10821

The introduced tree *Prosopis juliflora* is a serious threat to native species of the Brazilian Caatinga vegetation

CrossMark

Clóvis Eduardo de Souza Nascimento [a,b], Marcelo Tabarelli [c], Carlos Alberto Domingues da Silva [d,e], Inara Roberta Leal [c], Wagner de Souza Tavares [f], José Eduardo Serrão [g], José Cola Zanuncio [h,*]

[a] Empresa Brasileira de Pesquisa Agropecuária, Centro de Pesquisa Agropecuária do Trópico Semi-Árido, 56300-970 Petrolina, Pernambuco, Brazil
[b] Departamento de Ciências Humanas, Universidade do Estado da Bahia, 48900-000 Juazeiro, Bahia, Brazil
[c] Departamento de Botânica, Universidade Federal de Pernambuco, 50670-901 Recife, Pernambuco, Brazil
[d] Empresa Brasileira de Pesquisa Agropecuária, Centro Nacional de Pesquisa de Algodão, 58428-095, Brazil
[e] Programa de Pós-Graduação em Ciências Agrárias, Universidade Estadual da Paraíba, 58429-570 Campina Grande, Paraíba, Brazil
[f] Departamento de Fitotecnia, Universidade Federal de Viçosa, 36570-900 Viçosa, Minas Gerais, Brazil
[g] Departamento de Biologia Geral, Universidade Federal de Viçosa, 36570-900 Viçosa, Minas Gerais, Brazil
[h] Departamento de Biologia Animal, Universidade Federal de Viçosa, 36570-900 Viçosa, Minas Gerais, Brazil

HIGHLIGHTS

- *Prosopis juliflora* reduced growth of native Caatinga species tested.
- *P. juliflora* increased the mortality of all species of native plants tested.
- *Mimosa tenuiflora* and *Caesalpinia ferrea* had the lowest mortality and highest height.
- *M. tenuiflora* and *C. ferrea* may present a viable option to management systems.

ARTICLE INFO

ABSTRACT

Despite its economic importance in the rural context, the *Prosopis juliflora* tree species has already invaded millions of hectares globally (particularly rangelands), threatening native biodiversity and rural sustainability. Here we examine seedling growth (leaf area, stem diameter, plant height) and seedling mortality across five native plant species of the Caatinga vegetation in response to competition with *P. juliflora*. Two sowing treatments with 10 replications were adopted within a factorial 2×5 randomized block design. Treatments consisted of *P. juliflora* seeds sowed with seeds of *Caesalpinia ferrea*, *Caesalpinia microphylla*, *Erythrina velutina*, *Mimosa bimucronata* and *Mimosa tenuiflora* (one single native species per treatment), while seeds of native species sowed without *P. juliflora* were adopted as controls. Overall, our results suggest that *P. juliflora* can reduce seedling growth by half and cause increased seedling mortality among woody plant species. Moreover, native species exhibit different levels of susceptibility to competition with *P. juliflora*, particularly in terms of plant growth. Such a superior competitive ability apparently permits *P. juliflora* to establish monospecific stands of adult trees, locally displacing native species or limiting their recruitment. The use of less sensitive species, such as *C. ferrea* and *M. tenuiflora*, to restore native vegetation before intensive colonization by *P. juliflora* should be investigated as an effective approach for avoiding its continuous spread across the Caatinga region.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Biological invasions have emerged as a major threat for global biodiversity as they already represent one of the main causes of species extinction (Vitousek et al., 1996, 1997; Lenda et al., 2013). In addition to species extinction and biotic homogenization at multiple spatial scales, synergisms between human-mediated disturbances and biological invasions may threaten ecosystem integrity further by providing biomass for intense fires, for example (van Wilgen et al., 2008). In the case of plants, deliberate introductions of "useful species" represent the major source for the increment of exotic floras, from which many species achieve invasive status (Pyšek, 1998; Chapple et al., 2012).

Prosopis juliflora (Sw.) DC L., 1753 is an evergreen tree species, which is native of rangelands (i.e. steppe and savanna-like vegetation types) in South America, Central America and the Caribbean. It refers to a fast growing species, which is tolerant to arid conditions and saline soils; i.e. a drought-resistant species (Pasiecznik et al., 2004; El-Keblawy and

* Corresponding author. Tel.: +55 31 3899 2924; fax: +55 31 3899 2642.
E-mail address: zanuncio@ufv.br (J.C. Zanuncio).

Al-Rawai, 2005) like others within this genus (Adams et al., 2010). In addition to its aggressive nature, *P. juliflora* can provide valuable goods and services, such as timber, firewood and soil rehabilitation (Pasiecznik et al., 2001). These "desirable" characteristics have fuelled intentional introductions of *P. juliflora* across rural areas globally, with the consequent invasion of millions of hectares of rangelands in South Africa, East Africa, Australia, coastal Asia (Pasiecznik, 1999), and America (Kemp and Michalk, 2005). *P. juliflora* is now one of the top global invasive plant species according to the International Union for Conservation of Nature (IUCN).

One of the key attributes frequently exhibited by invasive species is their superior competitive ability as compared to native species (Rejmánek and Richardson, 1996). For example, *P. juliflora* can displace both agricultural and exotic plants and native species (Mwangi and Swallow, 2005) by delaying seed germination and reducing plant growth in terms of roots, shoots, leaf area, stem diameter, and plant height (Inderjit et al., 2008). Studies suggest that allelopathic substances produced by *P. juliflora*'s leaves, fruits, seeds, roots and flowers (Noor et al., 1995) affect species such as *Bambusa arundinacea* (Retz.) Willd. (Poaceae) (Inderjit et al., 2008) and *Echinochloa crus-galli* (L.) Beauv (Poaceae) (Goel et al., 1989; Nakano et al., 2003, 2004). Direct competition in addition to allelopathy may be the forces behind the successful invasion of sedimentary lowlands and alluvial river plains by *P. juliflora* (Pegado et al., 2006; Siddiqui et al., 2009), although evidence in favor of such a superior competitive ability is still scarce. In these more humid habitats (wetlands, riverbanks, alluvial plains), the first individuals form small agglomerates, from which *P. juliflora* expands and forms monospecific and persistent stands (Archer, 1995; Rajwant et al., 2012).

The Caatinga vegetation is a mosaic of scrub vegetation and patches of dry forest (Leal et al., 2005), which has been considered as a seasonally dry tropical forest in northeast Brazil (Bullock et al., 1995; Pennington, 2006; Santos et al., 2011). This singular biogeographic area (covering ca. 800,000 km^2) supports more than 1500 plant species, including a myriad of endemics; i.e. nearly 1/3 of the Caatinga flora consists of endemic species (Araújo et al., 2007; Albuquerque et al., 2012). As a semiarid region devoted primarily to activities such as agriculture and cattle-raising, the Caatinga has experienced deliberate species introductions as attempts to improve or turn viable farming-based activities (Cavalcante and Major, 2006). This region has also faced intensive habitat degradation from soil exhaustion, particularly in the case of low-input agriculture and overgrazing by livestock, creating a sort of synergism between human poverty and environmental degradation (Leal et al., 2005; Santos et al., 2011).

In this socio-ecological context, *P. juliflora* was introduced in the Caatinga region in the 1940s (Pegado et al., 2006) as a source of forage for livestock, charcoal, firewood, cuttings and stakes, among other uses (Pometti et al., 2007). Economically, *P. juliflora* is a key element across several land use systems that apparently have improved rural livelihoods (Rajwant et al., 2012) and prevented further soil degradation (El-Keblawy and Abdelfatah, 2014). Conversely, *P. juliflora* has naturally spread over degraded river banks and other habitats previously disturbed by human activities (i.e. *P. juliflora* has achieved the invasive status), establishing monospecific stands which, in the case of the Caatinga vegetation, compete with a myriad of native plant species such as *Caesalpinia pyramidalis* Tul. (Fabaceae) (Pegado et al., 2006) and *Pilosocereus tillianus* R. Gruber & Schatzl (Cactaceae) (Larrea-Alcázar and Soriano, 2006). In this region, *P. juliflora* is also able to compete with traditional short-cycle crops such as maize (*Zea mays* L., Poaceae) and cotton (*Gossypium hirsutum* L., Malvaceae) (Porto Filho, 1981). One single *P. juliflora* tree is able to produce between 630,000 and 980,000 seeds per year (Hardin, 1988) which are then consumed and scarified by livestock, with a subsequent deposition in the ground and mixed with manure, resulting in increased germination and invasive potential (Felker, 2003).

For the sake of both the Caatinga biodiversity and rural sustainability we must understand the mechanisms providing the increased invasive potential exhibited by *P. juliflora* and inform stakeholders about restoration and/or management techniques to mitigate potential negative impacts resulting from spread of this plant at regional scale. Here we examine the seedling performance across five native woody plant species of the Caatinga vegetation as exposed to competition with *P. juliflora* in two experimental conditions: native species growing alone (controls) or in mixed stands with *P. julifora* (treatments). Seedling growth (height, stem diameter and leaf area) and mortality were monitored during a six-month period. We hypothesize that plants experiencing interspecific competition will exhibit lower total biomass than those that grow alone (Laird and Aarssen, 2005). We discuss the uncovered patterns in the context of biological invasion, particularly the ecology of *P. juliflora* and sustainable development of the Caatinga region.

2. Materials and methods

2.1. Experimental site and native plant species

The study was carried out in 2006 at the experimental station of the Center for Agricultural Research in the Semi-Arid Tropic, which is located in the Petrolina municipality (09° 23′S and 40° 30′W, 376 m a.s.l.), Northeast Brazil (Fig. 1). Five woody species from the Fabaceae family were selected because species of this family usually form symbiotic associations with *Rhizobium* (Rhizobiales: Rhizobiaceae). In fact, most of the Fabaceae species are able to establish symbiotic relationships with nitrogen-fixing bacteria in the Caatinga vegetation, helping to maintain soil fertility (Teixeira et al., 2006). Additionally, Fabaceae species represent a substantial portion of the Caatinga flora (from herbs to tree species), with characteristic taxa inhabiting the majority of the Caatinga
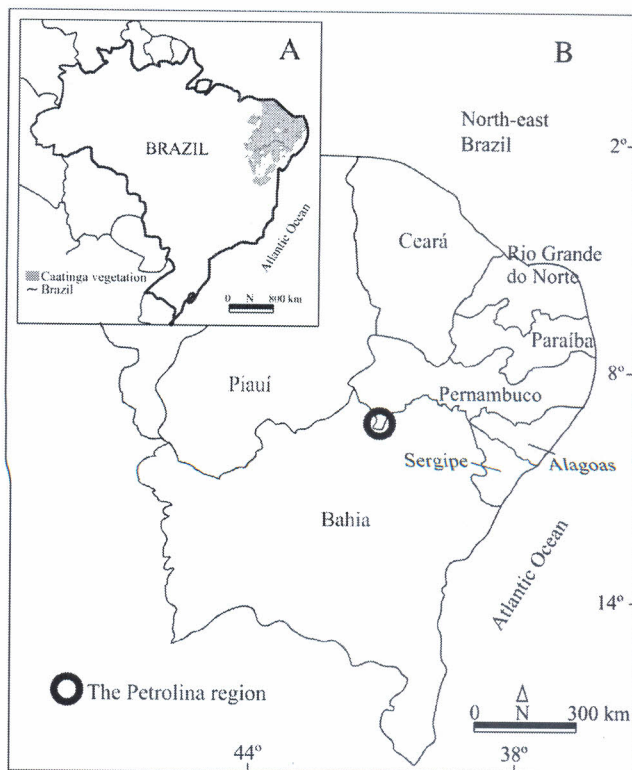

Fig. 1. The area covered by the Caatinga vegetation (A), and location of the Petrolina region, north-east Brazil (B).
Source: adapted from Leal et al. (2007).

habitats, including degraded areas (Leal et al., 2003, 2005). Fabaceae, Euphorbiaceae, Cactaceae and Bromeliaceae account for the majority of native plant species in the Caatinga vegetation (Giulietti et al., 2004). We adopted: Mimosa tenuiflora (Willd.) Poir., Erythrina velutina Willd., Mimosa bimucronata (De Candolle, O. Kuntze), Caesalpinia microphylla Mart. ex G. Don and Caesalpinia ferrea Mart. ex Tul.

2.2. Experimental design and plant parameters

The experiment consisted of a randomized block and factorial design with 2 × 5 treatments with 10 replications which consisted of two types of sowing methods: (1) seeds of each native species sowed separately (controls), and (2) seeds of P. juliflora interspersed with seeds of each native species. Across controls (one for each native species), fifty-six seeds per plot were sown at 6 × 6 cm spacing, leaving 26 seeds as a margin. In the treatments, half of the seeds were from P. juliflora and the other half from native species, resulting in five combinations of P. juliflora and native species. Seed dormancy was artificially broken by a small cutting with blunt scissors into the seed side opposite to the micropylar region. This procedure usually facilitates water absorption and standardizes seed germination (Bastos et al., 1992). Seeds were then sown into iron barrels measuring 56 cm in diameter and 50 cm in height and filled with Caatinga soils. Irrigation was carried out three times a day using two liters of water per plot. The effects of interspecific competition between plants may be inferred from the relationship between distance and size of neighboring plants on the assumption that competition among them is density-dependent; i.e. the smaller the spacing, the lower the development and survival (Larrea-Alcázar and Soriano, 2006).

Fifteen randomly selected seedlings were assessed per plot and species every 20 days along a six-month period. Height, stem diameter and seedling mortality were recorded. Plant height and stem diameter were measured with a ruler and digital caliper, respectively. Leaf area was determined for two central plants in each plot for each treatment, using an area meter LI-3100, LI-COR. Leaf area, stem diameter, plant height and mortality among native species at the end of the experimental period were used for statistical analyses. By examining the impact caused by P. juliflora across five species we are able to address the generality of uncovered patterns. We chose an experimental approach versus a field approach to better control environmental variations, such as soil conditions for example. Note that allelopathy is a potential mechanism influencing interspecific competition in this biological system. Finally, our mixed flocks of seeds mimic those occurring in the natural conditions as flocks of P. juliflora reach the ground via feces of livestock (Nascimento, 2008).

2.3. Data analyses

Cross-treatment and cross-species differences in terms of seedling growth and mortality were compared via analyses of variance followed by Student–Newman–Keuls tests available from the Statistical Analysis System and Genetics package (SAEG) (Ribeiro Júnior, 2001).

3. Results

Leaf area differed among sowing methods (F = 140.89, p < 0.0001) and species examined (F = 7.89, p < 0.0001), with a significant interaction between these two explanatory variables (F = 12.05, p < 0.0001; Table 1). Mean leaf area was similar across native species whether or not they were interspersed with P. juliflora. However, native species exhibited reduced leaf area when interspersed with P. juliflora (Fig. 2). E. velutina and C. ferrea exhibited the highest and lowest leaf areas when growing alone, respectively.

The sowing treatment (F = 42.34, p < 0.0001) and species tested (F = 493.42, p < 0.0001) affected plant growth in terms of stem diameter. However, there was no interaction between these variables

(F = 1.72, p < 0.152; Table 1), indicating similar responses among plant species. Overall, seedlings exhibited lower stem diameter in the presence of P. juliflora as compared to the controls (Fig. 3A). E. velutina exhibited the highest stem diameter while C. microphylla and C. ferrea exhibited the lowest (Fig. 3B).

Mean increments in seedling height followed the same pattern observed for stem diameter, with differences occurring between sowing treatment (F = 79.36, p < 0.0001) and plant species (F = 79.75, p < 0.0001). Again, the interaction between species and sowing treatment was not significant (F = 0.19, p < 0.530; Table 1). Lower growth rates were recorded among native seedlings interspersed with P. juliflora (Fig. 4A). Major increments were recorded for M. tenuiflora and C. ferrea, while there was only a minor increment in height for C. microphylla (Fig. 4B). Finally, sowing treatment affected plant mortality (F = 25.67, p < 0.0001) and species tested (F = 21.67, p < 0.0001), without interaction between these variables (F = 0.19, p < 0.442; Table 1). Seedlings interspersed with P. juliflora experienced higher mortality (Fig. 5A), with the lowest scores for M. tenuiflora and C. ferrea and the highest for M. bimucronata (Fig. 5B).

4. Discussion

Overall, P. juliflora can reduce seedling growth in terms of leaf area, stem diameter and plant height, as well as increase seedling mortality among native woody plant species of the Caatinga vegetation. Moreover, native species exhibit different levels of susceptibility to the presence of P. juliflora, particularly in terms of plant growth. Our results showed a 30%-reduction on plant growth (i.e. lower total biomass) with a similar decrease in seedling survivorship. Finally, such tangible and biologically relevant impacts emerge rapidly as seedlings were monitored for a short six-month period following seed germination. In case such trends are maintained, our results represent an underestimate of the total impact imposed on the recruitment of native species by P. juliflora.

P. juliflora negatively affected the early establishment of native plant species under certain conditions, although at this moment we are not able to separate those effects from direct competition for resources (e.g. water, nutrients and lights) from those resulting from allelopathic substances potentially produced by P. juliflora seedlings

Table 1
Summary of analysis of variance for leaf area, stem diameter, plant height and mortality of native plants according to sowing treatment and plant species. Petrolina, Pernambuco State, Brazil.

Variation source	Degrees of freedom	average square	F	P
Leaf area [a]				
Sowing	1	1790.58	140.89	0.0001
Native species	4	100.29	7.89	0.0001
Sowing × native species	4	153.12	12.05	0.0001
Residue	90	12.71		
Diameter				
Sowing	1	47.53	42.34	0.0001
Native species	4	553.81	493.42	0.0001
Sowing × native species	4	1.93	1.72	0.152
Residue	90	1.12		
Height				
Sowing	1	391121.40	79.36	0.0001
Native species	4	393076.80	79.75	0.0001
Sowing × native species	4	2614.30	0.19	0.530
Residue	90	4928.70		
Mortality [a]				
Sowing	1	10.93	25.67	0.0001
Native species	4	9.22	21.67	0.0001
Sowing × native species	4	0.19	0.19	0.442
Residue	90	0.43		

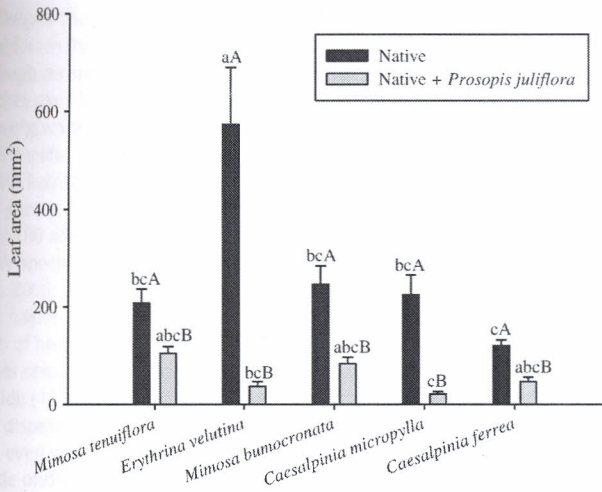[a] Data transformed to chi square root $(x + 0.5)$ for statistical analysis.

Fig. 2. Average seedling leaf area (±SE) exhibited by native plant species of the Caatinga vegetation per sowing treatment Student–Newman–Keuls test: columns followed by the same lower case letter per plant species or upper case letter per sowing treatment are not different (P = 0.05). Bars indicate the standard error.

(Pometti et al., 2007). Such a superior competitive ability is also supported by the reduced abundance of some Cactaceae species [*Stenocereus griseus* (Haw.) Buxb., *Cereus repandus* Haw. and *P. tillianus*] beneath adults of *P. juliflora* as compared to adults of Caatinga native species (Larrea-Alcázar and Soriano, 2006). Conversely, even seedlings of *P. juliflora* may respond negatively to light competition as they reduce biomass production and leaf area (Perez et al., 1999) beneath tree canopies or while growing in
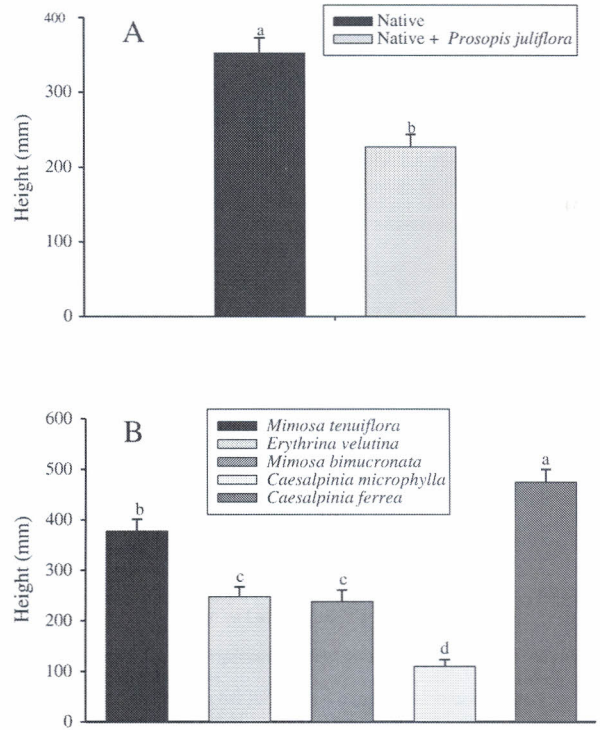

Fig. 4. Average seedling height (±SE) per sowing treatment (A) and plant species of the Caatinga vegetation (B). Student–Newman–Keuls test: columns followed by the same small letter are not different (P = 0.05).

pastures (Pasiecznik, 2002). Similar results have been found for *Prosopis glandulosa* Torr. (Fabaceae) (Bush and Van Auken, 1987, 1990).
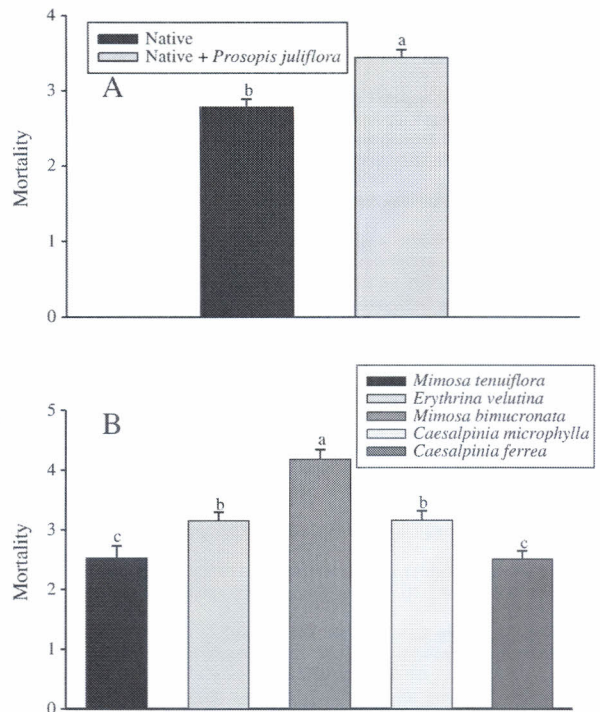

Fig. 3. Average seedling stem diameter (±SE) per sowing treatment (A) and plant species of the Caatinga vegetation (B). Student–Newman–Keuls test: columns followed by the same small letter are not different (P = 0.05).
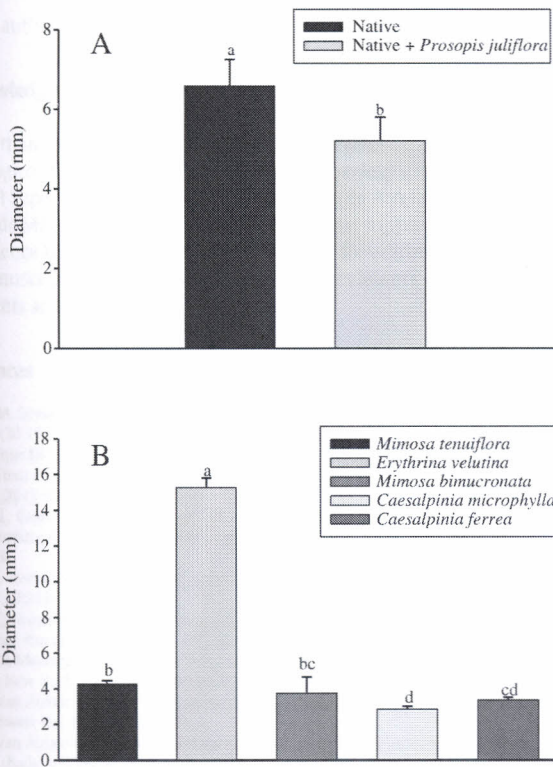

Fig. 5. Average seedling mortality (±SE) per sowing treatment (A) and plant species of the Caatinga vegetation (B). Student–Newman–Keuls test: columns followed by the same small letter are not different (P = 0.05).

Despite the scarcity of research addressing the invasion ecology of *P. juliflora* in the Caatinga region, we hypothesize the following scenario. Through intentional introductions in rural landholdings, *P. juliflora* reaches river banks/alluvial areas previously degraded by agriculture or overgrazing by livestock, most notably through gut seed dispersal by domestic animals (Nascimento, 2008). In these illuminated and humid habitats, a superior competitive ability (as suggested here) may permit *P. juliflora* to establish monospecific stands of adult trees (over 100 adult trees and 3000 saplings per hectare), locally displacing native species or limiting their recruitment (Lins e Silva, 1997; Pegado et al., 2006; Nascimento, 2008). Such "gallery forest stands" dominated by *P. juliflora* already represent a "typical" physiognomy across thousands of hectares in the entire Caatinga region (Negreiros et al., 1991). Stands result from a synergic relationship with rural activities as they provide (1), diaspore sources, (2) domestic animals acting as effective seed dispersers, and (3) degraded/open habitats to be colonized. However, even with a "superior" competitive ability, *P. juliflora* is not able to invade undisturbed stands of Caatinga vegetation, probably due to reduced light availability (Nascimento, 2008).

Humid areas represent key habitats for native biodiversity in semiarid regions (Bullock et al., 1995; Rodal et al., 2005). The Caatinga socio-ecological scenario is very similar to those described for rural areas in Africa, where there have been public appeals and intense debates for the appropriate management or even eradication of *P. julifora* stands for a series of reasons, including invasion of crop fields and communal grazing areas (Mwangi and Swallow, 2005). The use of less sensitive species, such as *M. tenuiflora* and *C. ferrea*, to restore native vegetation before intensive colonization by *P. juliflora* is one among many approaches probably required for avoiding its continuous spread across the Caatinga region (Lacerda et al., 2010). Further studies should investigate the efficiency of such approach.

Conflict of interest statement

The authors declare that they have no competing financial interests.

Acknowledgments

References

Adams MA, Simon J, Pfautsch S. Woody legumes: a (re)view from the South. Tree Physiol 2010;30:1072–82.
Albuquerque UP, Araújo EL, El-Deir ACA, Lima ALA, Souto A, Bezerra BM, et al. Caatinga revisited: ecology and conservation of an important seasonal dry forest. Sci World J 2012;2012:205182.
Araújo EL, Castro CC, Albuquerque UP. Dynamics of Brazilian Caatinga — a review concerning the plants, environment and people. Funct Ecosyst Commun 2007;1: 15–28.
Archer S. Herbivore mediation of grass–woody plant interactions. Trop Grasslands 1995;29:218–35.
Bastos GQ, Nunes RS, Cruz GMF. Reavaliação de quebra de dormência em sementes de algaroba (*Prosopis juliflora* (SW) DC). Rev Bras Sementes 1992;14:17–20.
Bullock SH, Mooney HA, Medina E. Seasonally dry tropical forests. Cambridge University Press New York: Cambridge University Press; 1995 [468 pp.].
Bush JK, Van Auken OW. Light requirements for growth of *Prosopis glandulosa* seedlings. Southwest Nat 1987;32:469–73.
Bush JK, Van Auken OW. Growth and survival of *Prosopis glandulosa* seedlings associated with shade and herbaceous competition. Bot Gaz 1990;151:234–9.
Cavalcante A, Major I. Invasion of alien plants in the Caatinga biome. Ambio 2006;35: 141–3.
Chapple DG, Simmonds SM, Wong BBM. Can behavioral and personality traits influence the success of unintentional species introductions? Trends Ecol Evol 2012;27:57–64.

El-Keblawy A, Abdelfatah MA. Impacts of native and invasive exotic *Prosopis* congeners on properties and associated flora in the arid United Arab Emirates soil. J Arid Environ 2014;100–101:1–8.
El-Keblawy A, Al-Rawai A. Effects of salinity, temperature and light on germination of invasive *Prosopis juliflora* (Sw.) DC. J Arid Environ 2005;61:555–65.
Felker P. Management, use and control of *Prosopis* in Yemen. Mission report, project number: TCP/YEM/0169 (A); 2003.
Giulietti AM, du Bocage Neta AL, Castro AAJF, Gamarra-Rojas CFL, Sampaio EVSB, Virgínio JF, et al. Diagnóstico da vegetação nativa do bioma Caatinga. In: Silva JMC, Tabarelli M, Fonseca MT, Lins LV, editors. Biodiversidade da Caatinga: áreas prioritárias para a conservação. Ministério do Meio Ambiente. Brasília e Universidade Federal de Pernambuco; 2004. p. 48–90.
Goel U, Saxena DB, Kumar B. Comparative study of allelopathy as exhibited by *Prosopis juliflora* Swartz and *Prosopis cineraria* (L) Druce. J Chem Ecol 1989;15:591–600.
Hardin ED. Succession in Buffalo Beats prairie and surrounding forest. Bull Torrey Bot Club 1988;115:13–24.
Inderjit, Seastedt TR, Callaway RM, Pollock JL, Kaur J. Allelopathy and plant invasions: traditional, congeneric, and biogeographical approaches. Biol Invasion 2008;10:875–90.
Kemp D, Michalk D. Grasslands for production and the environment. In: McGilloway DA, editor. Grassland: a global resource. Wageningen Academic Publishers; 2005. p. 193–208.
Lacerda AV, Barbosa FM, Soares JJ, Barbosa MRV. Flora arbustiva-arbórea de três áreas ribeirinhas no semiárido paraibano, Brasil. Biota Neotrop 2010;10:275–84.
Laird RA, Aarssen LW. Size inequality and the tragedy of the commons phenomenon in plant competition. Plant Ecol 2005;179:127–31.
Larrea-Alcázar DM, Soriano PJ. Spatial associations, size–distance relationships and population structure of two dominant life forms in a semiarid enclave of the Venezuelan Andes. Plant Ecol 2006;186:137–49.
Leal IR, Tabarelli M, Silva JMC. Ecologia e conservação da Caatinga: uma introdução ao desafio. Ecologia e conservação da Caatinga. Recife: Editora Universitária da UFPE; 2003. p. 13–6.
Leal IR, Wirth R, Tabarelli M. Seed dispersal by ants in the semi-arid Caatinga of north-east Brazil. Ann Bot 2007;99:885–94.
Leal IR, Silva JMC, Tabarelli M, Lacher Junior TE. Changing the course of biodiversity conservation in the Caatinga of northeastern Brazil. Conserv Biol 2005;19: 701–6.
Lenda M, Witek M, Skórka P, Morón D, Woyciechowski M. Invasive alien plants affect grassland ant communities, colony size and foraging behavior. Biol Invasion 2013;15:2403–14.
Lins e Silva ACB. Characteristics of *Prosopis juliflora* invasion of semi-arid habitats in northeast Brazil. M.Sc. Thesis University of Durham, Durham: University of Durham; 1997 [76 pp.].
Mwangi E, Swallow B. Invasion of *Prosopis juliflora* and local livelihoods: case study from the Lake Baringo area of Kenya. ICRAF Working Paper – no. 3. Nairobi: World Agroforestry Centre; 2005.
Nakano H, Nakajima E, Fujii Y, Yamada K, Shigemori H, Hasegawa K. Leaching of the allelopathic substance L-tryptophan from the foliage of mesquite (*Prosopis juliflora* (Sw.) DC.) plants by water spraying. Plant Growth Regul 2003;40:49–52.
Nakano H, Nakajima E, Hiradate S, Fujii Y, Yamada K, Shigemori H, et al. Growth inhibitory alkaloids from mesquite (*Prosopis juliflora* (Sw.) DC.) leaves. Phytochemistry 2004;65:587–91.
Nascimento. Comportamento invasor da algarobeira *Prosopis juliflora* (Sw) Dc. nas planícies aluviais da caatinga. Tese de Doutorado Biologia Vegetal; 2008 [115 pp.].
Negreiros AN, Carvalho MM, Xavier Filho J, Blanco-Labra A, Shewry PR, Richardson M. The complete amino acid sequence of the major kunitz trypsin inhibitor from the seeds of *Prosopis juliflora*. Phytochemistry 1991;30:2829–33.
Noor M, Salam U, Khan MA. Allelopathic effects of *Prosopis juliflora* Swartz. J Arid Environ 1995;31:83–90.
Pasiecznik NM In: Brinkman W Summer, editor. *Prosopis* – pest or providence, weed or wonder tree? ETFRN News - Arid and Semi-Arid Areas Ryton-on-Dunsmore, Coventry, UK: Henry Doubleday Research Association (HDRA); 1999. p. 12–4.
Pasiecznik NM. *Prosopis* (mesquite, algarrobo): invasive weed or valuable forest resource? HDRACoventry, UK: HDRA; 2002 [2 pp.].
Pasiecznik NM, Harris PJC, Smith SJ. Identifying tropical *Prosopis* species: a field guide. HDRACoventry, UK: HDRA 0 905343 34 4; 2004.
Pasiecznik NM, Felker P, Harris PJC, Harsh LN, Cruz G, Tewari JC, et al. The *Prosopis juliflora–Prosopis pallida* complex: a monograph. HDRACoventry, UK: HDRA; 2001 [172 pp.].
Pegado CMA, Andrade LA, Félix LP, Pereira IM. Efeitos da invasão biológica de algaroba – *Prosopis juliflora* (Sw.) DC. sobre a composição e a estrutura do estrato arbustivo-arbóreo da caatinga no Município de Monteiro, PB, Brasil. Acta Bot Bras 2006;20:887–98.
Pennington TD. Flora da Reserva Ducke, Amazonas, Brasil: Sapotaceae. Rodriguésia 2006;57:251–366.
Perez SCJGA, Fanti SC, Casali CA. Efeitos do sombreamento artificial no crescimento e resistência à seca da algarobeira (*Prosopis juliflora* S.W. DC.). Rev Tecnol Ambiente 1999;5:7–29.
Pometti CL, Cialdella AM, Vilardi JC, Saidman BO. Morphometric analysis of varieties of *Acacia caven*: (Leguminosae: Mimosoidae): taxonomic inferences in the context of other Argentinean species. Plant Syst Evol 2007;264:239–49.
Porto Filho F. Estudo comparativo de custos e receitas dos principais sistemas de produção recomendados pela EMATER/RN. Mossoró, DSc/ESAM (Monograph); 1981.
Pyšek P. Is there a taxonomic pattern to plant invasions? Oikos 1998;82:282–94.
Rajwant K, Gonzáles WL, Llambi LD, Soriano PJ, Callaway RM, Rout ME, et al. Community impacts of *Prosopis juliflora* invasion: biogeographic and congeneric comparisons. PLoS ONE 2012;7:e44966.

Rejmánek M, Richardson DM. What attributes make some plant species more invasive? Adv Invasion Ecol 1996;77:1655–61.

Ribeiro Júnior JI. Análises Estatísticas no SAEG. Editora UFV. Universidade Federal de Viçosa, Viçosa, MG: Universidade Federal de Viçosa; 2001 [301 pp.].

Rodal MJN, Sales MF, Silva MJ, Silva AG. Flora de um brejo de altitude na escarpa oriental do planalto da Borborema, PE, Brasil. Acta Bot Bras 2005;19:843–58.

Santos JC, Leal IR, Almeida-Cortez JS, Fernandes GW, Tabarelli M. Caatinga: the scientific negligence experienced by a dry tropical forest. Trop Conserv Sci 2011;4:276–86.

Siddiqui S, Bhardwaj S, Khan SS, Meghvanshi MK. Allelopathic effect of different concentration of water extract of *Prosopsis juliflora* leaf on seed germination and radicle length of wheat (*Triticum aestivum* Var-Lok-1). Am Euras J Sci Res 2009;4:81–4.

Teixeira FCP, Reinert F, Rumjanek NG, Boddey RM. Quantification of the contribution of biological nitrogen fixation to *Cratylia mollis* using the ^{15}N natural abundance technique in the semiarid Caatinga region of Brazil. Soil Biol Biochem 2006;38:1989–93.

van Wilgen BW, Reyers B, Le Maitre DC, Richardson DM, Schonegevel L. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. J Environ Manag 2008;89:336–49.

Vitousek PM, D'Antonio CM, Loope LL, Westbrooks R. Biological invasions as global environmental change. Am Sci 1996;84:468–87.

Vitousek PM, D'Antonio CM, Loope LL, Rejmánek M, Westbrooks R. Introduced species: a significant component of human-caused global change. New Zeland J Ecol 1997;21; 1–16.