Plant Ecol (2007) 190:23–35
DOI 10.1007/s11258-006-9188-2

ORIGINAL PAPER

Impacts of the invasive exotic *Prosopis juliflora* (Sw.) D.C. on the native flora and soils of the UAE

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Received: 21 February 2005 / Accepted: 28 June 2006 / Published online: 28 July 2006

Abstract The effects of the invasive exotic *Prosopis juliflora* shrubs on the natural plant communities and soil chemical characters were assessed in two regions of the United Arab Emirates (UAE). Five sites were selected subjectively: three in Sharja with 73 stands and two in Ras Al-Khima with 37 stands. Stands were located randomly within each site to cover density variation in Sharja and size variation in Ras Al-Khima. Density, frequency, richness and evenness of the associated annual and perennial species were studied in nine quadrats distributed under, at the margin and outside the canopy of a *P. juliflora* shrub located in the center of each stand. The results indicated that the effect of *P. juliflora* on the associated flora depends significantly on the density and size of the canopy. Larger individuals and greater densities have significantly greater negative impacts on the associated plants. All the studied community attributes were significantly lower under *P. juliflora* canopies than outside. Annuals were inhibited more than perennials. The number of annuals with significant reductions in density and/or frequency under *P. juliflora* canopies was significantly greater than the number of perennials. Density of more than 50% of the associated annuals was significantly inhibited under *P. juliflora* canopies. Density of *P. juliflora* seedlings was greater underneath the canopy of the same species than away from them, indicating little or no self allelopathic effect (auto-inhibition) under field conditions. *P. juliflora* ameliorated some soil characters, through significant pH reduction and increase in K, N and P and organic matters. Hence, plant diversity might be enhanced following eradication of *P. juliflora*.

Keywords Allelopathy · Community structure · Desert habitats · Introduced species · Invasive species · Size effect · Species diversity

Introduction

Many plants have extended their ranges in the past few centuries as a consequence of human activities. Many of these introduced species are considered pests for agricultural and horticultural industries as they pose an economic threat to these industries (Dunbar and Facelli 1999). Several authors have considered the increasing number of introduced or invasive species as a

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major component of global change because of their potential to alter primary productivity, decomposition, hydrology, nutrient cycling, and natural disturbance regimes (Vitousek et al. 1997; Harrod 2001; Zalba et al. 2000). Several international organizations have incorporated the invasive plant species issue in their main activities and have formulated guidelines for their management and eradication (Vitousek et al. 1997).

The invasion of non-indigenous plants is considered as a primary threat to integrity and function of ecosystems (Blossey et al. 2001). For example, in Florida, about 39–64% of the invasive exotic species has potentially altered ecosystem properties including geomorphology, hydrology and biogeochemistry (Gordon 1998). In addition, several recent investigations have shown that invasive plants have changed several community attributes including species diversity, richness, species composition and abundance (Prieur-Richard et al. 2002; Collier et al. 2002; Badano and Pugnaire 2004; Hoffmann et al. 2004). For example, Lockhart et al. (1999) showed that the invasive *Cupaniopsis anacaudioides* significantly reduced species richness in Florida. Frankel (1999) showed that alien plants displace local flora, change ecosystems and upset biodiversity in the parkway reservation in Westchester, New York. Ewe and Sternberg (2003) have shown that dense infestations of *Schinus terebinthifolius*, an invasive exotic plant widely found in Florida and Hawaii, displaced native species and reduced species diversity. More recently, Badano and Pugnaire (2004) showed that diversity of native species in sites invaded with the *Agave* species in Spain was lower than in non-invaded sites. In addition, the invasive alien grass *Melinis minutiflora* negatively affected the number of species at the savanna-forest ecotone in the Brazilian Cerrado (Hoffmann et al. 2004).

Several reviews have shown deserts to be among the least-invaded ecosystems worldwide, at least in terms of the number of naturalized and invasive species (e.g., Lonsdale 1999; Brooks and Pyke 2001). In desert habitats, many studies described the factors that promote plant invasions, but few investigated the impacts on biodiversity (Brooks and Pyke 2001, but see Fischer et al. 1996; Badano and Pugnaire 2004).

Although some exotic plant introductions were accidental, many were intentional for wildlife and habitat improvement, ornamental purposes, wood or fiber production, soil conservation, livestock forage production, or other crop uses (Harrod 2001). *Prosopis juliflora* (Sw.) DC. (Mesquite) is a shrub native to Central and South America. It was introduced to several deserts in the subtropical regions, including Arab Gulf regions, for greening of landscapes and for sand and desertification control (Western 1989; Ghazanfar 1996). Currently, it has escaped plantations and dominates many plant communities and is considered a weed. It is highly aggressive and coppices so well that it crowds-out native vegetation (Tiwari 1999; Al-Rawai 2004). The aim of the present study is to evaluate the impacts of *P. juliflora* on the community structure of native flora in the desert environment of the UAE. We examine community attributes including number of species, species richness, relative evenness of species, species density, species frequency and species composition. The impact of this species on soil physical and chemical characters will be also evaluated in order to assess the role of this factor on native plants growing with *P. juliflora*. We expect that the invasion and spread of *P. juliflora* will cause local extinctions of the native flora, resulting in the reduction of species richness and diversity.

Methods

Study area

Two representative regions (Ras Al-Khima and Sharja) were selected to cover the distribution range of *Prosopis juliflora* in the UAE. Ras Al-Khima is located on the northern coast and Sharja on the eastern coast of the UAE. Soils of Sharja are sandy and those of Ras Al-Khima are loamy. The average rainfall is comparable in the two regions, but Ras Al-Khima receives extra amount of water rainfall through run-off from the surrounding mountains.

Impacts of *P. juliflora* on associated flora

Three sites were selected subjectively in Sharja and two in Ras Al-Khima. Sites of each region were selected to have a reasonable degree of physiognomic homogeneity and to be as close to each other as possible (within 1 km). In Ras Al-Khima, *P. juliflora* varied greatly in their sizes but had an almost homogenous density (about 10 individuals/100 m^2). On the other hand, *P. juliflora* in Sharja sites had medium sizes (5–10 m diameters), but with different densities. The densities in the three Sharja sites were 9.5, 14 and 35 individuals/100 m^2. A total of 73 stands were located randomly in the Sharja sites and 37 stands in the Ras Al-Khima sites. These stands covered the density variation in Sharja and size variation in Ras Al-Khima.

A shrub of *P. juliflora* was localized near the center of each stand to serve as a focal point. The area of each stand was 225 m^2 (15×15 m). In each stand, nine 1 m^2 quadrats were distributed on three transects; 3 quadrats under, 3 at the margin and 3 outside the individual *P. juliflora* canopy. A species list was compiled in each stand. The absolute density (the number of plants of a certain species rooted within 100 m^2) and frequency (the number of total quadrats that contain at least one rooted individuals of a given species) were estimated for each species. Some other community attributes were also estimated, including species number, species richness (average number of species per stand), and species evenness as estimated by Shannon-Weaner index. Nomenclature was according to Western (1989). Sizes of *P. juliflora* individuals were classified based on their average canopy diameters into small (<5 m), medium (5–10 m) and large (>10 m).

Soil analysis

In each stand, two soil samples were collected from the upper 10 cm of the soil: one from underneath (halfway between the trunk and the edge of the canopy) and one from at least 2 m away from the edge of *P. juliflora* canopy. Soil samples from the same position (underneath or outside the canopy) were mixed in each of the three Sharja sites, which have different densities. In Ras Al-Khima, soil samples from the same position were mixed, regardless of the site. All soil samples were air dried, homogenized and sieved to remove large particles. Soil organic matter content, pH, salinity and some nutrients were estimated. Organic matter content was estimated using loss of mass by combustion at 430°C on the < 2 mm soil fraction. Soil water extracts (1:2.5 of soil:water) were prepared for the determination of electrical conductivity (EC) and pH using conductivity and pH meters. Available nitrogen was extracted using 2 M KCl and determined by the micro-Kjeldahl method. Available phosphorous was estimated using Olsen's solution (sodium bicarbonate) as an extracting agent. Na and K were estimated by using flame photometry. These methods are outlined in Black (1965).

Statistical analysis

The differences in total number of species between different positions from the individual canopy (under, margin and outside the canopy) and between different sizes of *P. juliflora* shrubs were assessed by using χ^2 tests. Two-way analyses of variances (ANOVAs) were used to evaluate the effect of the main factors (crown size or density and position from the canopy) on species density, evenness, and richness and soil characters in Sharja. Density effect was evaluated in the three Sharja sites. In order to minimize the confounding effect of site and density study, sites which had a reasonable degree of physiognomic homogeneity and were as close to each other as possible (within 1 km) were selected.

One way ANOVAs were used to compare the density of associated species at different position from *P. juliflora* canopies in both Sharja and Ras Al-Khima. The sites of each region were pooled to provide a reliable sample size. One way ANOVAs were also used to compare soil characters beneath and outside canopies in Ras Al-Khima region. Species density was square-root transformed to meet the assumption of the ANOVA. This transformation improved the normality of the distribution of the data. Tukey test (Honestly significant differences, HSD) was used to estimate the least significant range between means. All statistical methods were performed using SYSTAT, version 11.0.

Results

Effects on species diversity and density

Effect of P. juliflora *density*

The effects of *P. juliflora* density on the number of associated species, species evenness, richness and density were evaluated in three sites in Sharja (Fig. 1). Two-way ANOVAs showed significant effects for both density and position from the *P. juliflora* canopy on evenness, richness and density of associated species (Table 1). At lower density of *P. juliflora*, species evenness, richness and density were significantly lower under than outside or at the edge of the canopies. On the other hand, species evenness and density did not differ significantly between under and outside the canopies of medium and higher densities. Species evenness, richness and density were significantly lower for all positions at medium and higher densities than at those of lower density (Fig. 1).

Table 1 Two way ANOVAs (*F*-values) for the effects of density and position from canopies of *Prosopis juliflora* on evenness, richness and density of associated species

Community attributes	Density (*D*)	Position from canopy(*P*)	*D***P*
Evenness	12.61**	3.2*	1.20
Richness	18.5**	8.04**	2.22*
Density	70.5**	14.9**	13.4**

* $P < 0.05$, and ** $P < 0.001$

The interaction between density and position from *P. juliflora* canopy on species richness and density of associated species was significant ($P < 0.05$, Table 1). Richness was significantly greater under and at the margin of medium density stands than those of higher density stands, but there was no significant difference outside the canopies in the two densities. In sites with lower density of *P. juliflora*, density of associated species was significantly greater outside than at the margin of the canopies and both attained significantly greater values than under the canopies. In sites with medium and higher densities of

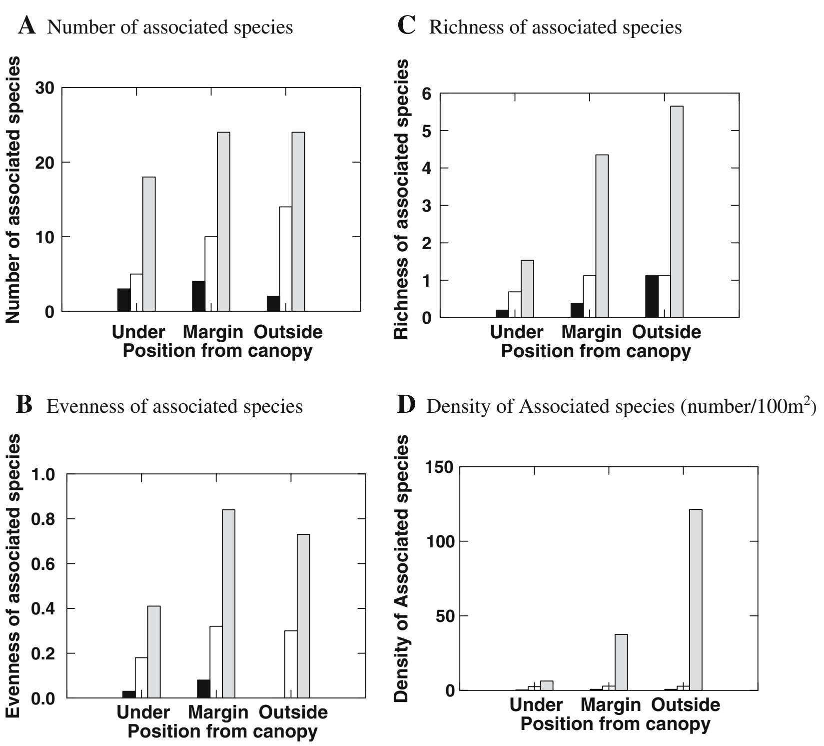

Fig. 1 Effects of density and position from canopies of *Prosopis juliflora* on total number of species, evenness, richness and absolute density of associated species in the three sites of Sharja. Closed, open and shaded bars are for high, medium and low densities of *P. juliflora* (35, 14 and 9.5 individuals/1000 m^3, respectively)

P. juliflora, however, there were no significant differences between the three positions (Fig. 1). This indicates that the depressive effect of the *P. juliflora* extended outside their canopies when their density is medium or high.

The effect of *P. juliflora* canopies on the number of associated species was significant in sites with lower ($\chi^2 = 6.95$, $P < 0.05$) and medium ($\chi^2 = 8.02$, $P < 0.01$) densities, but not in the site with higher densities ($\chi^2 = 3.0$, $P > 0.05$). The number of species was greater outside than underneath the canopies by 180% and 33.3% in sites with lower and medium densities, respectively. In the site with higher density, there was no significant difference between the numbers of species at the different positions from *P. juliflora* canopies. All canopy positions in the site with higher density exhibited significantly lower number of species than those in the other two sites with lower densities (Fig. 1).

Effect of P. juliflora *size*

The size effect of *P. juliflora* canopies on community attributes was studied in Ras Al-Khima (Fig. 2). Two-way ANOVAs showed significant effects for both canopy size and position from the *P. juliflora* canopy on species evenness and species richness and for position from the canopy on absolute density of associated species (Table 2). The χ^2 analysis also showed significant effect for the position from canopies on the number of species associated with medium ($\chi^2 = 6.65$, $P < 0.05$) and large ($\chi^2 = 10.69$, $P < 0.001$), but not with small ($\chi^2 = 2.13$, $P > 0.05$) *P. juliflora* canopies.

Generally, large and medium sized individuals of *P. juliflora* significantly reduced the number of species, species richness and evenness, and density under compared to outside their canopies. On the other hand, small shrubs did not significantly affect most of these attributes (Fig. 2). All community

Table 2 Two way ANOVAs (*F*-values) for the effects of size and position from canopies of *Prosopis juliflora* on evenness, richness and density of associated species

Community attributes	Size (S)	Position from canopy (P)	S * P
Evenness	8.41***	19.1***	1.91
Richness	6.61**	82.3***	12.2***
Density	1.65	28.8***	3.47*

* $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$

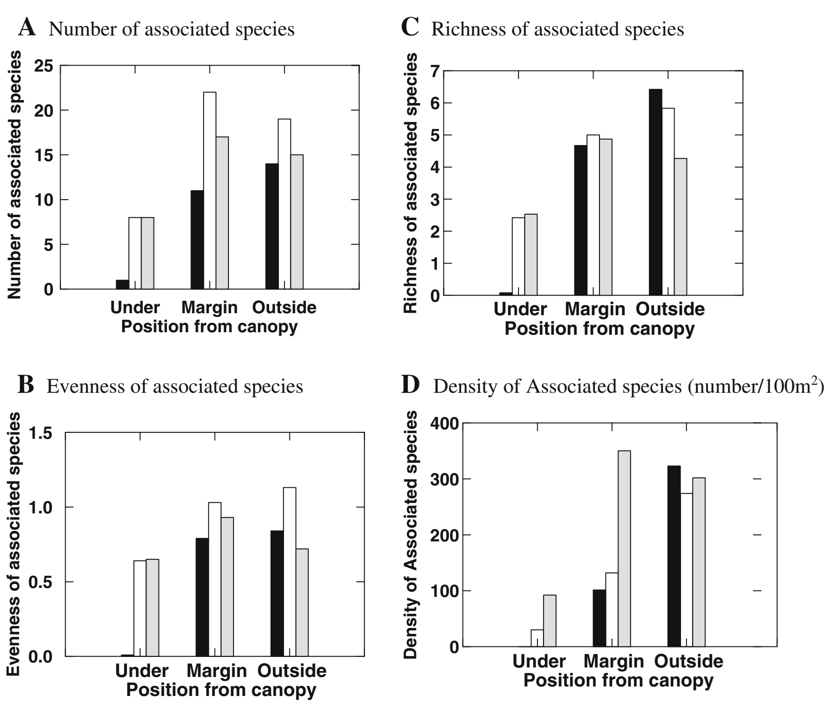

Fig. 2 Effects of size and position from canopies of *Prosopis juliflora* on total number of species, evenness, richness and absolute density (number/100 m^2) of associated species in Ras Al-Khima. Closed bars = large sizes, open bars = medium sizes and shaded bars = small sizes of *P. juliflora*

attributes were inhibited under large shrubs. There were one and eight species under large and medium canopies, respectively; increased to 19 and 14 outside them, respectively. The effect of *P. juliflora* canopies on density of associated species increased with the increasing size of canopies. Species density decreased from 92.3 and 30.1 individuals under the canopies of small and medium shrubs to only 0.1 individuals/100 m^2 under the canopies of large shrubs (Fig. 2).

The interaction between canopy size and position from canopy on species richness and density of associated species was significant ($P < 0.05$, Table 2). There was no significant difference in species richness between the three positions of small and medium shrubs, but it was significantly greater at the edge and outside the larger canopies than beneath them. Similarly, density of associated species being significantly lower beneath than both at the margin and outside the canopies of the three sizes, but was almost inhibited under the canopies of larger shrubs (Fig. 2).

Effects on species composition

Ras Al-Khima region

One-way ANOVAs showed that density of 18 species, out a total of the 30 species recorded at

Table 3 Effect of *Prosopis juliflora* canopy on frequency (N = number of stands in which species appeared and percentage out of a total 37 examined stands) and density (number of individuals per 100 m^2) of associated species in Ras Al-Khima sites

Species	Place from canopy									F^+
	Under			Margin			Outside			
	N	%	Den	*N*	%	Den	*N*	%	Den	
Anagallis arvensis	0	0.0	0.0	3	7.7	30.8	3	7.7	30.8	**
Anastatica hierochuntica	0	0.0	0.0	0	0.0	0.0	3	7.7	15.4	**
Asphodelus tenuifolius	1	2.6	2.6	1	2.6	5.1	0	0.0	0.0	
Astragalus tribuloides	0	0.0	0.0	5	12.8	12.8	9	23.1	23.1	*
Bromus sp.	0	0.0	0.0	4	10.2	94.9	4	10.2	1312	***
Centaurea pseudosinaica	0	0.0	0.0	1	2.6	2.6	0	0.0	0.0	
Chenopodium murale	15	38.5	256	20	51.3	217	22	56.4	217.9	
Cutandia memphitica	0	0.0	0.0	2	5.1	7.7	2	5.1	7.7	
Emex spinosus	6	15.4	15.4	24	61.5	264	14	35.9	351.3	***
Erodium neuradifolium	0	0.0	0.0	2	5.1	23.1	1	2.6	2.6	***
Hammada elegans	0	0.0	0.0	0	0.0	0.0	1	2.6	2.6	
Hippocrepis constricta	0	0.0	0.0	1	2.6	2.6	1	2.6	2.6	
Launaea capitata	2	5.1	5.1	3	7.7	15.4	5	12.8	17.9	
Lotus glinoides	0	0.0	0.0	1	2.6	7.7	3	7.7	23.1	**
Lycium shawii	2	5.1	2.6	1	2.6	1.3	0	0.0	0.0	
Malva parviflora	16	41.0	600	30	76.9	4015	30	76.9	4289	***
Medicago laciniata	3	7.7	23.1	12	30.7	930	22	56.4	2741	***
Melilotus indicus	11	28.2	420	16	41.0	364	12	30.8	330.8	
Paronychia arabica	0	0.0	0.0	4	10.3	28.2	5	12.8	20.5	**
Plantago ovata	0	0.0	0.0	9	23.1	79.5	12	30.8	92.3	***
Prosopis juliflora	9	23.1	23.1	0	0.0	0.0	0	0.0	0.0	***
Salsola baryosma	3	7.7	43.6	9	23.1	15.4	2	5.1	12.8	**
Schismus barbatus	0	0.0	0.0	6	15.4	76.9	4	10.3	89.7	***
Silene villosa	0	0.0	0.0	2	5.1	30.8	3	7.7	25.6	**
Sisymbrium erysimoides	3	7.7	25.6	10	25.6	192	11	28.2	315.4	***
Spergularia marina	4	10.2	33.3	19	48.7	138	20	51.3	166.7	***
Sporobolus spicatus	2	5.1	5.1	0	0.0	0.0	0	0.0	0.0	
Tragus berteronianus	0	0.0	0.0	0	0.0	0.0	9	23.1	23.1	***
Trigonella hamosa	0	0.0	0.0	2	5.1	10.2	4	10.3	17.9	*
Urospermum picroides	0	0.0	0.0	3	7.7	15.4	3	7.7	15.4	*

* $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. $^+$ F-values test the difference between the densities of each species

Ras Al-Khima, was significantly reduced beneath than outside canopies of the *P. juliflora* ($P < 0.05$, Table 5). Density of 11 out of these 18 species was only 0–2 individuals/100 m^2 under canopies. The other seven species attained more than 15 individuals/100 m^2 under canopies (one of them, *Malva parviflora*, attained 600 individuals under compared to 4,289 individuals/100 m^2 outside canopies). In addition, six other species were not represented by a single individual under *P. juliflora* canopies, so their densities did not differ significantly by location outside and under the canopy ($P > 0.05$). All the species that were inhibited by *P. juliflora* canopies were annuals. Two other annuals (*Chenopodium murale* and *Melilotus indicus*) attained higher densities and frequencies both under and outside the canopies. However, seedlings of *P. juliflora* attained significantly greater density under than at the margin and outside the canopies. Individuals of *Salsola baryosma*, another perennial species, attained significantly greater density at the margin than both beneath and outside canopies of *P. juliflora* (Table 3).

By using the total number of annuals (24 species) and perennials (6 species) recorded in Ras Al-Khima as expected values, χ^2 showed that the number of annuals that attained significantly lower density under *P. juliflora* canopies (18 species) was significantly greater than number of perennials (1 species) ($\chi^2 = 5.67$, $P < 0.05$).

Sharja region

In the Sharja region, density of 10 annual species were significantly reduced beneath *P. juliflora* canopies than outside them ($P < 0.05$). Similar to Ras Al-Khima, seedlings of *P. juliflora* attained significantly greater density under than at the margin and outside their canopies. Also, *Salsola baryosma* attained significantly greater density at the margin than both beneath and outside canopies of *P. juliflora* (Table 4). Again, the number of annuals that attained significantly lower density under *P. juliflora* canopies was significantly greater than number of perennials (one species) ($\chi^2 = 17.83$, $P < 0.001$; 10 out of 21 annuals and 1 out of 14 perennials showed reductions).

Effects on soil characters

In Sharja, two-way ANOVAs showed significant effects for both position from canopy and density of *P. juliflora* on most of soil characters ($P < 0.05$, Table 5). In sites with low and medium densities, pH values were decreased but those of EC, Na, K, N and organic matter were increased beneath rather than outside *P. juliflora* canopies. N, P, and organic matter content attained greater values in sites with higher density than sites with medium and low densities of *P. juliflora* plants (Table 6). The interaction between position from canopy and density of *P. juliflora* shrubs was significant for EC and Na ($P < 0.05$, Table 5). EC and Na attained significantly lower values outside than beneath canopies of sites with medium and low densities, but no significant difference was detected in site with higher density (Table 6). In Ras Al-Khima sites, one way ANOVAs showed that pH decreased, but EC and P increased significantly under *P. juliflora* canopies (Tables 5, 6).

Discussion

Several studies have shown that the ecological impacts of invasive plants include displacement of indigenous species and declines in species richness and diversity (e.g., Lonsdale 1999; Brooks and Pyke 2001; Kedzie-Webb et al. 2001; Lesica and Miles 2001; Prieur-Richard et al. 2002; Badano and Pugnaire 2004; Hoffmann et al. 2004). The present study showed a great depressive effect of the invasive *P. juliflora* on the number, richness, evenness, density and frequency of the associated native species. Especially important is that the depressive effect extended beyond the canopy-covered ground for dense sites. Old and dense sites of *P. juliflora* resulted in significantly lower density, frequency and diversity for most associated annual species. In a similar study, Collier et al. (2002) found lower species richness and abundance in plots under canopies of *Lonicera maackii* than in plots outside. Similarly, in their study on silvopastoral farming system in the semi-arid regions of south-east Rajasthan, India, Kothari and Jain (2003) found the lowest

Table 4 Effect of the canopy of *Prosopis juliflora* on species frequency (*N* = number of stands in which species appeared and percentage out of a total 73 examined stands) and density (number of individuals per 100 m^2) in Sharja sites

Species	Place from canopy									F^+
	Under			Margin			Outside			
	N	%	Den	*N*	%	Den	*N*	%	Den	
Aeluropus massauensis	4	5.47	2.7	0	0.0	0	0	0.0	0	
Anastatica hierochuntica	0	0.0	0	4	5.47	9.0	6	8.22	12.6	
Bassia muricata	0	0.0	0	1	1.37	1.8	1	1.37	1.4	
Cenchrus ciliaris	0	0.0	0	4	5.47	6.4	4	5.47	4.6	
Centaurea pseudosinaica	0	0.0	0	4	5.47	4.6	11	15.1	16.9	**
Chenopodium murale	2	2.74	1.8	4	5.47	6.4	5	6.85	9.6	
Cleome rupicola	0	0.0	0	2	2.74	0.9	6	8.22	2.7	
Cornulaca monacantha	0	0.0	0	0	0.0	0	1	1.37	0.4	
Cutandia memphitica	2	2.74	0.9	12	16.4	18.3	17	23.3	44.7	**
Cyperus conglomeratus	0	0.0	0	0	0.0	0	1	1.37	0.5	
Emex spinosus	2	2.74	0.9	6	8.22	28.3	8	10.9	53.8	**
Erodium neuradifolium	0	0.0	0	6	8.22	22.8	6	8.2	26.5	**
Eremobium aegyptiacum	0	0.0	0	2	2.74	0.9	0	0.0	0	
Hippocrepis constricta	2	2.74	0.9	4	5.47	1.8	0	0.0	0	
Launaea capitata	0	0.0	0	8	10.9	3.6	11	15.1	7.8	
Lotus glinoides	4	5.47	3.6	18	24.6	350	24	32.9	1444	**
Lycium shawii	0	0.0	0	0	0.0	0	2	2.74	0.9	
Malva parviflora	2	2.74	6.4	4	5.47	21.9	7	9.59	7.8	*
Medicago laciniata	0	0.0	0	6	8.22	3.6	2	2.74	0.9	*
Neurada procumbens	0	0.0	0	2	2.74	0.9	10	13.7	13.7	**
Panicum turgidum	1	1.37	0.4	1	1.37	0.4	1	1.37	0.5	
Paronychia arabica	4	5.47	5.5	10	13.7	20.1	12	16.4	14.6	*
Pennisetum divisum	4	5.47	4.1	3	4.11	2.7	2	2.7	1.4	
Phalaris minor	4	5.47	50.4	3	4.11	14.4	5	6.84	15.5	
Phragmites australis	1	1.37	0.9	2	2.74	3.6	2	2.74	6.8	
Plantago ovata	4	5.47	15.5	12	16.4	53.9	13	17.8	32.4	**
Prosopis juliflora	8	10.9	9.1	3	4.11	3.6	0	0.0	0	*
Salsola baryosma	2	2.74	0.9	10	13.7	9.6	5	6.85	3.2	*
Schismus barbatus	4	5.47	5.5	8	10.9	34.7	12	16.4	38.4	**
Setaria verticellata	5	6.84	8.7	2	2.7	5.0	3	4.11	7.8	
Spergularia marina	0	0.0	0	6	8.22	1.8	4	5.47	1.4	
Sporobolus spicatus	3	4.11	5.9	3	4.11	1.8	1	1.37	0.5	
Stipagrostis plumosa	4	5.47	6.4	9	12.3	15.5	14	19.2	9.6	
Tragus berteronianus	2	2.74	0.9	5	6.85	6.8	7	9.59	10.0	
Zygophyllum hamiense	6	8.22	6.4	9	12.3	8.6	7	9.59	5.5	

* $P < 0.05$, and ** $P < 0.001$, $^+$ *F*-values test the difference between the densities of each species

Table 5 *F*-values for the effects of density and position from canopies of *Prosopis juliflora* on some chemical characters of soils in Sharja and Ras Al-Khima

Soil character	Sharja (two-way ANOVA)			Ras Al-Khima (one-way ANOVA)
	Density (*D*)	Position from canopy (*P*)	*D* * *P*	Position from canopy
pH	2.71	16.45***	0.82	79.3***
EC	42.0***	69.3***	24.4***	57.24***
Na	4.59*	4.5*	3.75*	0.20
K	0.13	9.12**	0.76	2.29
N	9.58**	28.22***	2.56	1.28
P	6.26*	1.42	0.17	29.0**
OM	4.77*	9.55**	2.56	0.20

* $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$

Table 6 Effects of *Prosopis juliflora* canopy on the mean values of some soil characters in Sharja and Ras Al-Khima sites

Region	Site	Place from canopy	pH	EC dS/m	Na meq/l	K meq/l	N ppm	P ppm	OM %
Sharja	1	Outside	7.55^a	3.9^b	30.2^b	7.5^b	6.2^b	4.6^b	5.5^b
		Under	6.99^b	11.7^a	63.1^a	13.3^a	8.7^a	6.6^b	9.3^a
	2	Outside	7.30^a	3.4^b	30.5^b	8.5^b	7.2^b	4.0^b	3.9^b
		Under	6.75^b	14.2^a	68.9^a	12.4^a	9.8^a	4.9^b	8.0^a
	3	Outside	7.10^a	3.0^b	32.0^b	9.9^b	8.9^a	10.2^a	9.5^a
		Under	6.85^a	2.5^b	21.4^b	11.4^a	9.8^a	11.1^a	9.7^a
Ras Al-Khima	1 + 2	Outside	6.99^a	1.2^b	23.4^a	13.9^a	5.7^a	8.2^b	5.9^a
		Under	6.64^b	2.1^a	26.9^a	20.6^a	7.5^a	13.7^a	8.2^a

Means of each soil character, within each region, with the same letter are not significantly different at $P < 0.05$. Densities of *P. juliflora* were 9.5, 14 and 35 individuals/1000m^3 in sites 1, 2 and 3 respectively

mean dry grass biomass under *P. juliflora* and *Eucalyptus* canopies. Another study investigated the vegetation succession on salt-affected soils after 5 years of plantation with two exotic salt bushes and three tree species indicated that only three species were recorded with *P. juliflora*, compared to 7–8 species with the other trees (Arya 2003). The growing of *P. juliflora* shrubs, as well as exotic *Eucalyptus*, in the forests of the UAE has resulted in significant reductions in both species diversity and abundance of understory species, compared to the native *P. cineraria* and *Acacia arabica* (El-Keblawy and Ksiksi 2005).

The success of exotic plants in invading some communities has been attributed to superiority of the exotic over the native species in some measurable traits, such as reproductive and dispersal capabilities, seedling establishment and survivorship, genome size, phenotypic plasticity, growth related characteristics, plant height, susceptibility to herbivory and pathogens, phenology, mutualistic interactions, allelopathy and plant–soil relationships (Pattison et al. 1998; Smith and Knapp 2001; Ridenour and Callaway 2001; Cadotte et al. 2005, Barrat-Segretain 2005, Orr 2005). Shiferaw et al. (2004) reported that *P. juliflora* is equipped with a number of biological characteristics related to seed dormancy, germination and dispersal that can facilitate its rapid invasion of new areas (see also El-Keblawy and Al-Rawai 2005). In addition, *P. juliflora* has great ability to resprout with quick coppice growth from stumped/damaged trees, making it a very strong competitive invader (Shiferaw et al. 2004). Furthermore, Sharma and Dakshini (1998) described *P. juliflora* as fast growing, highly aggressive, and able to cause substratum degradation in the semi-arid and arid areas of north and north-west India. Al-Rawai (2004) attributed the great invasive ability of*P. juliflora* to its rapid growth rate and greater reproductive efforts. The smaller individuals of *P. juliflora* were observed to double their size within 1 year (Al-Rawai 2004).

The depressive effect of some exotic species on the associated flora has been attributed to allelopathy, which is an interference mechanism by which plants release chemicals that affect other plants (Wardle et al. 1998; Ridenour and Callaway 2001; Brewer 2002; Bais et al. 2003, Orr et al. 2005). For example, the release of some organic compounds from the dead vegetation and litter of *Hex glabra* inhibited seedling emergence in the southeastern United States (Brewer 2002). In addition, Wardle et al. (1998) indicated that the secondary metabolites released from *Carduus nutans* (nodding thistle) in New Zealand pastures and *Empetrum hermaphroditum* (crowberry) in Swedish boreal forests alter both structure of the plant community and ecosystem properties. Bais et al. (2003) reported that the invasive *Centaurea maculosa* in western United States displaced native species by exuding phytotoxin from its roots. Furthermore, Aqueous extracts derived from soil, leaf litter, or live leaves of *Lolium arundinaceam* and *Elaeagnus umbellate* (two invasive species) exhibited some inhibitory effects on three native tree species (*Acer saccharinum, Populus deltoids* and *Platanus occidentalis*) (Orr et al. 2005).

Several experimental studies have shown allelopathic effects for *P. juliflora* under laboratory conditions. A water-soluble extract from different parts of *P. juliflora*, including litter, had been shown to inhibit seed germination of many species. For example, aqueous extracts from under canopy soil and from different parts of *P. juliflora* inhibited germination and early seedling growth of various cultivars of *Zea mays, Triticum aestivum* and *Albizia lebbeck* (Noor et al. 1995). In addition, Al-Humaid and Warrag (1998) concluded that *P. juliflora* leaves contain water-soluble allelopathins which could inhibit seed germination and retard rate of germination and seedling growth in *Cynodon dactylon*. In pot studies examining the allelopathic effects of *P. juliflora* leaf litter, Chellamuthu et al. (1997) indicated that germination of black gram (*Vigna mungo*), sorghum (*Sorghum bicolor*) and *P. juliflora* was significantly reduced with the maximum reduction occurring at 2% incorporation of *P. juliflora* leaf litter. In addition, Warrag (1994, 1995) concluded that *P. juliflora* pericarp and leaves contain water-soluble allelopathins which inhibit germination and seedling growth of the same species. Furthermore, several studies showed that the leaf extract of *P. juliflora* inhibited mycelial growth and spore germination of several pathogenic fungi including *Pyricularia oryzae*, which cause blast disease in rice (Kamalakannan et al. 2001), as well as *Colletotrichum capsici* and *Gloeosporium piperatum* infecting *Capsicum annum* (Gomathi and Kannabiran 2000).

In the present field study, total number of species, species richness, evenness, frequency and density of native plants attained significantly lower values underneath compared to away from *P. juliflora* canopies. However, the number of seedlings of *P. juliflora* recorded underneath the canopy of the same species was significantly greater than away from them. This indicates that *P. juliflora* plants under field condition could produce allelopathic substances that would inhibit the growth of associated species, especially annuals, but not their seedlings. This contradicts results published by Warrag (1994, 1995) and Chellamuthu et al. (1997) who concluded that *P. juliflora* pericarp and leaves contain water-soluble allelopathins which inhibit germination and seedling growth of the same species under laboratory conditions. Chellamuthu et al. (1997) suggested that the allelopathic effect of *P. juliflora* leaf litter is due to the presence of some phenolic compounds. Nakano et al. (2001) suggested that L-tryptophan may play an important role in the allelopathy of *P. juliflora* leaves. The content of L-tryptophan in the exudates of freeze-dried mesquite leaves (1 mg eq.) was estimated to be 4.8×10^{-3} mM (Nakano et al. 2001). Nakano et al. (2004) also isolated plant growth inhibitory alkaloids from the extract of *P. juliflora* leaves.

It has been demonstrated that some native plants respond differently for allelopathic substances produced from the same exotic species. For example, Orr et al. (2005) indicated that *Populus deltoids*, a native tree, may gain a competitive advantage when colonizing sites with one or both of two exotic plants (*Lolium arundinaceam* and *Elaeagnus umbellate*), whereas other species (e.g., *Platanus occidentalis*) may be suppressed. In the present study, the depressive effect of *P. juliflora* canopies on abundance of annuals was significantly greater than on that of perennials. This could be attributed to the shorter life cycles of annuals compared to perennials. Most seedlings of both annuals and perennials could be prevented from emergence, or their growth inhibited, because of some allelopathic substances produced by *P. Juliflora* litters. Annuals need to establish their seedlings every year, but the established seedlings of perennials continue in the community for more than 1 year.

The ability of some *P. juliflora* seeds to tolerate conspecific allelopathic substances and grow underneath their canopies increases poses more challenges to the invasive ability of this species; especially interspecific competition is reduced by the inhibition of other associated species. More than 25% of the populations of *P. juliflora* are seedlings of less than 1-year-old (El-Keblawy, unpublished data), indicating that populations of this species are rapidly growing.

In arid and semi-arid environments, where plant cover is scarce and patchy, there is often a conspicuous concentration of vegetation near and especially beneath shrubs, that form the so called ''islands of fertility'' (Garner and Steinberger 1989; Pugnaire et al. 1996; Hagos and Smit 2005).

Shrubs and trees may cause an accumulation of mineral nutrients and water, leading to a local increase in soil fertility (Pugnaire et al., 1996) while protecting the understory species against high irradiance and temperature (Vetaas 1992). In the present study, soil fertility was significantly enhanced beneath rather than away from *P. juliflora* canopies (Table 6). In addition, rainfall interception in the canopy would reduce water run-off and permit water to be absorbed and stored in the soil. However, the understory vegetation was significantly inhibited under canopies of *P. juliflora*. This further supports the hypothesis of the allelopathic inhibition from *P. juliflora* on the associated plants.

Even though *P. juliflora* showed negative impacts on the abundance and biodiversity of native flora, it did ameliorate the soil characters. The growing of *P. juliflora* resulted in a significant reduction of soil pH and increase in K, N, P and organic matters (Table 6). Several studies have shown the ability of *P. juliflora* in fixing atmospheric nitrogen (e.g., Aronson et al. 1992). Garg and Singh (2003) have shown that nutrient concentrations (N, P, K, Ca and Mg) of *P. juliflora* stand were significantly greater than that of other woody species. Also, Goel and Behl (1999) reported that *P. juliflora* plantation resulted in a marked decrease in soil pH and sodium content, and improved organic carbon, N, K and P concentrations of the soil. Results of Menezes et al. (2002) indicated that *P. juliflora* in semi-arid northeastern Brazil significantly affected the microclimate and the dynamics of litter and soil nutrients, and may contribute to increases in the rate of nutrients cycling in these systems. The amelioration of soil characters by *P. juliflora* is particularly important in sandy soils of the UAE, which are characterized by lower fertility and higher pH. Greater plant diversity would be expected on these soils following the eradication of *P. juliflora*.

Acknowledgements This work was financially supported by the Research Affairs at the UAE University Under a contract no. 18-2-11/01. The authors are grateful to Marc Cadotte, Dept of Ecology and Evolutionary Biology, University of Tennessee, Jon Lovett-Doust, University of Windsor, Canada, Taoufik Ksiksi and Tony Quirke, UAE University, for their critical revision of the manuscript.

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