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Effect of associated species on distribution of *Commiphora wightii* in Indian Arid Zone

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ABSTRACT: *Commiphora wightii* (Arn.) Bhandari, a medicinal shrub of the family Burseraceae has been ruthlessly tapped for oleo-gum resin, thus killing its widespread populations in nature. Its regeneration being slow, the recruitment is also minimal. Consequently, existing sparse populations also face competition from its associates. Understanding vegetation composition and dynamics of associates of *C. wightii* are vital to arrive at clues for its *ex-situ* conservation and also for its *in-situ* populations build up. Present study carried out in 20 districts of Rajasthan at 604 sites revealed presence of *C. wightii* at 68 sites. Its associates were *Acacia senegal, Euphorbia caducifolia, Grewia tenax, Prosopis juliflora, Acacia leucophloea* and *Boswellia serrata*. In all the six districts, density of *C. wightii* varying from 1 to 20 per tenth hectare indicated its mutual co-existence with other species except *P. juliflora.* Regulating and controlling populations of *P. juliflora* emerged as a prime requirement to ensure success in both, *in-situ* and *ex-situ* conservation. Being ecologically co-dominant, it survives best in mixed plantation with suitable trees that serve as upper canopy in the plantation area. It also emerged that its optimum plantation density of 200 plants per hectare would most likely ensure its success in reintroduced paddocks.

KEY WORDS: Burseraceae, *Commiphora wightii*, Density, Dominance, Piedmonts, *Prosopis juliflora*.

INTRODUCTION

Commiphora wightii is a source of oleo-gum resin which has immense medicinal value in both ancient and modern system of medicine. In order to obtain more and more oleo gum resin, its ruthless and indiscriminate tapping in the last 50 years has lead to its extermination over large areas in Rajasthan (Kulloli and Kumar, 2013). Atal *et al.*, (1975) recorded that a "large number of plants of *C. mukul* (=*C. wightii*) were present some 10 to 15 years ago in Rajasthan, but the number has come down considerably, largely due to the faulty techniques of tapping employed by the local inhabitants." Similarly in Gujarat state of India, the Forest Department of Gujarat collected 30 tons of gum-resin in 1963, but in 1999, only 2.42 tones were collected (Dixit and Rao, 2000). These observations by Atal *et al.*, (1975); Dixit and Rao (2000) are indications of declining *C. wightii* stocks. Increasing demands of oleo gum resin in India are believed to be met by importing large quantities of gum guggul from other countries (Kulhari *et al.*, 2014) resulting in sharp increase in prices of gum guggul from 25 rupees/kg to 300 - 500 rupees per kg in the ten years. Kumar (2013) quantified *C. wightii* distribution along 123 belt transects and concluded that cutting and lopping to extract the medicinal resin was the major threat to *C. wightii* populations. The Government of India includes *C. wightii* under their Rare, Endangered, Threatened (RET) category of species (Samantaray *et al.*, 2011). In fact Government of Rajasthan has banned the tapping of *C. wightii* trees (Samanta and Mandal, 2014). Although considered Data deficient (DD) on the IUCN Red List, the threat status to this species is considered much higher by Indian scientists. Over a decade ago, Parmar (2003) considered that the *C. wightii* population had declined to less than 50% of its original size, leaving isolated subpopulations. In 2002, *C. wightii* was classified as 'Lower risk and conservation dependent (LRcd)' (GEC, MSU and GUIDE 2002, cited in Kumar, 2013). More recently, a conservation threat assessment by Reddy *et al.*, (2012) suggested that this species is threatened across all of Rajasthan and Gujarat and should be considered endangered. Increase in area under mining of rocky uplands, which support this plant has also shrunk its distribution (Moharana, 2015). Its recruitment in nature has never been noted or reported by any worker.

In view of above, large numbers of studies on its various facets have been taken up by many workers as reviewed by Kulloli and Kumar (2013). Same authors have also reported its distribution in Rajasthan state of India (Kulloli *et al.*, 2013a), its seed size and germination (Kulloli *et al.*, 2013b), its relationships with edaphic factors (Kulloli *et al.*, 2015) and its ecological niche modelling for predicting potential areas for its reintroduction (Kulloli and Kumar, 2014). In order to be successful in its re-introduction it is paramount to understand its associated plant species in nature so that this information is internalized while

designing its conservation strategy. Keeping this in view attempts have been made in the past to study its associates by Dixit and Subba Rao (2000) describing a positive association of *C. wightii* with *Acacia nilotica, Acacia senegal* and *Euphorbia nivulia,* while negative association with *Cassia auriculata* in arid Gujarat. In Rajasthan Reddy *et al.,* (2012) reported its associates, area of occurrence and area of occupancy based on satellite data of 2007 and field sampling up to 2009 and inferred its endangered status. But his datasets based on Jaisalmer, Jodhpur and Jalore districts out of 12 arid districts in western Rajasthan, cover inadequate area to reach a conclusion. Similarly, Lal and Kasera (2010) also listed its associates but only from four sites in western Rajasthan. Thus there is inadequate information on associates of *C. wightii*, such as species composition and likely mutual impacts of these species on *C. wightii* spread in many parts of Indian arid zone.

Hence this study was aimed to know trends of distribution, density, dominance and vigor of *C. wightii* and its associates in both protected and unprotected situations across Indian arid zone to answer following questions:

1. What is the ecological status of *C. wightii* in native populations?
2. What could be the optimum density of *C. wightii* upon reintroduction?
3. Are there any weedy associates that may require managements in reintroduced plantations?
4. Which are the most preferred sites of its introduction for maximizing its success?

MATERIALS AND METHODS

Study area

The study was carried out in Rajasthan state of India. Twenty districts of Rajasthan (Jaisalmer, Barmer, Jalore, Sirohi, Pali, Nagaur, Jodhpur, Ajmer, Sikar, Jhunjhunun, Churu, Bikaner, Shri Ganganagar, Hanumangarh, Kota, Bundi, Rajsamand, Bhilwara, Chittorgarh, Jhalawar) were surveyed and *C. wightii* populations were assessed. Average annual rainfall varies from 200 mm in Jaisalmer to 550 mm in Sirohi. Rains are erratic, uneven and variable across the year; coefficient of variability being over 55%. Extremes of temperatures like 50 ^{o}C in summer and -2 ^{o}C in winters result in hot winds and frosts, respectively. High wind speed (20-40 km/hr), high evapotranspiration (1500-2000 mm/ year), soils having poor soil fertility and low water retention capacity as well as deep brackish ground water pose challenge to plant survival and growth (CAZRI, 2007). Consequently, arid landscape has poor tree cover and dominance of sparsely located shrubs.

Sampling Design and Data Analysis

Using locations inferred from DEM map, these sites (604) were visited. Those having absence of *C. wightii* were recorded accordingly. Those sites having *C. wightii* were sampled in 5 to 10 quadrats of 10 m × 10 m placed beside each other (Ludwig and Reynolds, 1988). Presence, density, height and cover of *C. wightii* and all associated species were recorded. Plant cover was calculated as πr^2, where 'r' is half of the averaged diameter measured as north-south and east-west directions above the canopy. Height and cover of canopy were used to infer plant vigour. Recorded data were analysed for relative importance value (RIV) as described by Curtis and McIntosh (1950). Higher RIV indicated higher dominance. RIV data were further analyzed for richness, evenness and Shannon- Wiener index (H') and standard error following Ludwig and Reynolds (1988). Richness was total species count per 1000 m^2. Evenness was calculated by the formula, $E= H/H_{max}$

Where H= Shannon-Wiener index

Shannon- Wiener index (H') calculated as follows

$H' = - \Sigma\, pi\, Inpi$

Where, pi = the proportion of important value of the i^{th} species ($pi = ni / N$, ni is the importance value index of i^{th} species and N is the important value index of all the species).

Density, height and canopy of *C. wightii* occurring in three rainfall zones (200-350 mm, 351-500 mm and over 500 mm) were analyzed for significant differences among their means by Tukeys Test ($p<0.05$).

RESULTS AND DISCUSSION

One of the ways to protect the threatened species of such immense economic value, *C. wightii* in native habitats is to shift from its wild harvest to managed plantations. Bottlenecks in success of plantation of *C. wightii* are expected more due to lack of information about phytosociological parameters across different agroclimates ranging from low (150 mm) to high (550 mm) rainfall gradient in Indian Thar Desert. Sporadic and isolated studies on raising its plantation in Aravalli hills, near Gulta, Jaipur, (Soni, 2010), Madhya Pradesh and elsewhere are known to face problems. Hence the present work on understanding trends in density, dominance and vigour of *C. wightii* along with its associates across a variety of agroclimate assumes importance.

Distribution patterns of C. wightii in Rajasthan

A total of 604 sites in 20 districts were visited. The maximum number of sites of presence of *C. wightii* occurred in Ajmer district (14 sites) followed by Barmer district (13 sites). It occurred in the areas having rainfall 221 mm to 665 mm (Table 1). In this study, *C. wightii* was located at 68 sites i.e. only at 10.62% of total sites visited in the study area using satellite data, GIS and ground truthing validation. It preferably grows in rocky areas, and in shallow, gravelly, unfertile soils, hilly terrains and open canopies (Kumar and Shanker, 1982; Sabnis and Rao,

Table 1. *C. wightii* collection sites.

Sr. no.	District	Total sites visited	Total sites of collection		Protected sites	Unprotected sites	Annual Rainfall (mm)*
			Hills	Plains			
1	Jaisalmer	34	5	7	2	10	221.0
2	Barmer	59	6	7	5	8	287.7
3	Jalore	10	7	-	6	1	433.7
4	Pali	29	5	2	5	2	487.0
5	Sirohi	18	2	1	2	1	665.0
6	Jodhpur	9	2	1	2	1	379.2
7	Nagaur	26	1	-	1	-	392.0
8	Ajmer	49	12	2	10	4	529.0
9	Rajsamand	58	5	1	4	2	553.2
10	Jhunjhunun	17	1	-	1	-	480.0
11	Sikar	47	1	-	1	-	456.9
12	Bikaner	59	-	-	-	-	310.0
13	Churu	64	-	-	-	-	386.3
14	Jhalawar	41	-	-	-	-	883.0
15	Kota	5	-	-	-	-	717.3
16	Bundi	8	-	-	-	-	680.5
17	Bhilwara	7	-	-	-	-	633.9
18	Chittorgarh	23	-	-	-	-	762.7
19	Ganganagar	17	-	-	-	-	236.5
20	Hanumangarh	24	-	-	-	-	298.4
	Total	**604**	**47**	**21**	**39**	**29**	

1983; Soni, 2010). Population density of *C. wightii* as 25 stems ha^{-1} in desert and as many as 40 stems ha^{-1} in Aravalis has been reported by Reddy *et al.*,(2012) and in Gujarat it was reported 49 stems ha^{-1}(Dixit and Rao, 2000). In our study maximum population density of *C. wightii* has been recorded up to 200 plants per hectare in protected area while in unprotected areas it was 10-80 plants per hectare. It infers that populations of *C. wightii* are sparsely distributed and need to be protected for *in-situ* conservation so as to have achievable density of 200 plants/ha. This also indicated that in *ex-situ* conservation blocks the plantation density of 200 plants/ha of *C. wightii* is likely to be more successful as it will allow other associates to grow along with it.

Protected sites had low Shannon's diversity index (1.73) than unprotected sites (1.79). Higher diversity in moderately disturbed sites is reported by many workers (Brawn and Archer 1999; Archer 1989, 1995). Evenness was more in protected sites (0.90) than unprotected sites (0.86) (Table 2) again proving that given the favorable conditions such as protection, *C. wightii* facilitates optimum diversity and evenness, thus proving the need for protection during conservation to achieve more evenly dominant community.

Ecological status

Dominance of *C. wightii* was high (RIV=14.77) at protected sites compared to unprotected and degraded site (RIV=9.97) (Table 2) indicating favourable impacts of protection. In order to assess ecological status of *C. wightii*, its sites of occurrence were grouped into classes based on Relative Importance Value (RIV) at class interval of 5. In both protected and unprotected situations, over two third of the sites have RIV ranging from 5-25 (Table. 3). In fact its dominance has not exceeded in the entire sample beyond 35.11 indicating that remaining dominance is of other species. The highest dominance (=RIV) was always of other species (not *C. wightii*) except at 5 protected sites and hence its ecological status can be safely concluded as co-dominant to sub-dominant. Similar trend is also evident at unprotected sites which had *C. wightii* dominance (RIV) below 15. Thus its co-dominant status in nature points towards raising it in mixed plantation at reintroduction sites. If other species of mixture are highly weedy, then their management would be required for ensuring success in conservation.

Vigour attributes

Maximum numbers of protected sites (10 sites) were found in the district of Ajmer (Table 1), while maximum number of disturbed sites (10 sites) in the district of Jaisalmer followed by Barmer district (Table 1). In case of protected sites maximum height (300 cm) was found in Ajmer district and minimum (34 cm) in Pali district (Table 2). Maximum canopy cover (8.29 m^2) was found in Pali district, while minimum (0.7 m^2) in Ajmer and Pali districts at protected sites (Table 2). At disturbed sites maximum height (250 cm) was found in the district of Jodhpur and minimum (30 cm) in Jaisalmer district (Table 3).

Table 2. Summary of ecological parameters at protected and unprotected sites (mean ± SE/Range)

Parameter	Protected sites	Unprotected sites
RIV	14.77±1.30	11.78±1.08
	3.24-35.10	4.62-34.87
Height (cm)	171.2±11.24	116.8±11.58
	34-300	30-250
Canopy(m^2)	3.17±0.32	1.81±0.26
	0.17-8.29	0.25-5.25
Shannon_H	1.73±0.04	1.83±0.04
	1.23-2.56	1.08-2.14
Evenness_e^H/S	0.89±0.01	0.86±0.02
	0.65-0.99	0.58-0.98

Table 3. Number of sites having occurrence of ***C. wightii*** and ***P. juliflora*** in different dominance classes and in different density classes.

	Interval of dominance and density classes						
	0-5	**5.1-10**	**10.1-15**	**15.1-20**	**20.1-25**	**25.1-30**	**>30.1**
RIV of *C. wightii*							
No of Protected sites	1	9	13	7	5	3	1
No of Disturbed sites	4	12	10	1	2	0	0
RIV of *P. juliflora*							
No of Protected sites	17	6	3	6	5	1	0
No of Disturbed sites	12	2	7	4	2	2	0
Density of *C. wightii*							
No of Protected sites	20	12	4	3	0	0	0
No of Disturbed sites	17	10	1	1	0	0	0
Density of *P. juliflora*							
No of Protected sites	6	11	5	1	3	0	0
No of Disturbed sites	10	5	1	1	1	0	0

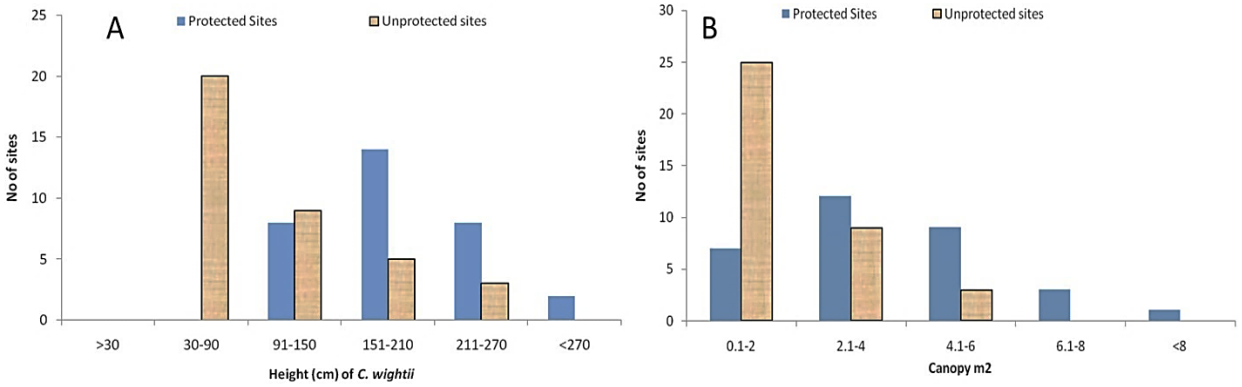

Fig. 1. Number of sites based on (**A**) height and (**B**) canopy cover at both protected and unprotected sites.

The height of *C. wightii* on 39 sites out of a total 54 protected sites was over 1.5 m while remaining 15 sites had the height less than 1.5 m (Fig. 1). Reverse was true for unprotected sites for obvious reasons of disturbance. Likewise, canopy spread (=cover) also was over 2 m^2 for 25 out of 39 sites in protection while it was 0.1 - 2 m^2 for 18 out of 29 sites under unprotected conditions (Fig. 2). Protection is therefore essential to attain uninterrupted growth so that plantations are available for gum tapping earlier than later.

Occurrence and density in different rainfall zones

Grouping sites of *C. wightii* according to their annual average rainfall revealed that maximum places of occurrence (28) are in rainfall zone of 200-350 mm/yr in Jaisalmer, Barmer and Jodhpur followed by 17 in Nagaur, Jalore, Sikar, Jhunjhunun and Pali district in 351-500 mm and 23 in rainfall zone of over 500 mm in Ajmer, Rajsamand and Sirohi (Fig. 2). Density, height and canopy spread of *C. wightii* in protected sites in the above three rainfall zones were compared so that anthropogenic impacts are excluded. It revealed that though their means were not different statistically, maximum average density and maximum average canopy spread of *C. wightii* was in areas receiving low rainfall (200-350 mm/year), but the height was minimum in such rainfall areas (Fig. 2). Thus, arid district of Jaisalmer, Barmer and Jodhpur favouring its more occurrence and growth emerged as preferred areas for its reintroduction. This is also confirmed by Ecological Niche Modelling (Kulloli and Kumar, 2014).

Relation with other associates on protected sites.

We considered data of protected sites only so that variations induced by anthropogenic factors are precluded. Density of *C. wightii* and its associates were examined. Increasing numbers of species as associates did not seem to be adversely affecting the density of *C. wightii* (Fig. 3). Since *P. juliflora* is a woody weed in this part of India, the density of *C. wightii* in relation to the density of *P. juliflora* was also examined in all districts. Results revealed that at most of the places density of *P. juliflora* was negatively impacting *C. wightii* density (Fig. 3). Density of *C. wightii* was favorably impacted with total density of all species with or without *P. juliflora* (Fig. 3). Thus in all the six districts the density of *C. wightii* indicated its mutual co-existence with all other species except *P. juliflora* which has perhaps been adversely affecting it. Similar results of *P. juliflora* occurrence and density on the *C. wightii* populations have been proved in a series of publications in Jamnagar district of Gujarat state in India, wherein this fact was also proved through satellite data followed by ground validation (Kumar and Mathur, 2014; 2012).

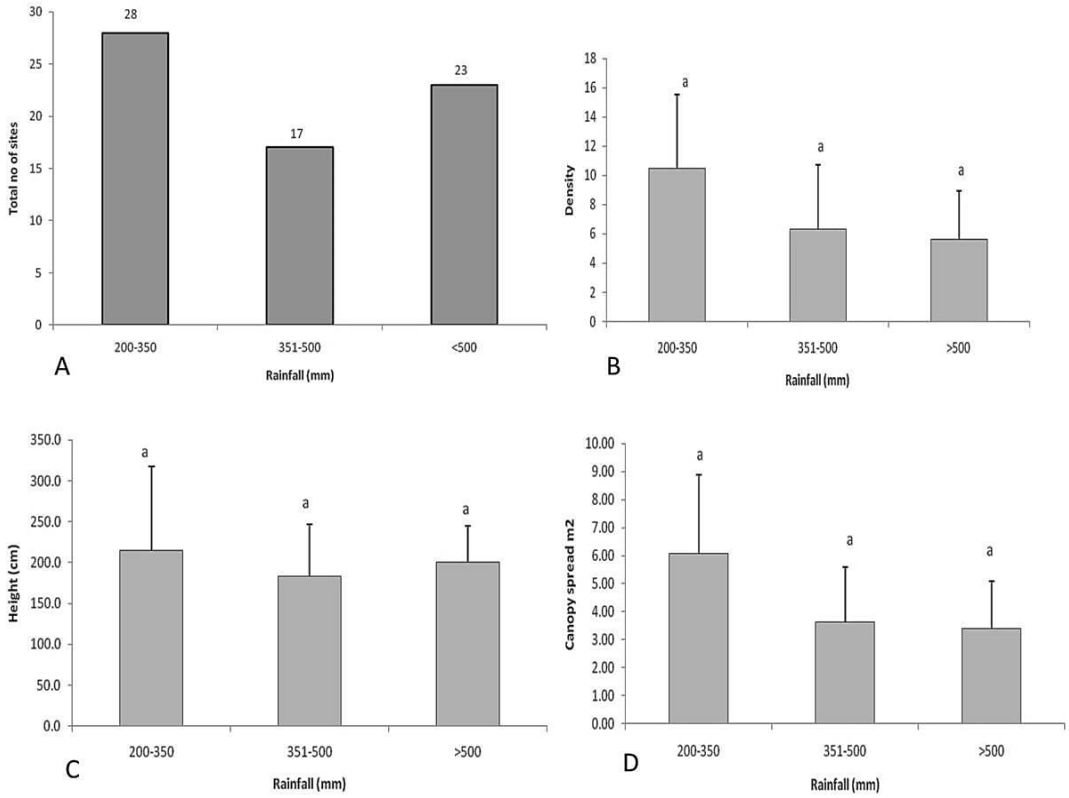

Fig. 2. (**A**) Number of ***C. wightii*** sites (**B**) Density of ***C. wightii*** on protected sites (**C**) Height of ***C. wightii*** on protected sites (**D**) Canopy spread of ***C. wightii*** in different district based on rainfall gradient.

Protected sites are mostly located at temples, sacred groves and protected by forest departments. At protected sites human interference is restricted. Sites protected by forest department manage invasive species. Similar impacts of invasive plants on native species were also reported in the Czech Republic by Hejda *et al.*, (2009). Sharma and Raghubanshi (2010) reported a decline in total species diversity and richness with increasing *Lantana camara* cover in Vindhyan's dry deciduous forest. Protected sites with *P. juliflora* having more richness may be due to localized site disturbance, which could enhance richness (Huston, 1994). Pawar *et al.*, (2014) studied the diversity along a disturbance gradient in dry tropics of Chattisgarh state of India and stated that vegetation in general had low density, low diversity and low basal area on highly disturbed sites. If such biotic pressure over the forest is removed the species associated with the dominant trees will also survive in future (Bodra *et al.*, 2007).

C. wightii richness and density in study area invaded by *P. juliflora* have declined. Likewise, Hejda *et al.*, (2009) report approximately 90 % decreases in species numbers per plot and total number of species recorded in invaded plant communities. Invasive plant species threaten ecosystem function and community diversity, dominating natural systems through suppression of, competition with, and replacement of native species (Kelly *et al.*, 2009; Ricciardi, 2004; Clavero and Garcia-Berthou, 2005). Rare species shows relatively high risk factors due to invasive plant species (Miller *et al.*, 2010). *P. juliflora* in study area suppresses native woody species (Daehler, 2003) causing lower species richness. It is most likely that its vigorous growth characteristic is responsible for its impact on native species. The species also has an extensive and dense root system that is important in propagation and competitive exclusion of other species. Mostly invasive species alter ecosystem characteristics like habitat disturbance, allelopathic effects, competition for nutrients and sunlight etc. Thus invasive species prove to have highly negative effect on ecosystem (Pimentel *et al.*, 2000) and deserve to be managed effectively so as to save the threatened, reintroduced species like *C. wightii*.

CONCLUSION

1. The distribution trends revealed that arid desert districts have more sites of this species, even as degraded sites have density similar to that on sites in other districts. Evidently, the districts of Jaisalmer (38,401 km^2), Barmer (28,387 km^2) and Jodhpur (22,850 km^2) are most appropriate for its reintroduction.

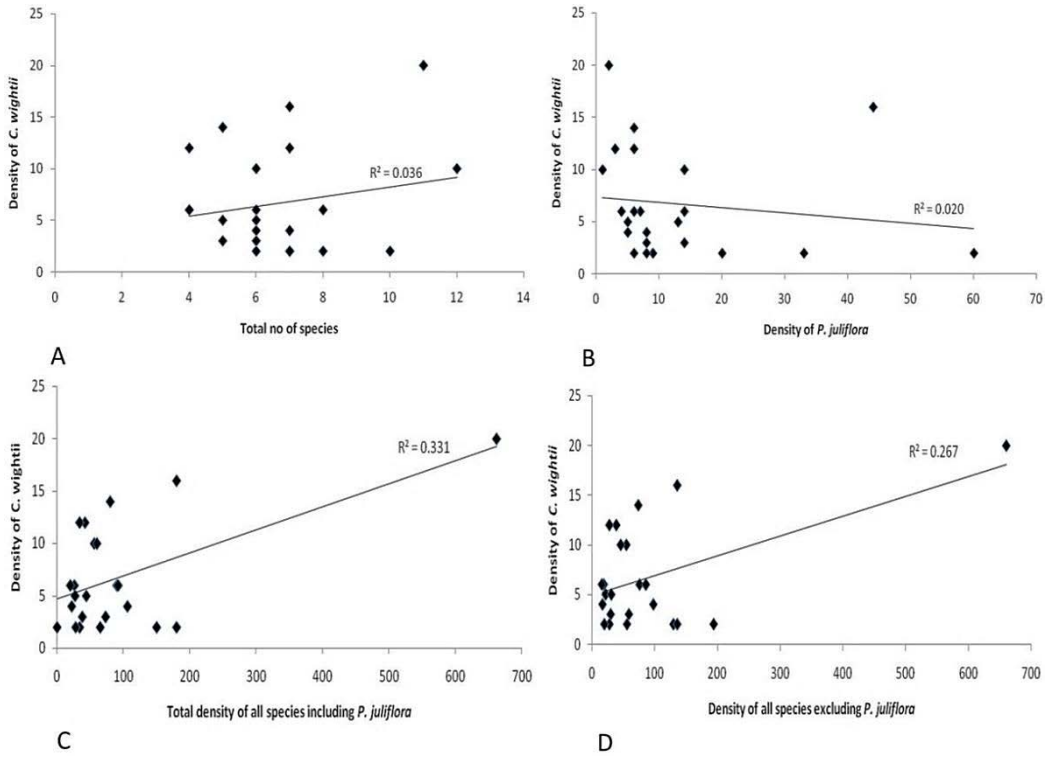

Fig. 3. Trends of density of ***C. wightii*** with respect to (**A**) total number of species at protected sites, (**B**) density of ***P. juliflora*** at protected sites, (**C**) total density of all species including ***P. juliflora*** at protected sites, (**D**) total density of all species excluding ***P. juliflora*** at protected sites.

2. The height and crown spread of *C. wightii* was also more in protected habitats. Hence, for its successful reintroduction for conservation, its paddocks need to be protected.
3. For its *ex-situ* conservation, the plantation density should preferably be kept low (100-400/ha) or say 200 plants per ha.
4. Its co-dominant status in nature is a guide to have it in mixed plantation with suitable trees that serve as upper nurse canopy as companion species.
5. Since it is open to invasion by shrubby weeds like *P. juliflora*, regular monitoring of weedy species is essential so as to check their spread through removal, if required.
6. For its conservation, the *ex-situ* and *in-situ* sites should be developed in arid districts of Barmer, Jaisalmer and Jodhpur. This is also supported by higher amounts of E and Z guggulsterones in plants from Bikaner and Jodhpur (247-257 µ/g) in arid western Rajasthan compared to those from southwest Rajasthan (135-166 µ/g) proving that desertic conditions of Jaisalmer, Barmer and Jodhpur favour more of E & Z guggulsterones, a desirable trait in this species (Kalia*et al.*, 2011).

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