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Prosopis *(Prosopis juliflora)*: blessing and bane

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Abstract: Among the invasive species of plants which are spreading at an alarming rate in the tropical and sub-tropical regions of the world, Prosopis *(Prosopis juliflora)* is arguably the most hardy and resilient. A xerophyte, which is adapted to survive and thrive in very harsh desert environments, it is a major boon for impoverished people subsisting in those environments as it provides them with badly needed shelter, reduces erosion, improves micrometeorology, and is a source of food, feed, fuel, medicines and cosmetics. Attempts made during the 19th and 20th centuries to exploit these virtues of *P. juliflora* has led to its introduction in many regions which had less harsh climate and better availability of soil and water than existed in the native habitat of *P. juliflora.* The relatively more favorable conditions resulted in *P. juliflora* growing and spreading much faster than it could be utilized. Soon it became a serious weed in all exotic regions where it was introduced, growing so explosively that it even enters roads and homes, driving humans out of their dwellings. The resulting damage to biodiversity is enormous. The present paper highlights the dual role of *P. juliflora* and itemizes the facets that make it a blessing in some contexts and a bane in other contexts. Beginning with a review of the special attributes which give invasive plants competitive advantage, the paper briefly recapitulates the systematics, origin, and spread of *P. juliflora.* It then dwells upon the morphology and other attributes of *P. juliflora* which have enabled it to invade and colonize so much of the world's landmass so rapidly. Detailed state-of-the-art is then presented on the beneficial and harmful impacts of *P. juliflora.* The paper concludes with a summary of assessments that have balanced the costs of destroying *P. juliflora* stands or utilizing them, with the possible benefits of either.

Key words: Avifauna, biodiversity, ecorestoration, invasive plant, *P. juliflora*, weed.

Introduction

Prosopis (*Prosopis juliflora*) is a xerophyte which, in its native habitats (Fig. 1), has been a desert plant. As long as it was confined to its natural habitat, *P. juliflora* was a great resource, especially to the economically weak inhabitants, who could beneficially use each and every part of that tree (Dave & Bhandari 2013; Dubow 2011; Mwangi & Swallow 2005; Pasiecznik *et al.* 2001; Walter 2011; Walter & Armstrong 2014).

But when *P. juliflora* was introduced in other regions of the world in a hope to derive similar benefits from it, things began to go awry. *Prosopis juliflora* started spreading and multiplying much faster than the rate at which it could be used. By now it has become one of the world's 100 most dominant invasives (Becker *et al.* 2016; Walter & Armstrong 2014).

It is well-known that a species can become invasive when it is taken to a region where it has lesser competition and greater security (from grazers/predators) than in its native habitat (Abbasi & Nipaney 1986; Ganesh *et al.* 2005; Walter 2011). But out of the species that are introduced to environments alien to them, only about 2% are known to survive (Hierro 2005). Of these, the ones that become highly invasive have one or more of the following attributes:

I. They are hardy, tolerating a wide range of conditions of temperature, water/soil quality, humidity, etc.
II. They grow vegetatively and/or through seeds that are produced in large numbers per plant and which generally achieve high germination success.
III. They have a fast growth rate.

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IV. They are allelopathic, discouraging other plants from growing around them, and toxic to other biota in ways that allows the invasives to monopolise space and nutrients at the exclusion of other species. In the native habitats of *P. juliflora* the other species have developed a mechanism to counter the allelopathy of *P. juliflora*, but such defense is not available to plants for which *P. juliflora* is an alien.

In addition, plants propagating in alien environments may not have the natural enemies that keep them in check in their native habitats. The invading plants capture 'empty niches'— spaces and its resources not used by the existing plants (Hierro 2005). Moreover selection pressures in the new environments bring in genetic changes in the invading plants that enhance their competitive edge.

Prosopis juliflora has all of these attributes. In addition it has a root system of which some parts spread horizontally while two or three tap roots dig deep belowground to pick water, even branching out on their way down to increase their reach. The former types of roots enable *P. juliflora* to utilize soil water in rainy season like other vegetation does (Saito *et al.* 2016), while the latter type gives *P. juliflora* enormous competitive advantage over less draught-tolerant species (Rembold *et al.* 2015). *Prosopis juliflora* can also aggravate a hydrological draught, thereby causing death of other species (Gunarathne & Perera 2016). Hence, it is small wonder that *P. juliflora* has become one of the most dominant and intransigent of invasives (Figs. 1 and 2). This paper aims to summarize the information that is available on *P. juliflora*, from its origin and systematics to its future prospects. It is shown that the only way to prevent further infestation of *P. juliflora* is by finding ways to gainfully utilize it so that its colonization and monopolization of land is checked by its frequent harvesting.

Prosopis: systematics

The *P. juliflora* genus, which belongs to the family Leguminosae (Fabaceae) and sub-family Mimosoideae, has 44 species (Burkart 1976). All but 4 of these are native to the Americas (Walter 2011). Asia (3 species) and Africa (one species) are other continents where species of *P. juliflora* have originated, contributing 3 and 1 species, respectively. The genus itself is believed to have evolved over the last 70 million years which had African and South American continents in a contiguous land mass before they separated and drifted away. Studies using morphological characters, isoenzymes, seed protein electrophoresis, and molecular markers have shown the occurrence of intra-species as well as inter-species hybrids in *P. juliflora* populations (Burghardt *et al.* 1997; Dave & Bhandari 2013; Ramirez *et al.* 1999; Saidman *et al.* 1996).

The systematics of the genus *P. juliflora* L. are summarized in Table 1 (Burkart 1976). The species encompass trees and shrubs of varying size, all distinguished by the presence in them of thorns and prickles.

P. juliflora*: origin and spread*

Forty of the 44 known species of the *P. juliflora* genera are native to the Americas. Of these, 28 are native to a single country — Argentina. Of the 44 *Prosopis* species, four are spread globally— *P. juliflora, P. pallida, P. glandulosa,* and *P. relutina* — and by far the most widespread is *P. juliflora* which is particularly invasive in exotic environments (Dubow 2011; Pasiecznik *et al.* 2004). The rest of the review is focused on *P. juliflora* which is also known widely by its common name mesquite (Walter 2011).

In its natural habitat, and for marginal, subsistence people, *P. juliflora* has been a boon (Dave & Bhandari 2013; Walter & Armstrong 2014). The tree could grow in the kind of harsh environments and poor soils where little else grew. And every part of the tree was utilizable for purposes as diverse as fuel, food, feed, medicines, and cosmetics (Tewari *et al.* 2013).

It was due to the popularity *P. juliflora* enjoyed in its natural habitat that it was introduced in newer regions. Accounts on when exactly *P. juliflora* was introduced in India vary but it is certain that it was introduced in the second half of the 19th century (Dubow 2011; Walter 2011). Among the introductions was in 1877 when *P. juliflora* seeds from Jamaica that had arrived an year earlier were sown in arid areas of Cuddapah District, Andhra Pradesh. In the same year *P. juliflora* seeds were sown in Sindh (now in Pakistan) to raise defense against sand dune encroachments.

Prosopis juliflora was continued to be introduced in more and more arid regions of India, of which some are now in Pakistan. It performed so well after its introduction in Rajasthan that the ruler of the Jodhpur state named *P. juliflora* a "Royal Plant". Further introductions followed into

Table1. The genus *P. juliflora* (Burkart 1976).

Section	***Species***
PROSOPIS	*P. cineraria (L.)* Druce
	P. farcta (solander ex Russell) Macbride
	P. koelziana Burkart
ANONYCHIUMA	*P. africana* (Guill., Perr., & Rich.) Taubert
STROMBOCARPA	*P. abbreviata* Bentham
	P. burkartii Munoz
	P. palmeri S. Watson
	P. pubescens Bentham
	P. reptans Bentham
	P. strombulifera (Lam.) Bentham
	P. torquata (Cavanilles ex Lagasca) DC.
CAVENICARPAE	*P. ferox* Grisebach
	P. tamarugo F. Philippi
MONILICARPA	*P. argentina* Burkart
ALGAROBIA	*P. kuntzei* Harms
	P. sericantha Gillies ex Hooker & Arnott
	P. fiebrigii Harms
	P. hassleri Harms
	P. ruscifolia Grisebach
	P. vinalillo Stuckert
	P. calingastana Burkart
	P. castellanosii Burkart
	P. denudans Bentham
	P. ruizleali Burkart
	P. affinis Sprengel
	P. articulata S. Watson
	P. campestris Grisebach
	P. elata (Burkart) Burkart
	P. humilis Gillies ex Hooker & Arnott
	P. pallida (H. & B. ex Willd.) H.B.K.
	P. rojasiana Burkart
	P. rubriflora E.Hassler
	P. tamaulipana Burkart
	P. alba Grisebach
	P. alpataco R.A. Philippi
	P. caldenia Burkart
	P. chilensis (Molina) Stuntz emend. Burkart
	P. flexuosa DC.
	P. glandulosa Torrey
	P. juliflora (Swartz) DC.
	P. laevigata (H. & B. ex Willd.) M.C. Johnston
	P. nigra (Grisebach) Hieronymus
	P. pugionata Burkart
	P. velutina Wooton

what are now the states of Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Maharashtra and Tamil Nadu (Harsh & Tewari 1998; Muthana 1985). By now *P. juliflora* has colonized most of India (Fig. 2).

Its invasion and colonization is particularly acute in India's southern peninsula. In that region's state of Tamil Nadu *P. juliflora* is spreading so rapidly that it may well lead to a mass uprising against the species! An indication of growing public ire against *P. juliflora* comes from a public interest write petition that was filed a few months ago in the Madras High Court. The petition led to a Court order directing the government to immediately launch a campaign for the mechanical removal of *P. juliflora* from all public spaces (Saravanan 2017a). A little later the Honb'le Court even reprimanded the government for a less-than-effective implementation of the order but then another litigant went to Court and got the earlier order stayed on the grounds that the mechanical removal was not going to prevent massive re-infestation (Saravanan 2017b). Elsewhere in India, too, *P. juliflora* continues to spread at the expense of species that were earlier dominant (Mukherjee *et al.* 2017).

Close to the heels of its arrival in India, *P. juliflora* was introduced in Sri Lanka (Dubow 2011; Walter 2011). Introductions in Australia, Hawaii Island, and several other countries followed to benefit from the ease with which *P. juliflora* could grow in harsh arid environments. The main purpose was to use *P. juliflora* as shade tree around homesteads and as a possible livestock feed. Economically challenged farmers and others found numerous other uses of *P. juliflora* (as detailed in later sections). But soon *P. juliflora* began to occupy areas it wasn't meant to. A few *P. juliflora* trees, planted in the 1930s around a homestead in Western Australia multiplied so rapidly that it soon led to the largest *P. juliflora* patch in Australia. By the year 2000, the patch extended to 30,000 ha of dense *P. juliflora* stands (Osmond 2003).

In Sudan *P. juliflora* cut loose from its region of introduction to invade large areas of irrigated farmlands, degraded and abandoned lands, watercourses, floodplains and highways. In Kenya it has threatened to cover 28 million ha in a region that had only 5% of this coverage in 1998 (Muturi *et al.* 2009). This is approximately 80% of the country's area (Maundu *et al.* 2009). In Ethiopia, *P. juliflora* has occupied 360,500 ha of land in the Afar region alone (Tilahun *et al.* 2016) and it is spreading rapidly in Saudi Arabia (Thomas *et al.* 2016). The story of *P. juliflora* invasion is similar in other regions: explosive colonization of agricultural lands, wetlands, and open spaces at great cost to biodiversity and natural resources (De Andrade *et al.* 2008, 2009; de Souza Nascimento *et al.* 2014; El-Keblawy & Al-Rawai 2007). In all regions colonized by *P. juliflora*, it is common to see the plant bearing down upon human dwellings and pathways (Fig. 3). Its impenetrable thickets can be seen encroaching upon wetlands and blocking roadsides (Fig. 4).

Morphology of prosopis (P. juliflora*) and the attributes which make it highly invasive*

Prosopis juliflora normally reaches heights of 12 m, but can also go up to 20 m in favorable conditions (Dave & Bhandari 2013). Some varieties of *P. juliflora* also exist as shrubs of just about 3 m height. Whether in a tree form or as a shrub, *P. juliflora* trunk is short and often crooked or twisted, reaching a diameter of about 65 cm. The bark is grey-brown, rough and fibrous, varying from finely fissured to furrowed.

As is seen with many other invasives, *P. juliflora* also produces a large number of small-size seeds: about 25 per pod (Shiferaw *et al.* 2004); 3600–3700 kg^{-1} When animals graze upon the pods, the unchewed of the ingested seeds passing through the guts of animals receive treatments that enhances germination success of the seeds when they are exited. Additionally the faeces act as fertilizer in the critical phase of the establishment of the seedlings (Alvarez *et al.* 2017). Ingestion by the animals who lead to eventual dropping of the seeds along with the faeces also facilitates dispersal of *P. juliflora* over a wide terrain. For example Shiferaw *et al.* (2004) recovered 760 and 2833 seeds kg^{-1} of goat and cattle droppings, respectively, suggesting that cattle are the major dispersers of *P. juliflora* seeds. Wildlife species, especially yellow baboons (*Papio cynocephlalus*), bush pigs (*Potamochoerus larvatus*), and gazelle (*Gazella gazelle*), also play a part (Mworia *et al.* 2011; Wronski *et al.* 2012). In Gujarat, India, *P. juliflora* is occupying ever larger territories due to the help in its propogation given by desert animals, especially the wild ass *(Equus hemionus,* khur; Pasha *et al.* 2015). *Prosopis juliflora* has a short juvenile period, with the ability of resprouting from stumped or damaged parts. This gives *P. juliflora* an advantage over other plants in the competition for space (Kolar & Lodge 2001; Shiferaw *et al.* 2004).

Prosopis juliflora can thrive in regions and environments widely different from one another. It can grow on soils ranging from sandy, to stony, to heavy clay (Maydell 1986). It can thrive in alkaline soils with a level of salinity as high as that of sea water (Felker *et al.* 1981). In a trial several multipurpose trees were grown under extremely arid conditions with very low and variable rainfall,

Table 2: Summary of reports on the use of *Prosopis* parts as feed.

S. No.	Type of Study	Key Findings	Reference
1.	Pods as feed for lambs	Pods can constitute upto 30% of the lamb diet.	Ravikala *et al.* 1995
2.	Ensiling with desert grass *Lasiurus sindicus.*	The pods can be used in silage as replacement for urea and molasses at 2 and 8% respectively.	Pancholy & Mali, 1999
3.	Pod meal in the diets of laying quails.	Upto 15% replacement of corn with pod meal appeared feasible; at higher fractions of replacement the egg production was adversely effected.	Da silva *et al.* 2002
4.	*In situ* ruminal and intestinal nutrient digestibility of pods.	The rumen happens to be the main site of digestion of pods and drying the pods had no adverse effect on the digestion.	Batista *et al.* 2002
5.	Digestibility of globulins from mesquite pods and cowpea by mammalian digestive enzymes.	Globulins from the pods, used as an alternative food, were difficult to digest, in comparison to immature cowpea.	Araujo *et al.* 2002
6.	Pods in the diets of laying hens	The pods can be included upto 13.6% of the diets without adversely affecting the performance of the laying hens	Vilar Da Silva *et al.* 2002
7.	*Prosopis* flour in diets of rats	Due to the protein content present in the flour, there was no adverse effect during pregnancy and lactation phases.	Da Silva *et al.* 2003
8.	General feed for livestock.	Pods could replace costlier feed ingredient such as grain and bran, contributing 10-50% of the diet. If the percentage increases to 20%, then phosphorous supplements need to be added.	Sawal *et al.* 2004
9.	Pod meal in the diet of growing crossbred heifers along with wheat straw.	Complete feed with 30% wheat straw and 20% *Prosopis* pods replacing rice polish, can be given as feed to heifers, without an adverse effect on growth and reproduction.	Pandya *et al.* 2005
10.	Pods as a feed for goats	Pods can be utilized as feed up to a proportion of 200 g^{-1} kg of rhodegrass hay. Higher pod fraction affects the carcass yield and quality.	Mahgoub *et al.* 2005
11.	Pods as a meal for horses.	Pod meal can be used in the diets of horses even though a decrease in dietary fiber digestibility is seen.	Da silva stein *et al.* 2005
12.	Pods as a feed for Awassi lambs.	Upto 200 kg^{-1} replacement of barely grains with pods is feasible, and is also cost effective. More than that will affect the growth, digestibility, and quality of the meat of the lambs.	Obeidat *et al.* 2008
13.	Pods as a feed for Nile tilapia fries.	Diet supplemented with 60 g kg^{-1} pods improved the growth, nutrient utilization and whole body composition in Nile tilapia fry.	Mabrouk *et al.* 2008
14.	Pod meal in diets of lactating goats.	Substitution of corn meal by pod meal had no significant effect on the ruminal parameters but showed a linear negative response for microbial efficiency synthesis.	Argolo *et al.* 2010
15.	Pods as a feed ingredient in the diets of broiler chicks.	Pods can replace corn by 20% in the diet of broiler chickens.	Al-Beitawi *et al.* 2010
16.	*Prosopis* seed meal for *Labeo rohita* fingerlings	Processed seed meal can be incorporated into the carp diet at an inclusion level of not more than 20%.	Bhatt *et al.* 2011
17.	Ground pods as feed ingredient in poultry diet (broilers).	About 20% of the broilers' diet can be replaced by ground pods which will reduce feed cost without any negative effect. More at 20%, will affect the feed intake, growth and carcass quality.	Girma *et al.* 2011

18.	Ground pods as feed ingredient in poultry diet (layers).	Upto 20% ground pod in layers' ration is recommended, even though 10% is better suited. But more than 20% results in reduction of egg production and egg mass.	Girma *et al.* 2011
	Pods as feed for sheep and goats	Pods can be used without restriction in the feed of sheep but goats may be kept in *Prosopis* invaded areas for no more than one fructification period	Riet – Correa *et al.* 2012
19.	Pods and leaves as feed for lambs.	Pods can be used as a supplement in the diets of lambs without any adverse effect. However, leaves are unpalatable.	Ali *et al.* 2012
20.	Ground pods as feed ingredient broilers.	Upto 30% inclusion of ground pods in broilers diet did not alter the chemical and fatty acid composition and sensory test of the meat. But at high levels the immune response to parasitic infection was impaired.	Girma *et al.* 2012
21.	Pods as feed for cattle and horses.	Despite their toxicity, pods can be used as cattle feed at concentrations of 30% of the food. Horses can be given pods as diet in confined and semi-confined systems. Horses are not recommended to be kept in grazing areas where *Prosopis* is in fructificating whereas cattle can be kept, butfor no more than 30 days.	Medeiros *et al.* 2012
22.	Assessment of nutritive value of pods of *Prosopis* along with some other plants.	*Prosopis* along with leucaena and blue panic plant might be promising alternative feed supplement for ruminants to replace alfalfa. *Prosopis* had the highest volatile fatty acids concentration.	Allam *et al.* 2012
23.	*Prosopis* pod meal in the diet of sheep	Pod meal can replace grass upto 45% in the diet.	Pereira *et al.* 2013
24.	*Prosopis* pod meal in the diet of lactating goats.	Pod meal can replace corn not exceeding 40.5% of the total diet.	Pereira *et al.* 2013
25.	Pods as feed along with cenchrus grass for sheep.	Pods can replace 40% of the feed mixture in sheep without any adverse effect.	Chaturvedi & Sahoo 2013
26.	*Prosopis* seeds in the diets of broiler chickens.	Upto 2% of the diet of broilers can have *Prosopis* seeds. More than that will have adverse effect.	Mohammadi *et al.* 2013
27.	Partial substitution of barley grain with *Prosopis* pods in lactating ewes's diets	Pods can be included in the diet of nursing ewes and their lambs, to reduce the cost of feed and improve milk production, upto 250 g kg^{-1}.	Obeidat & Shdaifat 2013
	Replacement of cottonseed meal with ground *Prosopis* pods as a supplementary feed for sheep	Compared to feeding hay alone, supplementing the feed with cottonseed meal and *Prosopis* pods is a better feeding strategy.	Yasin & Animut, 2014
22.	Substitution of corn for pod meal in lambs' diet.	At a substitution level of 47.5%, maximum weight gain is seen in the lambs.	Pereira *et al.* 2014
23.	Preference and ingestive behavior of sheep feed on tropical tree fruits.	The fruits of *Prosopis*were 'highly preferred'.	Pinto–Ruiz *et al.* 2014
24.	*Prosopis* pods as a partial replacement of corn in the diet of growing broiler chicken.	*Prosopis* pods can be included at levels of 5% in broiler diets without affecting performance.	Al-Marzooqi *et al.* 2015
25.	*Prosopis* pod meal in the diet of sheep	Diet consisting 30-45% of pod meal can be given to sheep.	dos Santos *et al.* 2015
26.	Pods as a replacement to concentrate feed for goats	Upto 40% of the concentrate feed can be replaced with *Prosopis* pods without any adverse effect.	Hintsa *et al.* 2015

27.	*Prosopis* pods as a replacement of corn in the diet of juvenile Nile tilapia.	*Prosopis* meal can completely replace corn in Nile tilapia juvenile diets during periods of low water temperature	Silva T. R. M. *et al.* 2015
28.	Milled mature *Prosopis* pods as a replacement of maize in the diet of broiler chicken	Milled *Prosopis* pods negatively affected the performance of the broiler chickens.	Odero-Waitituh, J. A. *et al.* 2016
29.	*Prosopis* pod meal as a total replacement of corn in the diet of Holstein-Zebu crossbred dairy sterrs.	*Prosopis* pod meal can totally replace corn in the diet of Holstein-Zebu crossbred dairy steer.	De Oliveira M. G.S. *et al.* 2016

strong salt-laden winds, and soils with high salinity. *Prosopis juliflora* survived and outgrew all other species that were tested and even withstood grazing by the goats. The results of the trial are consistent with the field observations which show that *P. juliflora* can produce firewood and bear fruits even under the most extreme climatic conditions (Pasiecznik *et al.* 1995).

Apparently the leguminous *P. juliflora* creates islands of fertility in nitrogen deficient soils through atmospheric N fixation (Geesing *et al.* 2000). In nitrogen-poor soils suffering from overgrazing, erosion, and degradation, *P. juliflora* seedlings gain competitive advantage as they can grow there while other species cannot.

Chemical constituents

Prosopis juliflora wood is comprised of 40–45% cellulose, 25–30% hemi-cellulose, and 11-28% lignin (Dave & Bhandari 2013). The species is very rich in flavonoids; its dry leaves contain as much as 3.6% flavonoids (Ibrahim *et al.* 2013), of which 21 have been identified. The leaves also carry high concentration of alkaloids (2.2%). Several of these alkaloids have not been known before and which have been named after *Prosopis juliflora*: juliflorine, julifloricine, julifloridine, juliprosinene, juliprosine, juliprosopine and mesquitol (Damasceno *et al.* 2017).

Prosopis: the blessing

When planted where it is really needed, and in moderation, *P. juliflora* can be a great blessing (Mwangi & Swallow 2005; Pasiecznik *et al.* 2001). In drylands it control soil erosion, stabilizes sand dunes, improves soil fertility, reduces soil salinity, provides fuelwood, construction timber, feed and food (Dave & Bhandari 2013; Walter & Armstrong 2014).

An agent for bringing environmental benefits

In severely arid regions, in highly sodic soils, in mine soils and overburden dumps, and in nutrient-lean wastelands − where few species of trees can grow *P. juliflora* cannot only thrive but improve the environment around it (Mahmood *et al.* 2016; Mishra *et al.* 2004; Saraswathi & Chandrasekaran 2016; Vallejo *et al.* 2012; Zollner 1986).

Being leguminous, *P. juliflora* significantly enhances the productivity of the soils on which it grows by contributing organic matter and bioavailable nitrogen to them (Herrera−Arreola *et al.* 2007). It regenerates well on fly ash dumps (Pandey *et al.* 2016a), sequestering atmospheric carbon dioxide (Pandey *et al.* 2016b), and in general helping in the site restoration efforts (Pandey *et al.* 2015).

Studies have indicated that wind speeds inside a five-year-old *P. juliflora* plantation were reduced by an average 14%, while evaporation losses were reduced by 22%. There was also considerable improvement in soil texture and soil organic matter under the tree canopy, with soils under the canopy having higher total nitrogen and available phosphorus, and lower soil pH than soils in the adjacent open field (El Fadl 1997). Organic carbon and total nitrogen concentrations in soils under *P. juliflora* were 13% and 45% higher than in the open areas. An evaluation of the performance of *P. juliflora* in comparison to other fast growing tree species *Albizia lebbec, Azadirachta indica, Dalbergia sissoo, Morus indica, Populus deltoids, Syzigium cuminii* and *Syzigium fructicosum* has shown that *P. juliflora* seedlings have the highest survival rate, height gain, girth growth and primary biomass production. In another assessment of the capability of 5 species of hardy trees in growing on salt-affected soils, *P. juliflora* showed the highest biomass accumulation of all, alongside *Acacia nilotica* (Gill & Abrol 1991). These findings

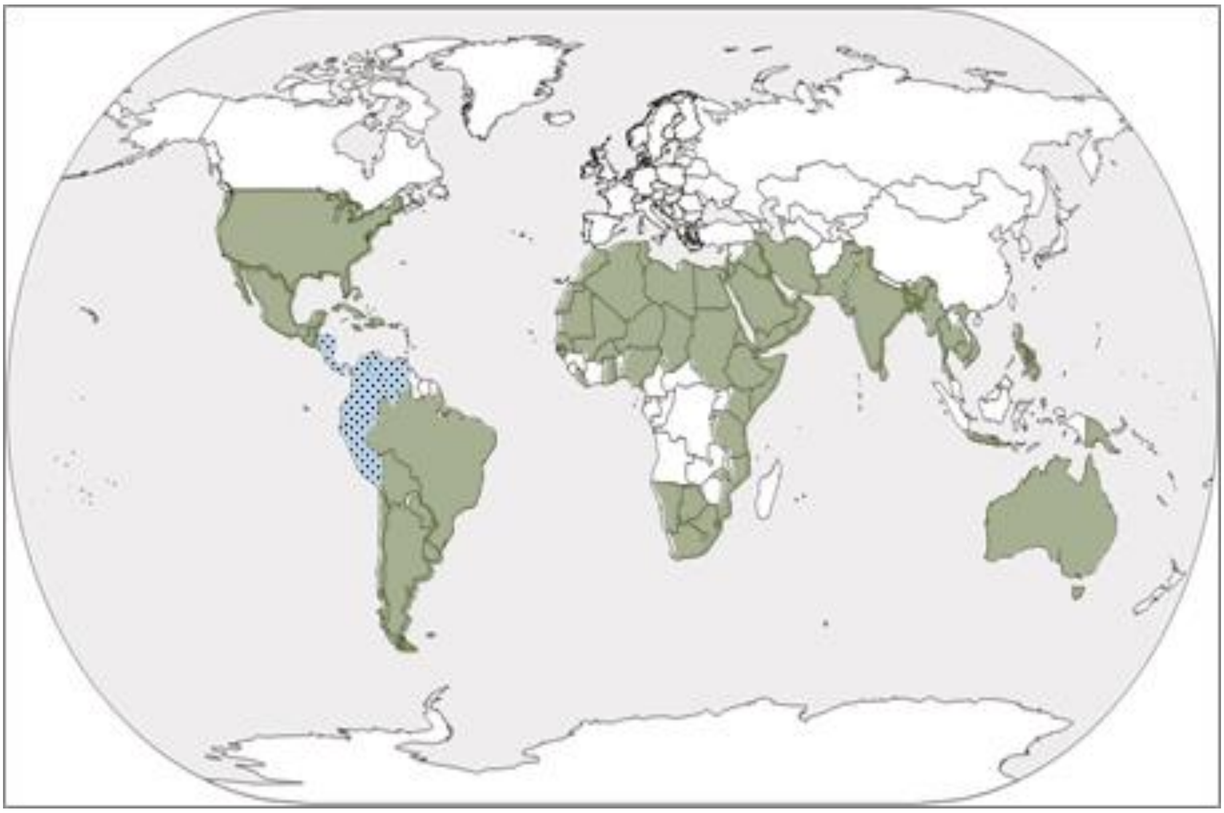

Fig. 1. Countries of origin of *P. juliflora* and regions in which it has become weedy.

are corroborated by other reports which document luxury growth of *P. juliflora* on highly saline soils (Patil & Nagarajan 2015). Additionally, *P. juliflora* has been seen to have improved the fertility of highly degraded sodic soils (Bhojvaid *et al.* 1996; Bhojvaid & Timmer 1998; Dagar *et al.* 2001; Deans *et al.* 2003; Garg 1998, 1999; Mahmood *et al.* 2016; Mishra *et al.* 2003a,b, 2004a,b; Mishra & Sharma 2010; Singh *et al.* 1998).

Prosopis juliflora helps in sand dune stabilization (Zollner 1986), being more effective than most other hardy tree species (Singh & Rathod 2002; Hussain & Alshammary 2008). It has been shown to grow well on gypsum mine soil (Rao & Tarafdar 1998), coal mine overburden (Chaulya *et al.* 2000), and fly ash landfills (Pandey *et al.* 2015; Rai *et al.* 2004), reducing their content of metals like Fe, Mn, Cu, Zn, and Cr by bioaccumulating them in its bark. Chromium−resistant bacteria, capable of tolerating the metal upto levels of 300 mg l^{-1}, have been isolated from *P. juliflora* growing on soils contaminated by chromium−rich tannery effluents (Khan *et al.* 2015). The isolates exhibited tolerance towards Cd, Cu, Pb, and Zn as well. Other studies have also shown high tolerance of *P. juliflora* for Cu (Michel-Lopez *et al.* 2016a), Cd (Michel-Lopez *et al.* 2016b), and several other metals and non-metals (Marques *et al.* 2015; Hernandez Viezcas *et al.* 2016) which the tree bioaccumulates, facilitating bioremediation. *Prosopis juliflora* has the potential of being used in establishing shelterbelts around oil refineries (Hussain & Alshammary 2008).

Substituting conventional pastures of tropical dry environments with *P. juliflora*-based silvopastoral systems leads to greater soil quality, higher enzymatic activity, and better nutrient levels beneath the *P. juliflora* canopy (Singh *et al.* 2014; Vallejo *et al.* 2012). *Prosopis juliflora* can be considered for greenbelt development and as air purifier when the land involved is not rich enough to support other trees (Saxena *et al.* 2011).

A source of fuel

With a calorfic value of 4000 kCal kg^{-1}, low ash production, and ability to burn well even when freshly harvested, *P. juliflora* wood has been a major source of fuel for subsistence people in arid regions (Walter 2011; Walter & Armstrong 2014).

Fig. 2. Regions in India in which *P. juliflora* has spread uncontrollably.

Several studies have shown *P. juliflora* wood to be as good, or better, than coconut shell or the wood of other multipurpose trees like neem, casuarina, and acacia (Bhoi *et al.* 2006; Goel & Behl 1995; Kumar & Chandrashekar 2016; Sakthivadivel & Iniyan 2017; Singh *et al.* 2010). When co-fired with coal in 1:3 *Prosopis*: coal blends, combustion efficiencies as high as 97% can be achieved (Kumar & Singh 2016). The charcoal of *P. juliflora* gives the barbecue a delicious flavor, making it popular with restaurants (Walter & Armstrong 2014).

In India, use of *P. juliflora* wood to feed biomass-based power plants, large burners, and charcoal production is on the increase, especially in areas where *P. juliflora* thickets are particularly large and abundant (Walter & Armstrong 2014; Chandrasekaran *et al.* 2017). Attempts are also afoot to generate ethanol from *P. juliflora* (da Silva *et al.* 2010, 2011; Gupta *et al.* 2009, 2011a,b, 2012; Naseeruddin *et al.* 2013, 2017; Pasha *et al.* 2008). Several chemicals, alone or with enzymes and with or without sonication have been tried to enhance biomass hydrolysis in *P. juliflora* for the extraction of sugars (Sivarathnakumar *et al.* 2016). But, as is the case with all other initiatives to obtain ethanol from lignocellulosic biomass, no economically viable process is in sight (Abbasi & Abbasi 2010a,b). *Prosopis juliflora* has also shown promise as a source of bio-oil (Mythili *et al.* 2017; Suriapparao *et al.* 2015) and biodiesel (Karthikeyan & Prathima 2016): its emulsion can replace upto 15% by volume of diesel in vehicles without adversely effecting their mileage (Masimalai & Kuppusamy 2015; Venkatesan & Senthilkumar 2015). Recently Patnaik *et al.* (2018) have shown that volatile fatty acids (VFAs) can be extracted from the leaves of *P.juliflora* and the VFAs can then be used to generate energy in the form of methane via anaerobic digestion (Abbasi *et al.* 2012; Tauseef *et al.* 2013).

A source of food

The flour made from *P. juliflora* pods has been a food item in North and South America since centuries (Choge *et al.* 2007) but its content of aflatoxins and ochratoxin A means it must be eaten in moderation and as a minor supplement to flour of other grains (Choge *et al.* 2007). According to Da Silva *et al.* (2007), *P. juliflora* pod flour is rich in sugars (56.5% by weight), moderate in proteins (9% by weight), and low in lipids (2.1% by weight). It has about 0.75% and 0.39% (by weight) of phosphorous and calcium. Another study by Shitanda *et al.* (2013) show fresh and dry pods containing 0.05% and 0.04% vitamin C, respectively. When used to the extent of 20% or less, the *P. juliflora* flour has a pleasant taste (Choge *et al.* 2007). From morphological and rheological standpoints, the *P. juliflora* flour is suitable for the making of bread, cookies and cakes (de Gusmao *et al.* 2016).

The brightly coloured *P. juliflora* flowers are a source of pollen and nectar attracting native pollinators. The resulting honey is of good quality (Dave & Bhandari 2013). The gum exuding from the *P. juliflora* trunk and branches forms adhesive mucilage and is useable as an emulsifying agent in confectionary and for mending pottery (Dave & Bhandari 2013; Khera *et al.* 2009). Tablets prepared using 8–10% of mucilage show the welcome attribute of slow drug release (over 5 h), and hardness (Selvi *et al.* 2010). Indeed *P. juliflora* gum was widely used by the Indian cultures of central northwestern Mexico and the southwestern United States since pre-Columbian times (Vernon-Carter *et al.* 2000). It was used mainly as a sweet, as ingredient in human and animal feedstuffs, and as a medicinal aid for sore eyes, sore throat, stomach ache, diarrhea, for preventing infections, and for the treatments of open wounds (Vernon-Carter *et al.* 2000). Small processing industries, mainly dealing with foodstuffs and confectionery goods, still use *P. juliflora* gum in Mexico. The gum is

Fig. 3. Typical scenes of *P. julifora* advancing towards human dwellings (left) and blocking pathways (right) in India.

highly nutritious, particularly rich in antioxidants (Sirmah & Mburu 2011).

At Central Arid Zone Research Institute (CAZRI), Jodhpur, attempts have been made to use powder of *P. juliflora* pods as a filler in a coffee formulation comprising of 70% pod powder, 20% raw coffee, and 10% chicory (Tewari *et al.* 2013). A syrup has also been developed by Tewari *et al.* (2013) which is claimed to be "highly nutritious". But these formulation are yet to pass the statutory safety tests (Tewari *et al.* 2013). According to Gonzalez & Castro (2011), *P. juliflora* gum can be used as an additive in the preparation of nectars of fruits with low caloric content.

A source of feed

Among possible ways of utilizing *P. juliflora*, its potential as feed has been most extensively explored (de Oliverira *et al.* 2016; Odero-Waitituh *et al.* 2016). Livestock spanning cattle, fawl, and fish have been studied *vis-a-vis* their response to consumption of *P. juliflora*, especially *P. juliflora* pods (Hintsa *et al.* 2015; Silva *et al.* 2015). The reports are summarized in Table 2. As may be seen, the pods have been the most explored of *P. juliflora* parts for use as feed. But nearly all reports emphasize that no feed based exclusively on pods, or with pods as the major fraction, is safe. Most authors recommend that pods should constitute no more than 20% of any feed; higher fractions are a health hazard (Awawdeh *et al.* 2017; Manhique *et al.* 2017).

At CAZRI, Jodhpur, a feed has been made of *Prosopis* pods admixed with other locally available ingredients tumba (*Citrullus colocynthis*), guar (*Cyamposis tetragonaloba*), and til (*Sesamum indicum*), with wheat bran, maize, and minerals added (Tewari *et al.* 2013).

The *P. juliflora* pod extracts, which are rich in juliprosine, prosoflorine and juliprosopine, can be used as ruminal feed additive to decrease gas production during ruminal digestion as well as an antibacterial agent (dos Santos *et al.* 2013). *Prosopis juliflora* feed, fortified with de-wormer, acts as an anti-helminthic agent (Syomiti *et al.* 2015).

A source of biopesticides

Prosopis juliflora leaf extract has been found effective against fungi *Pyricularia grisea* which causes rice blast disease (Kamalakannan *et al.* 2001). Its foliar application can control late leaf spot and rust diseases in groundnut (Kishore & Pande 2005). Its methanol extracts were as effective against tomato bacterial leaf spot disease as erythromycin, streptomycin and penicillin (Ahmed *et al.* 2009) and the amendment of soil with the powder of its leaves, flowers, and stem to 5% *w/w* controls root-effecting fungi (Ikram & Dawar 2013). Its alkaloid-enriched extracts have been as effective

Fig. 4. Encroachment of *P. juliflora* in a wetland (left), and typically impenetrable thickets formed by the species (right). Due to the thorns contained in *P. juliflora*, these thickets can seriously aggravate a road accident.

against *Xanthomonas* pathovars as synthetic antibiotics Bact-805 and K-cycline, and against human pathogens as gentamycin and streptomycin (Ahmed *et al.* 2009; Raghavendra *et al.* 2009, 2010). Pellets of its leaves incorporated in soil completely suppressed colonization of *Fusarium* spp, *Macrophomina phaseolina*, and *Rhizoctonia solani* (Ikram & Dawar 2016). Besides controlling root rot fungi infection in leguminous plants, a 1% *w/w* application of *P. juliflora* leaf pellets in soil also seemed to enhance the growth of crop plants (Ikram & Dawar 2016). Its fungal endophytes appear to possess strong antimicrobial activity (Srivastava & Anandrao 2015). The antibacterial activity of *P. juliflora* extracts has also been confirmed by Arunachalam *et al.* (2010), dos Santos *et al.* (2013), and Valli *et al.* (2014). It reduces the post-harvest anthracnose incidence in banana (Bazie *et al.* 2014) and mango (Deressa *et al.* 2015).

Prosopis juliflora extracts have shown insecticidal potential against whitefly eggs and nymphs (Cavalcante *et al.* 2006), stored grain pest *Tribolium castaneum* (Pugazhvendan *et al.* 2012), and mosquito vectors of malaria, dengue, chikungunya and filariasis (Bansal *et al.* 2012; Yadav *et al.* 2014, 2015). *Prosopis* leaf extract enhanced the pesticidal impact of endosulfan on the fecundity of *Spodoptera litura* (Murugesan *et al.* 2004).

Prosopis juliflora pods have shown antibacterial activity against common pathogens like *E. coli* and *P. aeruginosa* (Taj Bakhsh *et al.* 2015). The alkaloid rich fraction of leaves provide a promising defense against the fungi *Cryptococcus* (Valli *et al.* 2014).

A source of human medicine; a cosmetic

All parts of *P. juliflora* have been explored for ethno-medicinal use (Damasceno *et al.* 2017; Dubow 2011; Mazinani *et al.* 2017; Mwangi & Swallow 2005; Walter 2011). The decoction made from boiling its wood chips helps in toning of the skin; its bark extract is used as an antiseptic, and its gum is used to treat eye infections (Dave & Bhandari 2013). The tree's flour is used as an aphrodisiac, its syrup as an expectorant, and tea infusion to restore digestion and to treat skin lesions (Dubow 2011). *Prosopis juliflora* has also been used to treat sexually transmitted diseases and its anticarcinogenic effects have been reported (Dave & Bhandari 2013; Tiwari *et al.* 2013). All these medicinal properties stem from the alkaloids, flavonoids and tannins contained in *P. juliflora* (Dave & Bhandari 2013; Mazinani *et al.* 2017; Sirmah *et al.* 2011).

The ability of the alkaloid juliflorine, which is specific to *P. juliflora*, in suppressing acetylcholinesterase and butyryl cholinesterase enzymes in a concentration dependant fashion, has made the alkaloid a potential drug for Alzheimer's disease (Choudhary *et al.* 2005; Patočka 2008). The

Fig. 5. Cows (left) and a goat (right) looking for pods of *P. juliflora.*

flavanols content of *P. juliflora* displays antioxidant and antitumor capabilities (Sathiya & Muthuchelian 2010, 2011; Sirmah *et al.* 2011). The leaf, bark and flower extracts of *P. juliflora* have also been shown to possess antiplasmodial potential (Ravikumar *et al.* 2012). Galactomannan present in *Prosopis* gum (Cabral *et al.* 1999), is found to have a good disintegrating and binding efficiency, so can be utilized in pharmaceutical industry (Khanna & Dwivedi 1997).

As biosorbant and a raw material for activated carbon

Prosopis juliflora leaf powder has been shown as a potential biosorbant for malachite green dye (Sharmila *et al.* 2013c), and lead (Jayaram & Prasad 2009). Raw *P. juliflora* bark, treated with 0.1N hydrochloric acid, has been shown to absorb as much as 43.1 mg g^{-1}, or 97%, of Cu (II) from the latter's solutions (Andal *et al.* 2016). *P. juliflora* wood, on activation by zinc chloride at temperatures of ca 600 ^{o}C, yields about half of its mass of activated carbon (Ahamed & Ahamed 2008; Kailappan *et al.* 2000). The activated carbon is seen to have good ability to remove traces of dyes methylene blue (Kailappan *et al.* 2000), Victoria blue (Kumar & Tamilarasan 2013a, 2014), aniline blue (Kumar & Tamilarasan 2014), Direct Red 23 (Gopal *et al.* 2014), malachite green (Thilagavathi *et al.* 2015), Remazol Brilliant Blue (Nair & Vinu 2016), Rhodamine B (Gopal *et al.* 2016), Acid Blue 40 (Gopal & Asaithambi 2015) and chromium (Kumar & Tamilarasan 2013b). It is a potential substrate for developing slow release nitrogen fertilizers (Manikandan & Subramanian 2013).

Other potential uses of P. juliflora

Diaz *et al.* (1999) have reported that natural coagulants present in *P. juliflora* can remove turbidity from drinking water and the optimum *P. juliflora* based coagulant doses were lesser than that for alum. Ethanolic extracts of *P. juliflora* could remove 78% of total dissolved solids present in tannery and paint industry effluents (Sharmila *et al.* 2013a,b).

Prosopis juliflora has been explored as a source of paper pulp by Choudhury *et al.* (2008) and as a source of fiber composite by Sarvanakumar *et al.* (2014a,b). Silver nanoparticles, bearing anti-microbial activity have been synthesized biomimetically using aqueous extracts of fresh leaves of *P. juliflora* (Raja *et al.* 2012). Gold nanoparticles have been synthesized from a similar extract of *P. juliflora* seedlings (Raju *et al.* 2014).

The tree rings of *P. juliflora* hyperaccumulate and immobilize heavy metals, making *P. juliflora* a good bioindicator of heavy metal pollution (Beramendi-Orosco *et al.* 2013; Gabriel & Patten 1994, 1995). *Prosopis juliflora* leaves have also been used for this purpose (Bu-Olayan & Thomas 2002; Naveed *et al.* 2012). *Prosopis juliflora* accumulates Ni, Cu, Cd, and Cr to concentrations several times higher than the soil on which it is grown (Nivethitha *et al.* 2002; Senthilkumar *et al.*

2005), making it a candidate for effecting bioremediation of heavy metal contaminated sites (Jayaram & Prasad 2009; Usha *et al.* 2009; Varun *et al.* 2011). A novel ATPase peptide from *Prosopis* is perhaps involved in this attribute of *Prosopis* (Keeran *et al.* 2017). *Prosopis juliflora* is also capable of hyperaccumulating fluoride and can be used to phytoremediate fluoride-laden soils (Saini *et al.* 2012a,b; 2013a,b; Baunthiyal & Sharma 2014 a,b). Its growth over coal mine soil can develop carbon, nitrogen, and phosphate stocks in the soil while improving the soil's bulk density, fine earth fraction, and water holding capacity (Ahirwal *et al.* 2017). It appears to have potential of remediating phenol due to the peroxidase contained in it (Singh *et al.* 2017).

Prosopis juliflora pods flour can be used in the preparation of bacteriological media (Diaz Zavala & Gonzalez 1997; Ramasamy *et al.* 2014). It can be used for the production of enzymes xylanase (Murugan *et al.* 2015) and cellulosome (Jampala *et al.* 2015). The anti-corrosion properties of its extracts have been documented (Palanisamy *et al.* 2016; Venugopal *et al.* 2015) and high-energy hybrid electrochemical capacitors have been fabricated from the carbon derived from it (Sennu *et al.* 2016).

When the compost of *P. juliflora* is applied to farmlands, it not only increases the soil moisture but also the seed yield. It also controls the occurrence of diseases such as charcoal rot (Bareja *et al.* 2010; Bareja *et al.* 2013; Saxena *et al.* 2014).

***Prosopis juliflora*: the bane**

Intrusive growth

Outside dryland habitats and in regions not populated by marginal, subsisting people, *P. juliflora* is a great bane. Flood plains are particularly susceptible to *Prosopis* invasion (Ilukor *et al.* 2016) and *Prosopis* trees have been found to reduce inflow and capacity of structures set up for harvesting rainwater (Bitterman *et al.* 2016). Even in impoverished villages, where *P. juliflora* and its produce are extensively utilized, uncontrollable growth of *P. juliflora* becomes a serious existential threat as *P. juliflora* tends to colonize the little pieces of agricultural lands that may be held by the subsistence farmers, dispossessing them totally (Dubow 2011; Mwangi & Swallow 2005). *Prosopis juliflora* has also been known to overrun pathways and other spaces around dwellings, making the dwellings inhabitable and forcing the occupants to migrate. This is known to have generated social tensions (Admasu 2008). There are indications that increased climate variability in recent years has forced changes in land and water management that has facilitated invasion of *P. juliflora* (Becker *et al.* 2016; Oo & Koike 2015).

Allelopathy

Prosopis juliflora is known to inhibit germination of seeds of other species of plants that lie in its vicinity (Muturi *et al.* 2017; Shaik & Mehar 2015). It also discourages other species of plants to grow near it. It releases allelochemicals from its leaves, roots, as well as fruits to achieve this (Noor *et al.* 1995).Goel *et al.* (1989) found that leaf extracts as well as leaf leachates of *P. juliflora* carried allelochemicals, so did decaying leaves. These authors, as well as Chellamuthu *et al.* (1997), who studied the influence of *P. juliflora* leaf litter on the germination of seeds of other species, attributed the allelopathy to phenolic compounds present in *P. juliflora*. Al-Humaid *et al.* (1998) recorded suppression of seed germination and early growth of bermuda grass *(Cynodon dactylon)*, and Kaur *et al.* (2014) of *Brassica campestris,* by aqueous extracts of *Prosopis* leaves. These studies indicate that *P. juliflora* foliage may contain water-soluble allelochemicals, which get leached to the ground as rain water falls on them and tikles down (Abbasi & Abbasi 2011). These chemicals were isolated by Nakano *et al.* (2002, 2003, 2004) and identified as syringin, (-) - lariciresinol, L- tryptophan, juliprosopine, juliprosine, and juliprosopinal. Among these, juloprosine derivatives exhibited the most pronounced allelopathy.

Prosopis juliflora also displays autotoxicity: its leachates suppress the germination of its own seeds (Warrag 1994, 1995). This is, perhaps, one of the survival strategies with which *P. juliflora* prevents its sister trees to grow so close to it that they may jeopardize each other's nutrient and water availability.

Loss of biodiversity

Prosopis juliflora canopies discourage other vegetation, particularly suppressing the annuals (El-Keblawy & Al-Rawai 2007; El-Keblawy & Abdelfateh 2014). The negative impact of *P. juliflora* on phytodiversity has been stark (De Andrade *et al.* 2008, 2009, 2010) revealing the seriousness of jeopardy *P. juliflora* causes to native vegetation (Thomas *et al.* 2016). As *P. juliflora* invasion gets going, the diversity of indigenous woody species declines in proportion (Gunarathne & Perera 2016; Mworia *et al.* 2011; Rembold *et al.* 2015). In this happening allelopathy plays a strong part (Kaur *et al.* 2012; Shaik & Mehar 2015), besides other aspects — listed earlier — which give *P. juliflora* a competive advantage (Ayanu *et al.* 2014; Baka 2014; de Souza Nascimento *et al.* 2014; Haregeweyn *et al.* 2013; Pasha *et al.* 2015; Wakie *et al.* 2016).

The antimicrobial activity of the leaf litter harms the cellulolytic and symbiotically nitrogen fixing bacteria present in the soil (Zainal *et al.* 1988), thereby jeopardizing phytodiversity and agricultural production.

A lone report, by Naudiyal *et al.* (2017), questions the general perception of *P. juliflora's* negative impact on biodiversity. In a study on the plant community composition on Delhi ridge they found that grazing and other forms of anthropogenic disturbances, rather than *P. juliflora* that had significant negative impact on the ridge's vegetation diversity. They even found a positive correlation between *P. juliflora* and the native species, observing that *P. juliflora* acts as a nurse tree in facilitating the regeneration of native species under its canopy. But these observations are not as surprising as they appear at first glance. Any area covered by *P. juliflora* will have richer soil and better micrometeorology than a totally degraded open land. But any area under *P. juliflora* will have much poorer biodiversity than areas harboring multiple species of plants.

While a great deal of evidence has been generated, as above, on the harm caused by *P. juliflora* to phytodiversity, no reports are available on the impact of *P. juliflora* on fauna (except avia, discussed later, But it is not difficult to imagine that shift in floral community structure would strongly impact faunal diversity as well, especially the endangered species (Kumar & Mathur 2012, 2014).

Source of mammalian toxicity

Livestock tends to forage on *P. juliflora* pods (Fig. 5); in times of scarcity they may feed almost exclusively on the pods. But such uncontrolled feeding of *P. juliflora* pods is a serious health hazard for cattle, leading to neurological disorders and their secondary impacts (Silva *et al.* 2013). There is selective toxicity to neurons of cranial nerve nuclei (Tabosa *et al.* 2000, 2006), leading to partial anorexia, depression, salivation, twitching, dehydration and bloody diarrhea (Misri *et al.* 2003). Histopathological studies reveal necrotic lesions in the liver with bile duct hyperplasia. Degenerative changes occur in renal tubules and there is rarefaction of lymphoid tissue. There is a chronic and progressive injury to neurons, causing denervation atrophy (Tabosa *et al.* 2006). Clinical signs include progressive weight loss, atrophy of the masseter muscles, dropped jaw, tongue protrusion, difficulties in prehending food, tilting of the head during mastigation or rumination, salivation, impaired swallowing, and decreased tone of the tongue. There is emaciation and reduction in size of the masseter muscles, which appear thinner than normal and grayish due to muscular atrophy (Câmara *et al.* 2009). The alkaloids present in the pods appear responsible for the toxicity as revealed by cytotoxic and neurotoxic studies on the alkaloid extracts of *P. juliflora* pods and leaves (Hughes *et al.* 2006; Silva *et al.* 2007; Silva *et al.* 2013). Two of the alkaloids which are present only in *P. juliflora* - juliprosine and juliprosopine are particularly harmful in this respect (Silva *et al.* 2013). There is evidence that the pods cause teratogenic effect on rodents (Medeiros *et al.* 2014).

A facilitator of mosquito proliferation and other adverse impacts

Prosopis juliflora thickets provide breeding grounds for mosquitoes, causing increase in the incidence of malaria (Mwangi & Swallow 2005; Pasiecznik *et al.* 2001). Muller *et al.* (2017) examined the effect of *P. juliflora* on *Anopheles* mosquito populations through a habitat manipulation experiment that removed the flowering branches (which mainly attract mosquitoes) of *Prosopis* from selected villages in Mali, West Africa. This resulted in a threefold drop in the older (and the particularly dangerous) *Anopheles* female population. Their population density dropped by 69.4% and the species composition shifted from being a mix of three species of the *Anopheles gambiae* complex to one dominated by *Anopheles coluzzii*. The study demonstrates how *P. juliflora* promotes the malaria parasite transmission capacity of African malaria vector mosquitoes.

The hard seeds contained in the *P. juliflora* pods lodge between gums and teeth of cattle, especially goats, leading to inflammation; their jaws are eventually disfigured (Dubow 2011; Mwangi & Swallow 2005). It results in loss of health and even death. The dense stands of *P. juliflora* sometimes harbor predators, which prey on young goats (Mwangi & Swallow 2005; Pasiecznik *et al.* 2001).

A hazard for humans

The sharp, strong and poisonous thorns of *P. juliflora* make it difficult for people to penetrate its dense thickets to harvest fuel wood (Dubow 2011; Walter & Armstrong 2014). When they prick, the thorns cause serious inflammation that may take a week to subside. If left untreated the infections are known to have caused gangrene requiring amputation of limbs (Dubow 2011; Mwangi & Swallow 2005).

If *P. juliflora* leaves happen to fall on potable water, it makes the water bitter (Mwangi & Swallow 2005; Walter & Armstrong 2014). It has been reported from many parts of the world that pollens of *P. juliflora* trigger allergic asthma, rhinitis, and skin allergy (Ahlawat *et al.* 2014; Al-Frayh *et al.* 1999; Assarehzadegan *et al.* 2015; Bhuvaneshwari *et al.* 2004; Dhyani *et al.* 2008; Dousti *et al.* 2016).

A source of interference with water resources

Encroachment upon water bodies by *Prosopis* interferes with drainage, and exacerbates flooding. It may cause tap roots which aggressively grow downwards, make deep cracks in the ground, which pose risks for young goats (Dubow 2011; Mwangi & Swallow 2005).

A threat to avifauna

Prosopis juliflora is known to provide low-quality habitat for avifauna. In a study on tree species and avifaunal diversity, a negative relationship was found between *P. juliflora* density and the bird diversity it supported (Khera *et al.* 2009).

A recent study (Chandrasekaran *et al.* 2014) shows that *P. juliflora* poses significant threat to the nesting success of wetland birds. Like other invasive plants it also adversely impacts bird diversity by (i) drawing the birds into areas which are unsuitable for them and exposing them to unfamiliar risks; (ii) altering local bird assemblage pattern; (iii) altering prey–predator interactions; (iv) changing the temperature and humidity of the nesting season; (v) increasing the rate of nest predation; and (vi) providing low-quality habitats. In addition, the branching pattern of *P. juliflora* makes it particularly hazardous for wetland avifauna. The branching angle in *P. juliflora* is larger than in other trees: between 165° and 190°. This results in greater sliding of eggs and chicks from their nests made in *P. juliflora*. The branching architecture of *P. juliflora* is such that the branches stretch out sideways and overlap each other. This may be the reason for higher mortality of chicks who nest in *P. juliflora* canopy: the architecture leads to greater disturbance and mortality of eggs and chicks when birds take evasive action against predators, *P. juliflora* compared to other invasives.

Chandrasekaran *et al.* (2014) report that *P. juliflora* has colonized 5 out of 12 bird sanctuaries in Tamil Nadu and the remaining sanctuaries are also susceptible to *P. juliflora* invasion because of the similarity in their climate. Hence the total impact of *P. juliflora* on the wetland birds of Tamil Nadu can be very serious.

A contributor of global warming gases

Prosopis juliflora helps in ameliorating global warming—as all vegetation does—by sequestering carbon. But *P. juliflora* may also be adding to global warming as its plantation leads to higher emissions of CO_2 and N_2O than nearby unplanted soil (Herrera-Arreola *et al.* 2008). Of these the N_2O emissions are a cause of particularly serious concern because each molecule of N_2O contributes as much to global warming as 300 molecules of CO_2 do (Abbasi & Abbasi 2012; Premalatha *et al.* 2014).

Strategies to counter the *P. juliflora* infestation: destruction *vs* utilization

As has been the case with other weeds, extensive efforts have been made to control *P. juliflora,* too, by chemical, biological, and mechanical means (Goncalves *et al.* 2015; Yoda *et al.* 2015). And, as has been the case with other major weeds like water hyacinth *(Eichhornia crassipes),* ipomoea *(Ipomoea carnea),* lantana *(Lantana camara),* and parthenium (*Parthenium hysterophorus*), no strategy to even control these weeds; let alone eradicate them, has achieved any enduring success (Abbasi *et al.* 2016; Hussain *et al.* 2015, 2016a,b). At best *P. juliflora* spread can be halted by actions such as clear cutting followed by burning of the stump and application of pesticides in the cuts (Goncalves *et al.* 2015). Alternatively ways can be found to utilize the existing stands of *P. juliflora* so that frequent harvesting can exert a check on its expansion. Which of the two options is to be exercised would depend on which is more beneficial in a given setting.

In a benefit-cost analysis which is specific to Ethiopia, Wakie *et al.* (2016) have shown that a) conversion of *P. juliflora* infested areas into irrigated cotton fields may be economically viable there; b) charcoal production with existing stands of *P. juliflora* can also be profitable. They have further shown that production of flour from pods requires much higher capital investment than charcoal production systems but the former can become profitable if proper management strategies are adapted. In another study, also specific to Ethiopia, Ilukor *et al.* (2016) opine that utilizing *P. juliflora* has net benefits over the gains in clearing it.

The experience so far gained with not only *P. juliflora* but also other major weeds—as mentioned above—clearly indicates that attempts to eradicate *P. juliflora* from any region are unlikely to achieve any long-term success. Only by improving the economics of its utilization, as appropriate for a given region, can its dominance be reduced. This calls for intensification of efforts towards economically viable utilization of all components of *P. juliflora*. The *P. juliflora* wood is the most widely and gainfully utilized of all its parts. The pods come next in utility as food/feed supplement. Further work should be focused on maximizing the gains from these two components of *P. juliflora*. In comparison there is little use of the tree's leaves as of now. Even as the leaves are utilizable in traditional, or 'folk' medicine, and in the making of cosmetics, only insignificant quantities of *P. juliflora* leaves are actually used for these purposes because of the availability of much better alternatives at affordable prices. Hence future work should focus on finding ways to commercially utilize *P. juliflora* leaves on a large scale.

Summary and conclusion

A state-of-the-art review has been presented on the xerophyte *P. juliflora* in the context of its ongoing invasion of land masses in the tropical and sub-tropical world. It is shown that *P. juliflora* is a major boon when growing in its native habitat—desert lands—making the desert environment more habitable and providing fuel, food, feed, biopesticides, medicines, cosmetics, gum, and activated carbon.

But when taken to exotic environments, the same attributes of *P. juliflora* which enable it to survive and thrive in forbidding territories, make it a very aggressive invader and colonizer. It becomes a major monopoliser of natural resources and a destroyer of biodiversity. It also poses serious risk to humans, livestock, and wildlife.

While collating and summarizing all information on the past attempts to utilize *P. juliflora*, the review brings out the knowledge-gaps that urgently need to be filled if large-scale utilization of *P. juliflora* is to be achieved in an economically and ecologically viable manner. The review highlights the fact that this is the only way by which *P. juliflora* can be sustainably managed.

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