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Vegetation Diversity in Nebkhas of Phog (*Calligonum polygonoides* L.) in the Thar Desert of India

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Abstract: Nebkhas are hillocks formed by the accumulation of wind-blown sediment within or around shrub canopies in arid and semi-arid landscapes. These landforms create distinct micro-environments that strongly influence vegetation diversity and spatial distribution. In the present study, we examined the size characteristics and vegetation diversity of nebkhas associated with the shrub *Calligonum polygonoides* in the Tanot region of Jaisalmer District, located in the Thar Desert of India. The nebkhas were oval to ellipsoidal in shape and ranged from 0.5 to 2.0 m in height, with an average height of 1.13 m. The height of *C. polygonoides* growing on these nebkhas varied between 1.0 and 2.8 m, with a mean of 2.2 m. A total of 11 plant species belonging to 8 families and 11 genera were recorded on the nebkhas. The grass *Ochthochloa compressa* emerged as the dominant species, exhibiting the highest Importance Value Index (IVI) of 70.9. The co-dominant species were *Aristida* spp. and *Indigofera argentea* with IVI values of 54.3 and 43.4, respectively; both were present in all sampled nebkhas. These were followed by *Aerva javanica* and *Dipterygium glaucum*. The findings highlight that conserving *C. polygonoides* in desert ecosystems plays a crucial role in maintaining associated plant communities. Protection of this keystone shrub also supports the persistence of important desert species such as *Aerva javanica*, *Leptadenia pyrotechnica*, *Panicum turgidum*, *Lasiurus scindicus*, *Ochthochloa compressa* and *Indigofera argentea*.

Key words: *Calligonum polygonoides*, Nebkhas, species diversity, soil parameters, Thar Desert.

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Nebkhas are phytogenic miniature dunes created by wind borne sediments that accumulate around and within the canopies of some shrubs in many semi-arid and arid regions of the world (Tengberg and Chen, 1998; Batanouny, 2001). These phytogenic nebkhas change the local microclimate and micro-topographic structure together with increase in plant diversity, vegetation coverage and improve soil structure which leads to complex local interactions between vegetation and soil (Bendali *et al*., 1990; Bhark and Small, 2003). Vegetation of the Thar Desert is sparse and unique mixture of perennial

grasses, hardy shrubs and scattered trees (Roy and Roy, 2019). Important arid shrubs on sand dune or sandy plain are Phog (*Calligonum polygonoides* L.), Bawli (*Acacia jacquemontii* Benth.), Lana (*Haloxylon salicornicum* (Moq.) Bunge ex Boiss.), Kheep (*Leptadenia pyrotechnica* (Forssk.) Decne.), Bui (*Aerva javanica* (Burm.f.) Juss. ex. Schult.), and grass species like Murath (*Panicum turgidum* Forssk.), and Sewan (*Lasiurus scindicus* Henr.). Genus *Calligonum* belonging to family Polygonaceae, is represented by three species from western Rajasthan, India, namely *Calligonum polygonoides* L., *Calligonum comosum* L'Hér. and *Calligonum crinitum* Boiss. (Purohit and Kumar, 2020). Among them, Phog (*C. polygonoides*) is one of the most important perennial shrubs of sand dunes eco-system in Thar Desert of India. It is highly tolerant to abiotic stresses and is utilized as energy-rich fuelwood, livestock fodder, and for its flower buds, which are used as a food item. The seeds are usually eaten raw and flower buds are using as preparation of "Raita" (Goyal and Sharma, 2008). It is also an excellent sand binder on shifting sand dunes and plays a vital role in dune stabilization and enhancing soil fertility (Kumar *et al*., 2015; Faroda *et al*. 2024). The species is mainly distributed in Persia, Syria, Pakistan, and India. In India, it occurs predominantly in the sand dune regions of Bikaner, Jaisalmer, and Barmer districts of western Rajasthan (Bhandari, 1990; Faroda *et al*., 2024). Wind-borne sand accumulates within and around the extensive canopy of *C. polygonoides*, forming miniature dunes known as nebkhas (Mohil, 2013). The dried foliage that falls around the canopy-locally referred to as "Lassu"-is resistant to wind displacement and acts as a natural mulch, conserving soil moisture and increasing organic matter in the surrounding soil (Mohil, 2013; Shekhawat *et al*., 2012). These nebkhas function as "fertility islands" for numerous plant species by modifying biological activity, improving water infiltration, and supporting high plant diversity within their microhabitats (Shekhawat *et al*., 2012; Faroda *et al*., 2024).

Therefore, in the present study, we assessed the size of nebkhas formed by *C. polygonoides*, evaluated species diversity within their canopy zones, analyzed soil parameters within and between nebkhas, and explored the role of these nebkhas in biodiversity conservation in desert ecosystems.

Materials and Methods

The study site is located near Ranao village (27.559737°N, 70.458836° E; 120 m a.s.l.) in the Tanot region of Jaisalmer District, within the Thar Desert of India. The area is a typical hot-arid desert characterized by extreme temperatures, high wind velocities, and very low precipitation. Vegetation ranges from dry steppe to desert grassland, with *C. polygonoides* as the dominant shrub species. The soil throughout the region is predominantly sandy.

The climate is harsh, marked by low and erratic rainfall, high evaporation rates, and pronounced temperature fluctuations. The area receives an average annual rainfall of about 181 mm, with highly irregular temporal and spatial distribution. Summer temperatures frequently exceed 48°C, whereas winter minima occasionally approach the freezing point. This region also experiences some of the highest wind speeds recorded in the Thar Desert, with peak velocities reaching 27.2 km h^{-1} during June.

A total of twenty-five *C. polygonoides* nebkhas of varying sizes were randomly selected for study of nebkhas size and vegetation composition within its canopy. These nebkhas were completely independent to each other with no interconnections and distributed in dunes. The length (L), width (W) and height (H) of each selected nebkhas were measured and areas of nebkhas (A) were calculated using the following formula for the area of an ellipse. $A = [\pi (L \times W)/4]$. The morphological parameters like plant height, canopy diameter of *C. polygonoides* were also recorded. Vegetation sampling was carried out in each nebkhas after monsoon and during spring season when most of plant species are expected be germinated. We recorded the number of plant species in each selected nebkhas. The vegetation data were quantitatively analyzed for frequency, density, abundance and IVI using the formula given by Mishra (1968) and Curtis and McIntosh (1950). The soil samples were also collected from nebkha and internebkha space, and different soil parameters were also calculated.

Results and Discussion

Morphology of nebkhas and vegetation characteristics

The distribution of *C. polygonoides* nebkhas in study side sand dunes are presented in

Table 1. Morphological parameters of Calligonum polygonoides L. created nebkhas

Parameters	Minimum	Maximum	Mean ± SEM	SD
Height (m)	0.50	2.00	1.13 ± 0.21	0.51
Length (m)	3.00	10.00	6.20 ± 0.99	2.42
Width (m)	2.00	7.50	4.77 ± 0.81	1.99
Perimeter (m)	6.50	27.00	18.33 ± 3.14	7.69
Area (m^2)	4.71	58.88	26.28 ± 7.97	19.52

Table 2. Morphological characterization of Calligonum polygonoides L. in studied nebkhas

Plant attributes	Minimum	Maximum	Mean ± SEM	SD
Plant height (m)	1	2.8	2.2 ± 0.26	0.65
Canopy diameter (m)				
North-South	1.5	7.5	4.5 ± 0.84	2.06
East-west	1	6.5	3.6 ± 0.75	1.83

figure 1a. The shape of nebkhas was oval or ellipsoid shaped which were independent to each other (Fig. 1b). The height of nebkhas was ranged from 0.5 to 2.0 m with a mean of 1.13 m. The mean length, width, perimeter and area of these nebkhas were 6.2, 4.8, 18.3 m and 26.3 m^2, respectively (Table 1). *C. polygonoides* is a rigid, much branched leafless shrub which spread more in horizontal as compare to vertical. The height of *C. polygonoides* in studied nebkhas was ranged from 1.0 to 2.8 m with mean of 2.2 m. The mean canopy diameter in north-south and east-west direction was 4.5 and 3.6 m respectively (Table 2).

The higher vegetation diversity was observed within Phog nebkhas as compared to between nebkhas. A total of 11 plant species representing 8 families and 11 genera were observed in *C. polygonoides* created nebkhas. The field photographs of some important plant species are given in Fig. 1. The most commonly represented grasses were *Aristida* spp., *Octhochloa compressa* (Forssk.) Hilu, *Lasiurus scindicus* and *Panicum turgidum*. The other herbaceous perennials/shrubs were *Aerva javanica*, *Dipterygium glaucum* Decne., *Indigofera argentea* Burm.f. and *Leptadenia pyrotechnica*. The grass species, *O. compressa* was the dominant species with IVI value of 70.9. The co-dominant species were *Aristida* spp. and *I. argentia* with IVI value of 54.3 and 43.4, respectively. These were reported in all studied nebkhas followed by *A. javanica* and *D. glaucum* (Table 3). The seedlings of *A. javanica*, *I. argentea*, *L. scindicus* and *D. glaucum* were also observed in the miniature dune (Fig. 1e and f). It is also observed that the area of nebkhas increased, the vegetation diversity and coverage also increased.

These nebkhas were not only conserving the plant diversity but also provide grazing/ browsing material to small ruminants during extreme dry conditions (Fig. 1d). The reason behind the high plant diversity in *C. polygonoides* created nebkhas may be presence of higher soil moisture due to mulching of dried foliage (Lassu; Fig. 1c) and high organic matter in soil which provide good environment for germination and survival of different plant species. Further, these nebkhas changes the microclimate around the canopy area and create favorable microhabitats for different species which overall increases the plant biodiversity in hot arid of Thar Desert and also support long term ecological sustainability. *C. polygonoides* nebkha covers have strong effect on vegetation diversity and coverage in hot arid Thar desert. The higher vegetation composition in Phog created nebkhas as compared to between nebkhas (Shekhawat *et al.*, 2012; Mohil, 2013). The species diversity and vegetation distribution in nebkhas of *Nitraria tangutorum* Bobrov in the Desert Steppes of China revealed that as height and area of the nebkhas increased, species richness also increased (Zhou *et al.*, 2015). Many studies have also shown that nebkhas can concentrate nutrients and litter, and accumulate wind-driven fine sediments (Aguiar and Sala, 1999; Bhark and Small, 2003). El-Bana *et al.* (2003) studied the importance of *Retama raetam* (Forssk.) Webb & Berthel. created nebkhas in Northern Sinai and reported that the abundance and richness of herbaceous plants were positively related to nebkha area. The nabkhas of *Nitraria* and *Zygophyllum* are shelter

Table 3. Vegetation diversity in Calligonum polygonoides L. created nebkhas

Species	Frequency (%)	Density (Plants nebkha^{-1})	Abundance	Important Value Index
Ochthochloa compressa (Forssk.) Hilu	100.0	12.5	12.5	70.9
Aristida spp.	100.0	8.7	8.7	54.3
Indigofera argentea Burm.f.	100.0	6.2	6.2	43.4
Aerva javanica (Burm.f.) Juss. ex Schult.	83.3	4.5	5.4	35.1
Dipterygium glaucum Decne.	50.0	4.3	8.7	35.0
Leptadenia pyrotechnica (Forssk.) Decne.	50.0	0.8	1.7	13.5
Panicum turgidum Forssk.	33.3	0.8	2.5	12.2
Lasiurus scindicus Henr.	33.3	0.5	1.5	9.5
Cyperus spp.	16.7	0.5	3.0	9.5
Dactyliandra welwitschii Hook. f.	16.7	0.5	3.0	9.5
Calligonum polygonoides L. seedlings	16.7	0.3	2.0	7.2

for many halophytes and glycophytes species (El-Bana *et al*., 2002; Al-Dousari *et al*., 2008). El-Sheikh *et al*. (2010) also reported sixty-two plant species in nabkhas of *Nitraria retusa* (Forssk.) Asch., *Zygophyllum qatarense* Hadidi, *Haloxylon salicornicum* and *Panicum turgidum* in a coastal habitat of Jal Az-Zor National Park, Kuwait.

Soil parameters

The soil within the nebkhas had a pH of 8.5, similar to that of the inter-nebkha areas.

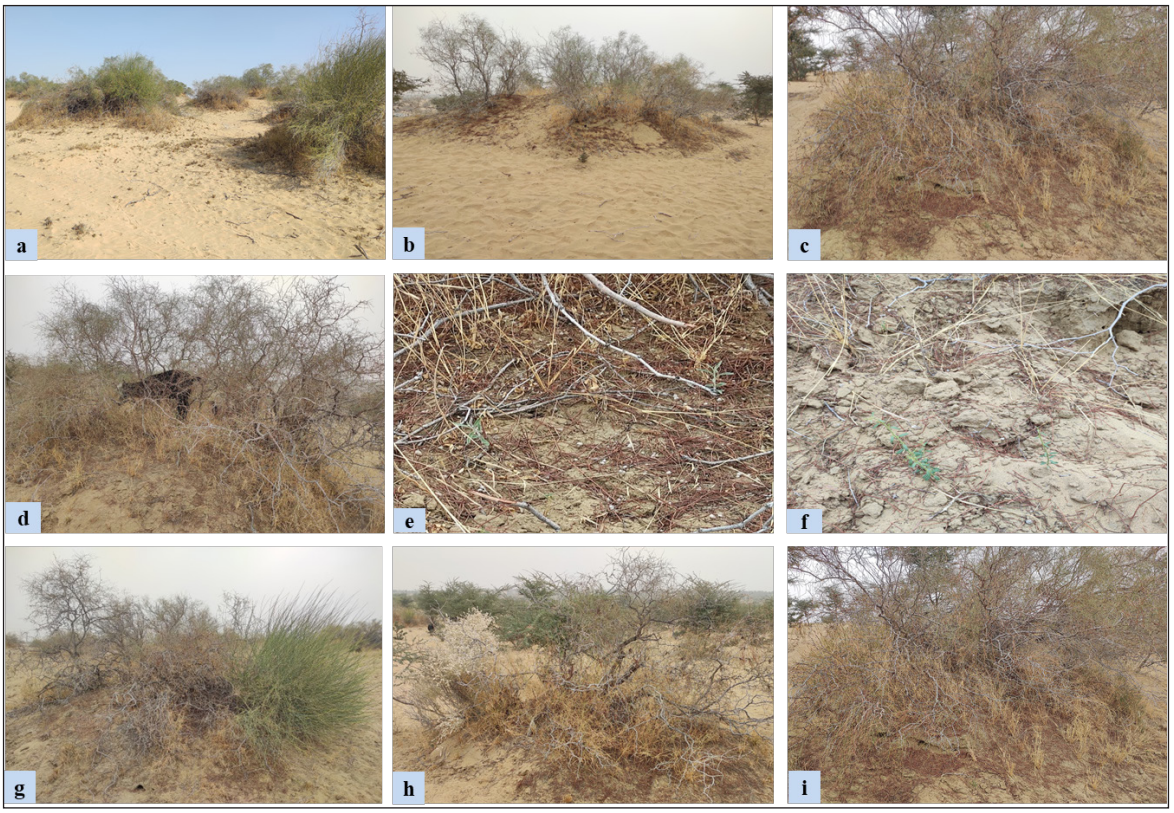

Fig. 1. Distribution of nebkhas of Calligonum polygonoides in sand dunes of Jaisalmer district (a). Individual nebkhas showing shape and size (b). Close up view of nebkhas showing dried foliage (Lasso) in reddish color act as mulching (c). Browsing by goats in canopy area of Calligonum polygonoides (d). Seedling of Aerva javanica (e) and Dipterygium glaucum (f) in nebkhas of Calligonum polygonoides. The species Leptadenia pyrotechnica (g) Aerva javanica (h) and Ochthochloa compressa (i) in nebkhas of Calligonum polygonoides.

However, notable differences were observed in other soil parameters. Electrical conductivity (EC) was lower in the nebkha soils (1.37 dS m^{-1}) *compared to the inter*-nebkha soils (3.03 dS m^{-1}). *Soil organic carbon (SOC) was substantially higher within the* nebkhas (0.17%) than in the inter-nebkha zones (0.04%). In contrast, calcium carbonate ($CaCO_3$) content was greater in the nebkha soils (3.55%) than in the inter-nebkha soils (1.33%). These differences indicate that nebkhas provide more favorable soil conditions, particularly in terms of organic carbon and carbonate accumulation.

Conclusion

Calligonum polygonoides created nebkha changes the microclimate around the canopy area and could provide varying microhabitats for different species which overall increases the plant biodiversity in hot arid of Desert steppe which support long term ecological sustainability of this environment. The plantation and conservation of *C. polygonoides* should be promoted in sand dune stabilization program which not only fix the shifting sand dune but also increase and support the local desert vegetation and overall improve the physical property of soil. Therefore, conserving the *C. polygonoides* in desert ecosystem also preserve many other important plant species as well.

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