 ± 0.008 ^a	0.09 ± 0.009 ^c	0.12 ± 0.006 ^b	0.09 ± 0.006 ^d
T3 (after 15 days)	0-20	0.045 ± 0.008 ^a	0.05 ± 0.009 ^a	0.043 ± 0.007 ^a	0.05 ± 0.009 ^a	0.04 ± 0.009 ^a	0.03 ± 0.008 ^a	0.03 ± 0.009 ^a

Table 3. Soil water content (m³ water /m³soil) occurring under different shrubs canopies and in open areas over time (5 days after rainfall, 10 days after rainfall and 15 days after rainfall). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $p < 0.05$).

4. Discussion

An overview of the literature reveals that numerous studies have focused on the impacts of Mediterranean shrubs on their understory plants, indicating both positive and negative effects (Noumi, 2015, 2020; Noumi et al., 2016). However, the extent to which shrub identity influences vegetation dynamics remains largely unexplored. Therefore, the primary focus of the current research was to evaluate the relative significance of plant species identity and abiotic factors on the presence of understory plants and to identify shrubs that could serve as nurse plants to support the growth of tree seedlings in the arid areas of Southern Tunisia. Our findings support the hypothesis that shrubs play a vital role as foundation species in Tunisia's arid lands. They contribute to increased abundance, cover, and density of plants within their shade (Noumi et al., 2011, 2012; Abdallah et al., 2008, 2012). Additionally, the identity of the nurse shrub has been shown to influence vegetation dynamics in arid ecosystems. The study observed distinct differences in vegetation parameters, which may be attributed to the effect of shrubs. One remarkable outcome of vegetation patchiness is the creation of "resource islands" beneath the shrub canopy (Reynolds et al., 1999). These areas exhibit distinct soil microclimatic conditions compared to adjacent vegetation-free areas (Titus et al., 2002). These changes promote facilitative interactions between plant species, leading to increased plant coexistence (Callaway, 1995; Maestre et al., 2001; Pugnaire et al., 1996). The life cycle of herbs in Mediterranean ecosystems is regulated by the alternating availability of ground moisture and heat throughout the season.

This study assumed that the canopy of various shrubs would provide higher water availability, particularly shortly after rainfall (Table 3), along with a decrease in temperature and light intensity compared to open areas, which are characterized by higher temperatures and light intensity. Moreover, the identity of the shrubs played a role in the vegetation dynamics of arid ecosystems. The observed differences among the studied shrubs highlight the context-dependent allocation of plants in dry ecosystems (Osem et al., 2007). It can be inferred that the growth of species beneath the shade of different plants, which facilitate their growth, depends on physiological tolerances and minimum

resource requirements, specifically in terms of light, temperature, and moisture content. Furthermore, apart from their role in species interactions, shrub patches have a substantial impact on the distribution patterns of vegetation. This is achieved through various processes such as water retention, dispersal of wind-dispersed seeds, and seed dispersion by birds (Aguiar & Sala, 1999).

Further investigation into these relationships and the variables impacting the dispersal of shrub patches will undoubtedly enhance our understanding of ecosystem functionality in arid degraded lands, as well as help in developing suitable approaches and strategies for managing, protecting, and restoring these ecosystems.

The observed recovery is likely linked to enhanced soil fertility, increased available water, and a more favorable microclimate within the diverse shrub canopy. Essential nutrients for all plants, such as nitrate, phosphorus, anions, cations, and various trace elements, play a vital role (Bell, 1982). The drylands of Tunisia, characterized by low levels of these elements in the soil, show that their increased concentration can significantly influence the composition, structure, and productivity of plants. Moreover, the presence of spines in woody plants can provide protection against grazing animals for herbaceous cover (Milchunas & Noy-Meir, 2002). In windy, dry areas, shrubs provide superior protection for plants growing beneath their shade. This may explain the higher vegetation cover observed beneath tree canopies compared to open areas.

Conclusion

The results obtained in the present study revealed a positive impact of endogenous shrubs on understory flora and soil fertility in Tunisian arid ecosystems. The effects of shrubs on their habitat, whether positive or negative, largely depend on the species. Given that *R. raetam* had the most favorable effect compared to the other shrubs, it is expected to have the greatest positive impact on soil nutrients and understory plants. Therefore, compared to other species, *R. raetam* appears to be an effective restoration plant for Tunisia's drylands and is particularly well-suited for creating resource islands.

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Disclosure statement

The author has a conflict of interest with Prof. Mohamed Chaieb from the University of Sfax.

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