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Research Article

Using Woody Shrubs as a Restoration Tool in Arid Areas: A Case Study from Tunisia

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Abstract

The objectives of the study, conducted in the National Park of Bou-Hedma (South Tunisia), were to identify the relative importance of shrub patch characteristics and abiotic factors as predictors of understorey species distribution. Soil water content and soil nutrient concentration were determined under the canopy of different shrubs and in open areas to evaluate the relative roles of shrubs in structuring vegetation composition and diversity patterns in arid pseudo-savanna. The herbaceous community (species density, species richness and dry matter) and soil characteristics (soil nutrients and soil water) were sampled using the quadrat method beneath and between different shrubs and in open areas. All studied shrubs improved soil water availability, as well as soil nutrient status (organic matter, total nitrogen, extractable phosphorus). Results also showed that *Retama raetam* (Forssk.) Webb. had the best effect compared to the other shrubs, it is expected that *R. raetam* presents the strongest positive effect on soil fertility and understory vegetation. Environmental management activities within this pseudo savanna should promote the conservation of remnant shrubs, as well as its introduction with restoration activities.

Introduction

The processes underlying the positive impact applied by woody species on other plant species can be clustered into two categories: a physical effect emanating from the canopy itself (namely the improvement of temperature and light extremes) and an edaphic effect (nutrient enrichment) [1]. Vegetation differences are known to occur at a smaller scale below shrubs or trees [2,3]. The differences of small-scale below-shrub vegetation may stem from a short term rather than a long-term effect [4]. The major drive behind below-shrub differences are mostly resource uptake by dominants, particularly light [5], nutrients and water [6]. In arid ecosystems, the features of shrub patches as species identity, age and size strongly affect seed banks, seedling recruitment, and community composition of understorey species [7,8].

Gomez-Aparicio et al. [9] and Michalet [10] have discussed differences among studies in species traits and strategies of both the nurse (plants that assist establishment of other plant species under their cover or offer protection against herbivores [11] and the target species, which may explain discrepancies in the literature [12,13,14]. However, little research has assessed how patch features influence the patterns of understory richness and diversity [15,16]. In arid and semi-arid environments, the introduction of shrubs species for the restoration of degraded arid and semiarid ecosystems has become increasingly important worldwide as a measure to protect soils, to combat desertification, supply natural resources and therefore, increase plant cover and species diversity [17]. In these areas, positive and negative interactions have been considered as a main driver of plant community dynamics and ecosystem [11]. Pugnaire et al. [8] predicted that interactions between overstory and understory plants depend on how the different species modify their environment. However, very few researchers have performed manipulative field experiments to dissect the net effects of woody species on soil nutrients and the characteristics of understorey vegetation in Mediterranean arid and semiarid [18,19]. This knowledge is necessary to understand community dynamics and to develop sound management programs.

Arid zones in Tunisia, covering more than 70% of the country's area [20], are characterized by drought stress with high temperature and relatively general salinity. Shrub species such as *R. raetam* and *Acacia tortilis* (Forssk.) Hayne subsp. *raddiana* (Savi) Brenan, ameliorate the stability of ecosystems in which they exist, and contribute to the reduction of desertification. They are also helpful in restoring degraded ecosystems [14,21].

The major goals of this study were: (i) to assess the importance of specific species and abiotic characteristics on understorey species occurrence, and (ii) to determine the shrub capable of acting as a nurse plant to facilitate seedlings of tree species in the arid areas of South Tunisia.

Materials and Methods

Study area and vegetation

The study site is situated in the BouHedma National Park (348°390 N, 9°480 E, southern Tunisia). The climate is Mediterranean, with temperate winters and large variations in the annual precipitation [21]. The mean annual rainfall in the area is 180mm in the plain and 250mm on the crest of the mountain. However, like other arid Mediterranean climates, inter-annual variability in precipitation is very high (180mm ± 25 between the years 1996 and 2018). Mean daily temperature ranges between 3.9°C during the coldest month (January) and 36.2°C during the hottest month (August).

Soil is composed of quaternary sandy deposits of alluvial origin on an extremely flat slope, and vegetation a savanna with *A. tortilis* subsp. *raddiana* as single tree species. it's the dominant vegetation type is an open pseudo-savanna of *Acacia tortilis* with many shrub species between trees (*R. raetam, Hammada scoparia*, *H. schmittiana*, *Rhanterium suaveolens*, *Lycium shawii*, *Gymnocarpos decander*, *Ziziphus lotus*, *Rhus tripartita*) and a sparse cover of grasses (*Cenchrus ciliaris*, *Digitariacommutata*, *Cynodon dactylon*, *Schismus barbatus*, *Hordeum maritimum*, *Bromus madritensis*, *Stipa lagascae*) and legumes and forbs (*Diplotaxis harra*, *D. simplex*, *Enarthrocarpus clavatus*, *Erodium triangulare*, *Echium humile*, *Reseda alba*, *Plantago albicans*, *Emex spinosus*, *Launea resedifolia*, *L. angustifolia*, *Medicago minima*). The botanical nomenclature in this paper is according to Noumi [21]. The park is lightly grazed (stocking density of approximately 1 animal per 40 ha) by introduced wild herbivores (Noumi et al. 2015), such as Saharan antipodeans (*Addax nasomaculatus* and *Oryx leucoryx*), dorcas gazelle (*Gazella dorcas*), mhor gazelle (*Gazella damamhor*), Barbary sheep (*Ammotragus lervia*) and some ostriches (*Struthio camelus*) [22].

Experimental design

Ten individuals of the six most frequent shrub species were randomly chosen in a uniformly flat area of about 20 ha. The species, normally found in arid and semi-arid environments of Tunisia [21], were *R. raetam, Lycium shawii, Rhanterium suaveolens, Rhus tripartita, Periploca angustifolia and Hammada scoparia*. Height and canopy diameter of all selected shrubs was recorded (Table 1), and annual plant community biomass sampled at peak production in April 2018, at four aspects (N, S, E, and W) under the canopy of each individual shrub and in ten gaps, using 30x30 cm quadrats. As in the understory, quadrats were situated half-way between the shrub trunk and the projected edge of the canopy. Within each quadrat, all aboveground plant mass was selected, and this material was sorted into individuals and species, plant density determined and then dried at 70 ºC for 48 hr.a

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 $P < 0.05$).

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

Environmental measurements

Volumetric soil water content was measured at 10 cm depth with an FDR probe (Theta Probe ML2x, Delta T, Cambridge, UK). Five replicates per habitat were conducted at different times. While the first water measurements were taken one day after a rain of 30 mm, the other ones which were found at the sampling intervals were conducted 5, 10 and 15 days after the rain.

For soil analysis, five samples (excluding litter and stones) per habitat from 5-10 cm deep were collected. After being air-dried, samples were sieved by a2-mm sieve and finely ground, and oxidizable soil organic matter (Walkley-Black procedure [23]; extractable phosphate (Olsen's bicarbonate extraction [24]) and total nitrogen (Kjeldahl method) determined.

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Data analysis

The data were subjected to one-way ANOVA using SPSS (SPSS for Windows, v.10.05), and the probability values below 0.05 ($P < 0.05$) were considered statistically significant sub-habitats (canopied or un-canopied sub-habitat). While the sub-habitats were the independent variables, the aboveground biomass, species density, soil nutrients and soil surface proprieties were the dependent variables.

Results

Shrub and vegetation characteristics

There was a significant effect of species identity on different vegetation parameters (Tukey test, Figures 1,2 and 3). Aboveground herb biomass in spring revealed a significant difference between open and understory areas of the six-shrub species (Figure 1). Between shrub species the lowest values were observed under *H. scoparia* and *R. suaveolens*, and highest values under *R. raetam.* Aboveground biomass had mean values ranging from 28mg/m^2 in open area to25 mg/m^2 for *R. raetam*.

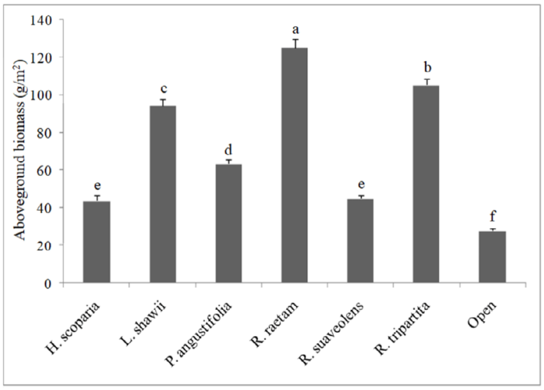

Figure 1: Aboveground biomass of species occurring under the six shrubs (mean ± SE). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $P < 0.05$).

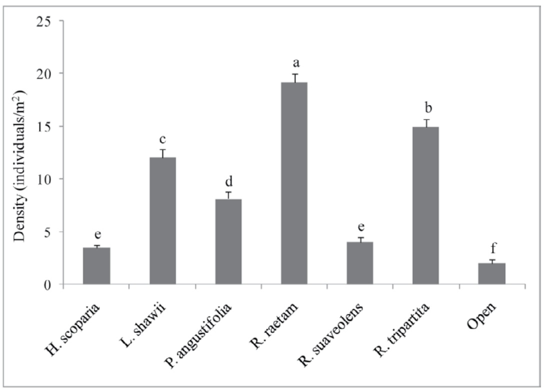

Figure 2: Density of species occurring under the six shrubs (mean ± SE). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $P < 0.05$).

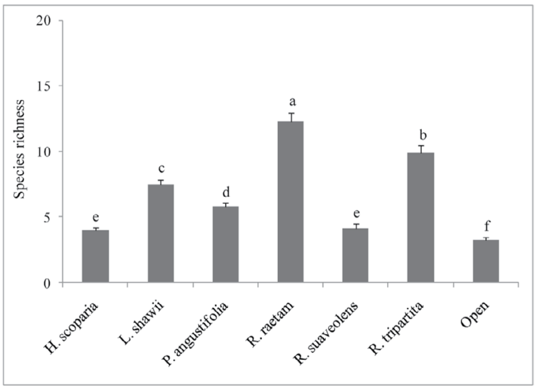

Figure 3: Species richness occurring under the six shrub species (mean ± SE). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test at $P < 0.05$).

The total number of species found in open and under the canopy of the different shrubs and the average number of species per sample, were considerably different among the shrubs under study (Figure 2). The lowest values were recorded in open areas. Statistical analysis of species density under each shrub and in the open indicated that the species under *H. scoparia and R. suaveolens* were akin to those in gaps (Figure 2), and that the species most different from those in the gaps were under *Retama*. Results revealed that the presence of shrubs facilitate establishment and development of herbaceous species. Between shrub species, *R. raetam* shrubs were found to have elevated values of aboveground biomass, density and species richness compared to the other shrubs species.

Shrubs and soil properties

The overall ANOVA of soil characteristics showed higher concentrations of all the nutrients in soils under shrubs compared with the open areas (Table 2). Differences in soil characteristics were noted among shrubs. The soil organic matter content (OM), the soil nitrogen content (N) and the extractable phosphorus (P) were significantly higher under the canopy of the Fabaceae shrub (*R. raetam*) compared to the other shrubs.

During the dry period, there were no significant differences in soil water content. Five days after 30mm of rain, there was significantly more soil water was found under the canopy of different shrubs than that of the open patch with the lowest values (Table 3). This tendency persisted for 10 days after rainfall, but 15 days after rainfall, no significant difference was recorded in soil water content.

Generally, the obtained results substantiated that the presence of shrubs improved all studied variables. Among shrub species, *Retama, Rhus* and *Lycium* shrubs were proven to have the highest values of soil organic matter content (OM), the soil nitrogen content (N) and the extractable phosphorus (P) compared to the other shrubs.

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).

	H. scoparia	*L. shawii*	*P. angustifolia*	*R. raetam*	*R. suaveolens*	*R. tripartita*	Open
OM ($g.kg^{-1}$)	24.6 ± 2.77^d	38.6 ± 2.37^b	32.5 ± 2.09^c	45.6 ± 3.02^a	25.2 ± 2.66^d	36.6 ± 3.25^b	10.02 ± 1.1^e
N ($g.kg^{-1}$)	1.09 ± 0.12^d	1.54 ± 0.22^b	1.24 ± 0.19^c	2.12 ± 0.34^a	1.04 ± 0.14^d	1.6 ± 0.24^b	0.72 ± 0.13^e
P ($g.kg^{-1}$)	0.025 ± 0.011^d	0.057 ± 0.015^b	0.043 ± 0.017^c	0.09 ± 0.01^a	0.028 ± 0.011^d	0.06 ± 0.012^b	0.02 ± 0.01^e

Table 3: Soil water content (m^3 water /m^3 soil) 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).

Measures	Depth (cm)	*H. scoparia*	*L. shawii*	*P. angustifolia*	*R. raetam*	*R. suaveolens*	*R. tripartita*	Open
T1 (5days after)	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 (10 days after)	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 (15 days after)	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

Discussion

Our results provide evidence to the hypothesis that shrub species is a foundation species in arid zones of Tunisia, contributing to the enhancement of plant species richness, plant cover and species density under its canopy through the improvement of soil fertility and soil water availability. Furthermore, the nurse's identity was proven to influence the vegetation dynamic under arid areas of Tunisia. In the present study, clear differences were confirmed in vegetation parameters, related to the shrubs' effects. One of the most dramatic and best-studied outcomes of patchiness in vegetation is the formation of "resource islands" underneath the canopy of shrubs [25]. Soil and microclimatic conditions are boosted in these locations in comparison with the adjacent areas without vegetation [25]. These changes favor the pervasiveness of facilitative interactions between plant species [19,14]. Comparable results were reported by Callaway et al. [11] with alpine plants and Belsky et al. [26] in a semi-arid savanna, who recorded a reduction of temperature extremes of air and soil under the plant canopies. This again led to a decrease of the air evaporative demand [27] and an increase of soil moisture. Besides, the role of shrubs identity had an impact on the dynamic of vegetation under arid bioclimate. The differences noticed among the shrubs under study affirm the subtle context-dependent distribution of species in this arid ecosystem [28]. It can therefore be concluded that the development of a plant beneath the canopy of another facilitating plant hinges on its physiological tolerances and minimal resource requirements, especially as regards light, temperature and soil water content. Along with their role in plant interactions, shrub patches greatly alter plant distribution patterns by processes such as trapping of water-, wind-and bird-dispersed seeds [17]. The further expansion of knowledge pertaining to these links and the factors controlling the shrub patches distribution, will certainly enhance the understanding of ecosystem operating in semi-arid degraded ecosystems, and will help in designing appropriate measures to manage, protect and reinstate these ecosystems.

Among the essential nutrients to all plants, nitrate, phosphorus, anions and cations and various trace elements can be mentioned [26]. In the Tunisian arid zone, is typified by soils with minimal levels of the before mentioned elements, whose increase in concentration can act as a determining factor of the composition, structure and productivity of vegetation. Moreover, the woody species may preserve herbaceous plants from herbivory, especially when they have spines [29]. In windswept arid zones, shrubs offer a much better shield for species growing under their canopy. This may very well explain the rise in the total plant cover spotted under tree canopy compared to the open area [30-34].

Conclusion

The obtained results in the present research work revealed the positive effect of endogenous shrubs species on understory vegetation and soil nutrients in arid ecosystems. The shrubs'net effect on their own environment, whether positive or negative, is strongly dependent on the species itself. Given that *R. raetam* had the best effect compared to the other shrubs, it is expected that the species presents the strongest positive effect on soil fertility and understory vegetation. Hence, it seems to be more beneficial than the other studied shrubs as a restoration species in the Tunisian arid areas and more appropriate to establish islands of resources and promote succession than the other examined shrub species.

Conflict of Interest

Zouhaier Noumi has a conflict of interest with Pr. Mohamed Chaieb from the University of Sfax.

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