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# Interspecific association and species composition of plants affected by erosion winds in the south west of Iran

**Zahra Mohebi[1]✉, Lyla Khalasi Ahvazi[2]**

1- Department of Natural Resources, Faculty of Agricultural Sciences, Natural Resources, Razi University, Kermanshah, Iran. E-mail: z.mohebi@razi.ac.ir
2- Desertification Expert of Natural Resources Department, Khuzestan, Iran

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## ABSTRACT

Species interactions are considered important in the process of understanding the structure and composition of natural plant communities. This study evaluated a field survey to investigate species composition and interspecific associations in natural vegetation of an arid area in Hanitie rangeland, Khuzestan Province, Southwest of Iran. The interspecific associations of major species were quantitatively analyzed using a 2 - 2 contingency table, $\chi^2$ test, and interspecific association coefficients. Eighty quadrates were located along four 800m transverse transects, two of which were located in the general direction of dominant winds while others were perpendicular to the dominant wind. This vegetation type's quadrate size was determined using the minimal area method (3×3m). Thirty-eight species belonging to 10 families were recorded on this site. The highest number of species belonged to the *Graminea*, followed by *Chenopodiacea*. This study shows that *Holocnemum strobilaceum* and *Aeluropus littoralis* have identical interspecific association patterns and share a positive interspecific association. But the distribution of *Tamarix leptopetala* was significantly different ($P<0.05$) within *Aeluropus littoralis* and *Agropyron elangatum*, which indicates a negative association. Also, the results show that when *Holocnemum strobilaceum* and *Aeluropus littoralis* co-occurred in the general direction of dominant winds, the mean frequency was significantly higher than when they co-occurred perpendicular to the dominant wind. This research may support the view that facilitation is more prominent in a severely disturbed habitat than the competition

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## Introduction

Interspecific relationships have been proposed to reveal how species interact with one other, the environment, and their spatial distribution relationship (Su et al., 2015), which is fundamental to succession theory. Because of competition between individuals, forests develop complex and stable communities when various tree species are replaced and established. By measuring tree sizes, we may study how forest communities evolve due to variations in tree species (Gu et al., 2019). Plants' relative spatial position has an impact on their resource allocation ratio, which impacts intraspecific and interspecific competitive relationships, among other factors (Harms et al., 2001). Spatial autocorrelation describes the pattern of plant populations, whereas the variance rule reflects the spatial scale (Yang *et al.,* 2018). A change in spatial patterns usually begins with the aggregation of young individuals who develop into randomly or evenly uniform patterns along the way (Getzin *et al.,* 2006).

It is critical to comprehend species interactions while studying succession. Research into succ ession may allow us to recognize possible effects (i.e., facilitation or inhibition) of species interactions (Walker *et al.,* 2007). In damage-prone habitats, facilitation will be more significant for species change and restoration, whereas competition will be more important in productive and established habitats. (Sutomo *et al.,* 2011).

Wind erosion leads to soil loss, including fine sediment, mainly clayey or silty, and nutrients such as nitrogen (N) (Li *et al.,* 2018; Lei *et al.,* 2019). A rapid expansion of shrubs (Alvarez *et al.,* 2012) may alter the composition of plant communities by enhancing the distribution of species with high nutrient efficiency (Funk and Vitousek, 2007). Moreover, soil removal and dust emission due to wind erosion may degrade young plant tissue, resulting in subsequent changes in plant communities (Alvarez *et al.,* 2012). Generally, fine dust deposited in dust source areas tends to deposit less than fine dust deposited in areas downwind from the dust source (Field *et al.,* 2010, Alvarez *et al.,* 2012).

In contrast to wind erosion, dust deposition provides additional nutrients to plant growth (Lawrence *et al.,* 2013), altering plant species interactions and affecting plant communities' composition and variety. According to some studies, nutrient enrichment can increase the dominance of plants that compete vigorously for light and, therefore, lower species diversity (Borer *et al.,* 2014; Harpole *et al.,* 2016).

Wind stress affects plants practically everywhere, especially mountain, coastal, and plateau habitats (Ceplick, 2017; Zhang *et al.,* 2021), where open-air areas or natural funneling allow winds to develop strength. The wind determines the leaf temperature regime on plants, which determines plant growth, morphology, physiology, dispersal, and ecology (Anten *et al.,* 2010; Mitchel, 2013). It is reasonable to suspect that wind erosion and dust deposition may impact the diversity and composition of plant communities since both processes have opposite effects on soil nutrient pools (Zheng *et al.,* 2020). Despite this, it remains unclear how wind erosion and dust deposition affect grassland plant communities. We examined how the composition and structure of plant communities changed due to wind erosion. We conducted simulations of aeolian processes (wind erosion and dust deposition) in an arid area in Hanitie rangeland Khuzestan Province, Southwest of Iran. Our experiment specifically tested this hypothesis: wind erosion would reduce vegetation cover by foraging, removing topsoil, and removing nutrients. The purposes of the present study were to determine (1) the correlation between dominant and preferred grass and shrubs species in the region and (2) relationships between major plant species interactions and wind erosion.

## Materials and methods

### *Study area*

Hanitieh site is an area of 2375 hectares located 30 km east of Ahvaz city, which is one of the winter rangelands of Khuzestan province and is grazed by native vegetarians. This region was located in west south of Iran (30º 59´ 14´´ N, 48º 46´ 48´´E to 31º 2´ 24´´N, 48º 50´ 50´´E) (Figure

1). Ecological and climatic characteristics the site can be inappropriate distribution and short rains, long drought period. Table 1 shows the precipitation rate. The average annual precipitation of the study area is 192 mm, and there isn't any precipitation in the summer and hot seasons (Ahwaz Natural Resources Department, 2013).

Low vegetation cover, strong surface winds, high temperatures and humidity (Tables 2 and 3), and being surrounded by huge deserts are all known as primary sources of dust storms (Kurosaki and Mikami, 2003). In terms of topography, it is completely plain (100%). This area has clay soils with heavy texture, high salinity and alkalinity, high groundwater level with wind erosion (Ahwaz Natural Resources Department, 2013).

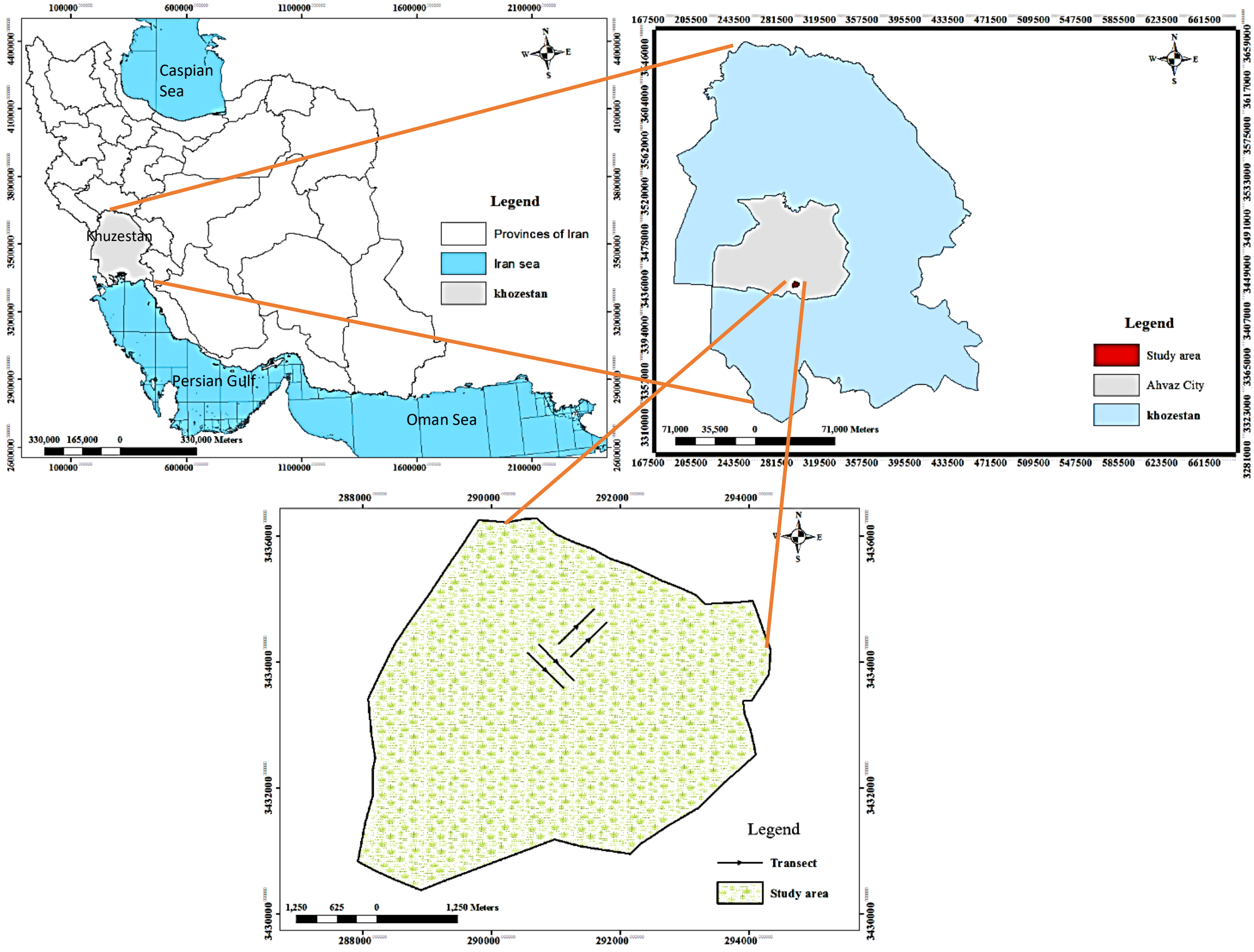

**Figure 1.** Location of study area and transects

**Table 1.** Statistical parameters of rainfall in the study area (Ahwaz Natural Resources Department, 2013)

| Station name | Statistic parameters | October | November | December | January | February | March | April | May | June | July | August | September |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ahvaz-Molasani** | Mean(mm) | 5.6 | 31.9 | 62.6 | 65.7 | 38.3 | 40.1 | 19.4 | 3.7 | 0.1 | 0.0 | 0.0 | 0.0 |
| | Rainfall regime (mm) | 2.1 | 11.9 | 23.4 | 24.6 | 14.3 | 15.0 | 7.2 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Standard Deviation | 9.3 | 34.3 | 47.0 | 36.3 | 26.5 | 31.4 | 22.7 | 4.4 | 0.4 | 0.2 | 0.2 | 0.0 |
| | Coefficient of Variation | 166.2 | 107.8 | 75.0 | 55.2 | 69.1 | 78.4 | 117.0 | 118.6 | 315.6 | 493.8 | 493.8 | - |
| | Maximum | 37.5 | 151.0 | 161.0 | 168.5 | 106.5 | 145.1 | 116.0 | 15.0 | 2.0 | 1.0 | 1.0 | 0.0 |
| | Minimum | 0.0 | 0.0 | 0.0 | 7.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table 2.** Monthly temperature (°C) (Ahwaz Natural Resources Department, 2013)

| Station name | Statistic parameters | October | November | December | January | February | March | April | May | June | July | August | September | October | November | December | January | February |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ahvaz** | Average maximum temperature | 35.3 | 26.8 | 19.0 | 17.2 | 19.1 | 25.0 | 30.7 | 38.4 | 44.0 | 45.6 | 45.2 | 42.5 | 27.1 | 20.4 | 38.6 | 44.9 | 32.8 |
| | Average minimum temperature | 17.3 | 11.7 | 6.9 | 5.9 | 7.3 | 11.4 | 16.1 | 21.7 | 24.3 | 26.2 | 25.8 | 22.2 | 14.3 | 10.0 | 23.0 | 27.4 | 18.7 |
| | Average daily temperature | 27.7 | 20.0 | 14.4 | 12.5 | 14.7 | 18.4 | 25.3 | 31.6 | 35.5 | 37.8 | 37.3 | 33.4 | 20.7 | 15.2 | 30.8 | 36.2 | 25.7 |
| | Absolute maximum temperature | 26.6 | 19.2 | 12.9 | 11.5 | 13.2 | 18.2 | 23.4 | 30.0 | 34.1 | 35.9 | 35.5 | 32.3 | 43.6 | 34.2 | 51.0 | 52.2 | 52.2 |
| | Absolute minimum temperature | 8.0 | 0.0 | -1.0 | -7.0 | -5.0 | -1.0 | 6.0 | 13.0 | 15.0 | 20.0 | 18.0 | 13.0 | 20.0 | -0.3 | 9.0 | 18.0 | -0.3 |

**Table 3.** The relative humidity (%) (Ahwaz Natural Resources Department, 2013)

| Station name | Statistic parameters | October | November | December | January | February | March | April | May | June | July | August | September | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ahvaz | Mean | 36.0 | 25.5 | 68.7 | 69.4 | 58.3 | 52.1 | 39.4 | 25.2 | 20.8 | 23.0 | 26.8 | 27.2 | 42.6 |

### *Data collection*

The field survey of vegetation quantities was performed in May 2013. The research method was based on a random statistical design and sampling method was randomized systematic. In the studied type, vegetative attributes were described within quadrates located along four 800m transverse transects. Two transects were located in the general direction of dominant winds in the study area, and the others were placed perpendicular to the dominant wind. The quadrate size was determined for the vegetation type using the minimal area method (4m×4m). Eighty quadrates with a distance of 40m from each other were established in the vegetation type, given the variety of vegetation. Floristic list, density, and canopy cover percentage were determined in each quadrate.

### *Data analysis*

First, dominant plant species were identified, and then association measurements for those plants were performed. An association was measured the departure of frequency of species combinations from the random expectation (Kershaw and Looney, 1985). The method used for palatability was "the weighting method".

In the studied field, 80 quadrates 4m×4m were laid down, and the root presence was recorded in each quadrate. The interspecific associations were determined by the usual analysis of the 2×2 contingency table and $\chi^2$ test for all species pairs. Species that appeared in 5 and fewer quadrats were excluded from the analysis. The number of transects and the distance between plots were determined based on the geographic properties, distribution patterns, and vegetation density. Within each plot, the presence/absence and the abundance of all species were recorded.

The data was arranged in a 2×2 contingency table to determine interspecific coefficients. Thus, the sampling units were examined for the presence or absence of both species (A and B), and some samples containing both (a), only species A (b), only species B (c), and neither (d) were recorded (Table 4).

**Table 4.** The sample of contingency table

| | | Species B | | |
|---|---|---|---|---|
| | | Present | Absent | |
| Species A | Present | a | b | a+b |
| | Absent | c | d | c+d |
| | | a+c | b+d | T |

The 2 × 2 contingency tables were used to determine interspecific associations. The significance of the interspecific association was tested by $\chi^2$ and a Pearson coefficient with Yates correction (Li *et al.*, 2008) that was expressed by Equation 1:

$$x^2 = N \frac{\left[|ad-bc|-\left(\frac{N}{2}\right)\right]^2}{(a+b)\times(c+d)\times(a+c)\times(b+d)} \tag{1}$$

where *a* is the number of plots where both species (x and y) occur, *b* is the number of plots where species x occurs but not species y, c is the number of plots where species y occurs but not x, d is the number of plots where neither x nor y is found. N is the total number of plots. The two species are associated if the calculated C2 is greater than the theoretical value for 1 degree of freedom (d.f.) at the 5% probability level. If a > E (a), a positive association, and if a < E (a), a negative association results. E (a) is the expected value for cell a, calculated from E (a) = [(a + b) (a + c)]/N (Ludwig and Reynolds, 1988). A Chi-square value was computed for the correlation of each species pair and compared with the critical Chi-square table (P < 0.05, d.f. = 1, 3.84) and (P < 0.01, d.f. = 1, 6.64).All data in this study were analyzed by SPSS computer software (version 15).

An independent t-test was used to compare the mean frequency of all dominant and preferred grass species present inside or near the canopy of nurse shrub species (both grass and nurse species present in the same plot) in the general direction of dominant winds and when they occurred in perpendicular to the dominant wind.

## Results

### *Species composition*

The floristic composition of the site was listed (Table 5). Thirty-eight species belonging to 10 families were recorded on this site. In addition, the results of figure 2 showed that the number of species belonging to different families. Chenopodiacea species had the most significant abundance, followed by Graminea and Leguminosae. Furthermore, most species have a palatability class of III, and livestock such as camels feed on them. Plants such as *Halocnemum strobilaceum*, *Tamarix leptopetala*, and others played a significant role in soil conservation.

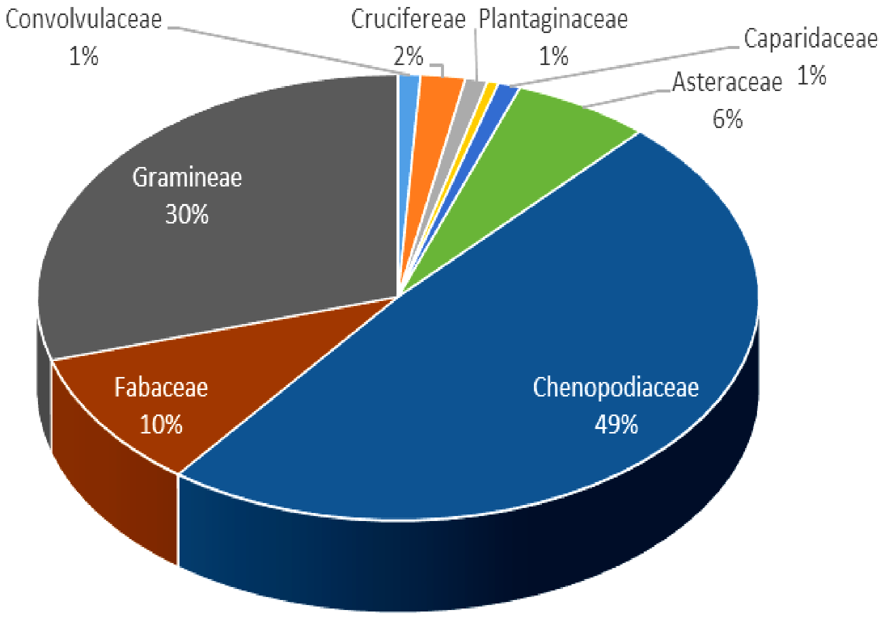

**Figure 2.** The number of plant families

Results showed that *H. strobilaceum, A. littoralis, T. leptopetala, A. elangatum,* and *S. baryosma* had the highest cover percent (Figure 3). These five species comprised the dominant populations to evaluate the interspecific association.

**Table 5.** Floristic list of study area

| No. | The scientific name | Order name | Life history | Growth form | Life form | Palatability |
|---|---|---|---|---|---|---|
| 1 | *Aeluropus littoralis* | *Gramineae* | P | Gr | Cha | III |
| 2 | *Agropyron elangatum* | *Poaceae* | P | Gr | The | I |
| 3 | *Alhagi camelorum* | *Fabaceae* | P | Sh | Cha | III |
| 4 | *Atriplex leococlada* | *Chenopodiaceae* | B | F | Cha | II |
| 5 | *Avena ludoviciana* | *Gramineae* | A | Gr | The | I |
| 6 | *Bromus dantonia* | *Gramineae* | A | Gr | The | III |
| 7 | *Bromus tectorum* | *Gramineae* | A | Gr | The | III |
| 8 | *Calendula persica* | *Asteraceae* | A | F | The | III |
| 9 | *Caparis soinosa* | *Caparidaceae* | P | Sh | Cha | III |
| 10 | *Carduus getulus* | *Asteraceae* | A | F | The | III |
| 11 | *Carthamus oxycantha* | *Asteraceae* | A | F | The | III |
| 12 | *Centaurea intricata* | *Asteraceae* | P | Sh | Cha | III |
| 13 | *Convolvolus arvensis* | *Convolvulaceae* | A | F | The | III |
| 14 | *Cornulaca leucacantha* | *Chenopodiaceae* | P | Sh | Cha | III |
| 15 | *Cressa cretica* | *Convolvulaceae* | A | F | The | III |
| 16 | *Cynodon dactylon* | *Gramineae* | P | Gr | He | I |
| 17 | *Cytrulus colocynthis* | *Curcurbitaceae* | P | F | Cha | III |
| 18 | *Echinops dirchrous* | *Asteraceae* | P | F | Cha | III |
| 19 | *Halocharis sulphurea* | *Chenopodiaceae* | A | Sh | Cha | III |
| 20 | *Halocnemum strobilaceum* | *Chenopodiaceae* | P | Sh | Cha | III |
| 21 | *Hordeum morinum* | *Gramineae* | A | Gr | The | II |
| 22 | *Koelpinia linearis* | *Asteraceae* | A | F | The | III |
| 23 | *Lophocloa pheloides* | *Gramineae* | A | Gr | The | II |
| 24 | *Medicago minima* | *Fabaceae* | A | F | The | I |
| 27 | *Medicago polymorpha* | *Fabaceae* | A | F | The | I |
| 28 | *Phalaris minor* | *Gramineae* | A | F | The | III |
| 29 | *Plantago coronupus* | *Plantaginaceae* | A | F | The | II |
| 30 | *Prosopis stephaniana* | *Fabaceae* | P | Sh | Cha | III |
| 31 | *Salsola baryosma* | *Chenopodiaceae* | P | Sh | Cha | III |
| 32 | *Salsola incanescens* | *Chenopodiaceae* | A | F | The | III |
| 33 | *Sedlitzia rosmarinus* | *Chenopodiaceae* | P | Sh | Cha | III |
| 34 | *Sinapis arvensis* | *Cruciferea*e | A | F | The | III |
| 35 | *Sonchus asper* | *Asteraceae* | A | F | The | III |
| 36 | *Stipa capensis* | *Gramineae* | P | F | Cha | III |
| 37 | *Suaeda foticusa* | *Chenopodiaceae* | P | Sh | Cha | III |
| 38 | *Tamarix leptopetala* | *Chenopodiaceae* | P | Bu | Cha | III |

Longevity: A: Annual, B: Biennial, P: perennial. Growth form: Gr: Grass, F: Forb, Sh: Shrub. Life form: Ch: Chamaephytes, Th: Therophytes

### *Association between major species pairs*

The results of the interspecific association of five dominant shrubs and herbs in this study are shown in table 6. Positive associations were found in four pairings of species, whereas negative associations were found in two pairs. The one pair of *Holocnemum strobilaceum* - *Aeluropus littoralis* showed high significance, while the other three pairs (*Holocnemum strobilaceum* - *Aeluropus littoralis, Salsola baryosma* - *Agropyron elangatum,* and *Salsola baryosma* - *Aeluropus littoralis*) indicated a relatively weak interspecific correlation. It was suggested that the two populations in the study area were in a stable distribution pattern, and the two species coexisted and held the common ecological niche.

*Tamarix leptopetala - Aeluropus littoralis and Tamarix leptopetala - Agropyron elangatum* had negative associations.

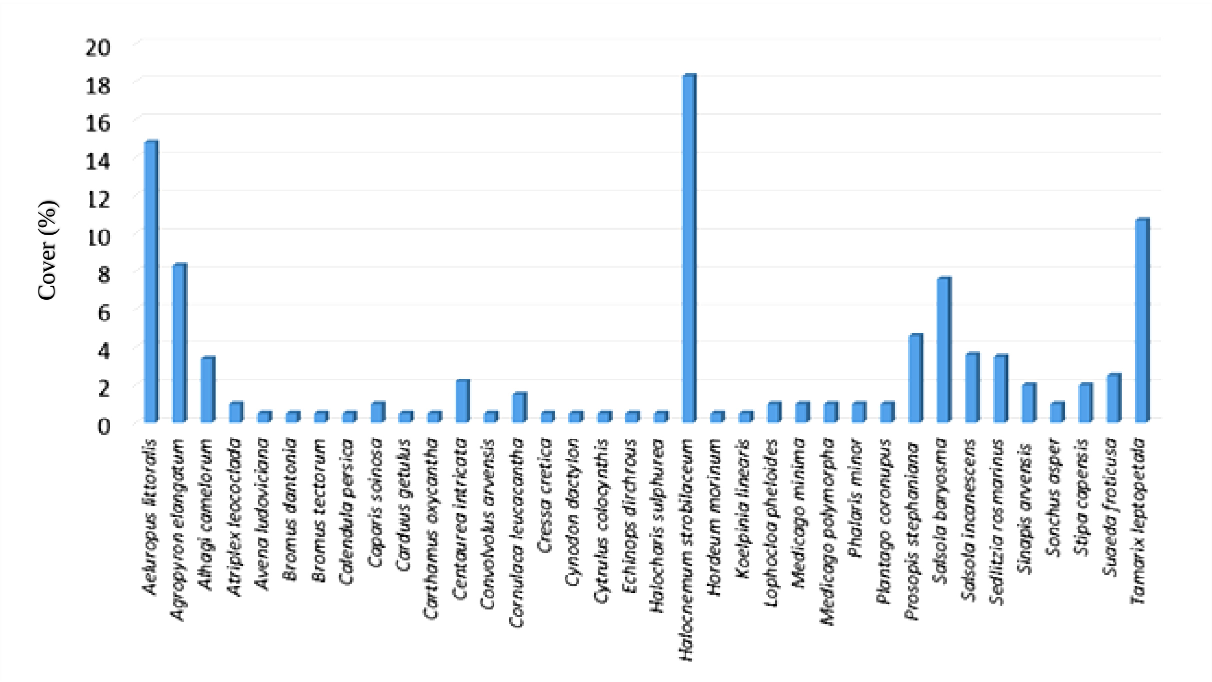

**Figure 3.** Cover percent of plant species

**Table 6.** Chi-square test of species association

| *Grasses/Shrubs* | *Halocnemum strobilaceum* | *Salsola baryosma* | *Tamarix leptopetala* |
|---|---|---|---|
| *Aeluropus littoralis* | $+12.33^{**}$ | +0.78 | $-2.59^{*}$ |
| *Agropyron elangatum* | +0.81 | +0.59 | $-1.80^{*}$ |

**P* < 0.05;***P* < 0.01. (-) and (+) indicate direction of the species

### *The effect of dominant wind on species association*

The mean frequency of the two common species (*Halocnemum strobilaceum-Aeluropus littoralis*), when co-occurring in the general direction of dominant winds, was significantly higher than when they occurred perpendicular to the dominant wind ($P < 0.01$) (Figure 4). Also, the results showed that these values (cover and frequency) weren't significantly different in two directions of erosion winds ($P<0.05$ - $<0.001$).

## Discussion

The results show strong clumped patterns in the spatial distribution of the two dominant species, *H. strobilaceum*, and *A. littoralis*, at different scales on the site. Statistical modeling of container records indicated that immature densities of *S.baryosma* in the presence or absence of *Ae.littoralis* and *A.ealnagatum* were not significantly different. Heavy soils may well have conspicuous physical crusts due to raindrop impact effects. This will be especially important in the bare soil areas. We have identified significant erosion and deposition in some patches of this study area.

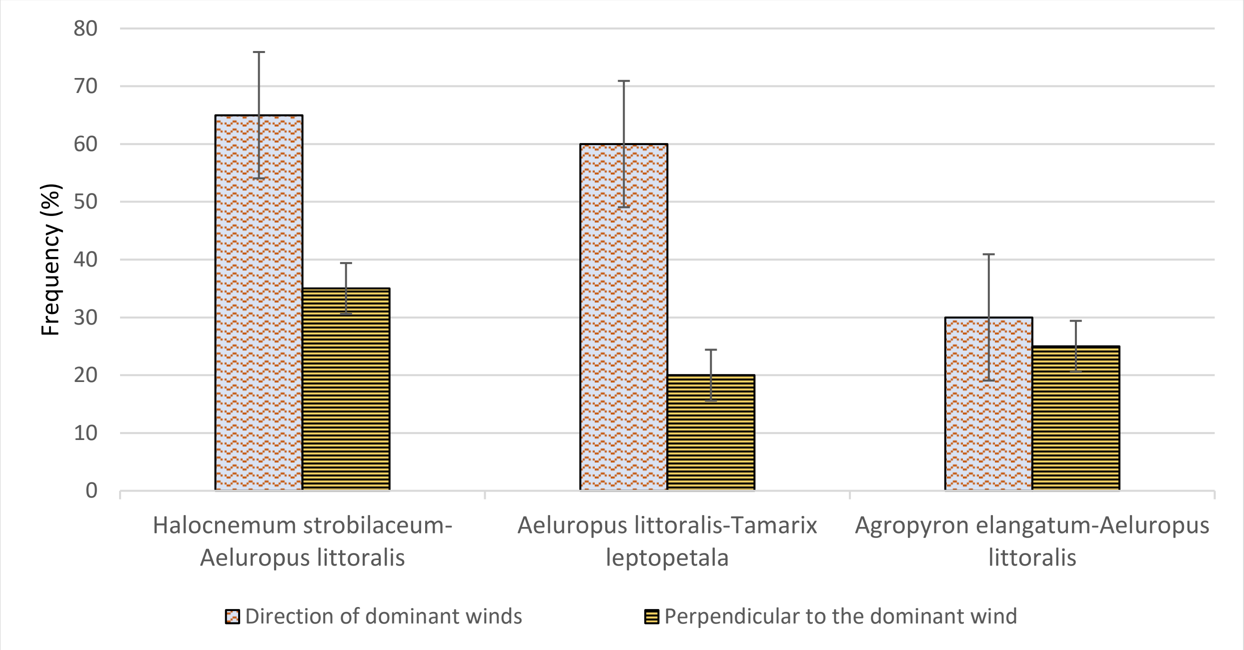

**Figure 4.** The mean frequency of the two common species in the general direction of dominant winds and perpendicular to the dominant wind (**$P < 0.01$)

The movement of sand blown by the wind is a common occurrence in deserts. Plant parts and individual plants often experience different levels of sand coverage in deserts (Liu *et al.,* 2014). Research undertaken in previous decades has shown small-scale variations in the degree of sand movement and the associated denudation of desert plants (Xu *et al*., 2013). Arid regions have led to the evolution of different strategies by indigenous plants to cope with their adverse environments (Su *et al.*, 2009). Clonal growth is one of these strategies (Maun, 1996). Even when seeds are regularly produced, there may be rare or irregular seedling recruitment in dune clonal environments (Li *et al*., 2015). Plants that live for long periods are likely to have extended juvenile stages due to sand movement and unpredictable rainfall, making seedling recruitment difficult. On the other hand, vegetative offspring are usually sustained by the parent plant through water, carbohydrates, and other nutrients until they are established (Li *et al.*, 2015; Fan *et al.*, 2018). There is evidence that several secondary factors, in addition to intrinsic characteristics like propagation and dissemination channels, may have influenced the spatial distribution of plant species in a given habitat (Nyatwere *et al.,* 2012; Khojaste *et al.,* 2013). For example, in the creation of clumped distribution patterns of grass species, interactions among species and susceptibility to erosion appear to play a key role (Kéfi *et al.*, 2007). Also, it is possible that wind erosion induced decrease in total cover may enhance light availability, and thus increase short-stature plant richness and consequent species richness (Hautier *et al.,* 2009; Borer *et al.,* 2014).

Wind erosion has been shown to deplete soil nutrients (Okin *et al.,* 2006; Li *et al.,* 2018; Lei *et al.,* 2019), and the soil nitrogen content falls as a result of this erosion, which might explain the decrease in plant cover due to wind erosion. Another mechanism that can suppress plant growth and consequent vegetation cover is wind erosion's abrasion effects on young leaves (Okin *et al.,* 2006).

If we can identify overt hoof-action as a cause of soil surface instability, management can be adjusted to minimize physical disturbance. Preferred species can be protected against grazing by grouping together beneath the understory of non-preferred species, a mechanism known as associational resistance (Holzapfel *et al.,* 2006; Soliveres *et al.,* 2011). The results also show that *A.littoralis* protects itself by grouping together beneath the H.strobilaseum. However, *A. elangatum* performed less well with H.strobilaceum than *A.littoralis*. Hunter *et al* (1992) highlighted the clonal reproduction of *A.littoralis* which is common in the wild, by way of root suckers and self-layering of fallen stems. Therefore, they can resist more against erosion by reducing the wind speed and trap wind-blown sand in the foredunes. Similar results have been reported by Lee *et al* (2020).

In this landscape, *Tamarix lepotopetala*, a known salt accumulator (indeed, a hyper-accumulator), creates such a high EC that grasses are excluded from the canopy due to salinization. This study found that *T. lepotopetala* has a negative association with most of the grasses in this site. Simply stated, grass species' individuals may be clumped since there are various advantages to being close to shrubs (McIntire and Fajardo, 2009). Indeed, shrubs like *Halocnemum strobilaceum* are strong candidates for becoming benefactor species for perennial herbaceous plants, as they improve soil characteristics and protect perennial herbaceous species from grazers, wind and frost.

## Conclusion

The response patterns of shoot features to wind velocity, particularly mechanical properties, were idiosyncratic among species. Furthermore, the wind effects on plant performance through changing leaf microclimate could be negative or positive depending on confounding factors, including plant properties and local weather. Our results provided sufficient justification to further explore any interspecific associations. Awareness of interactions between species helps detect how members of two species are distributed in relation to each other. On the other, a community is formed by the continual changes of species, and those species are fitter for the environmental conditions, and also the components of the community. Therefore, the strength of competitive would decrease with time and during changes in the number of positive and negative species pairs. This information may be useful for the restoration and improvement of endangered ecosystems. Especially in areas where severe climate change eliminates low-tolerant species over time and stabilizes resistant species.

## References

Alvarez LJ, Epstein HE, Li J, Okin GS. 2012. Aeolian process effects on vegetation communities in an arid grassland ecosystem. Ecology and Evolution, 2; 809-821.

Anten NPR, Alcala-Herrera R, Schieving F, Onoda Y. 2010. Wind and mechanical stimuli differentially affect leaf traits in *Plantago major*. New Phytologist, 188; 554-564.

Borer ET, Seabloom EW, Gruner DS, Harpole WS, Hillebrand H, Lind EM. 2014. Herbivores and nutrients control grassland plant diversity via light limitation. Nature, 508; 517-520.

Borer ET, Seabloom EW, Gruner DS, Harpole WS, Hillebrand H, Lind EM, Adler PB, Alberti J, Anderson TM, Bakker JD. 2014. Herbivores and nutrients control grassland plant diversity via light limitation. Nature, 508; 517–20.

Cheplick GP. 2017. Responses of native plant populations on an unprotected beach to disturbance by storm-induced overwash events. Plant Ecology, 218; 105-118.

Fan B, Changming Z, Xiaowei Z, Kun S. 2018. Impacts of Sand Burial and Wind Erosion on Regeneration and Growth of a Desert Clonal Shrub. Front. Frontiers in plant science. 9; 1696.

Field JP, Belnap J, Breshears DD, Neff JC, Okin GS, Whicker JJ, Painter TH, Ravi S, Reheis MC, Reynolds RL. 2010. The ecology of dust. Frontiers in Ecology and the Environment, 8; 423-430.

Funk JL, Vitousek PM. 2007. Resource-use efficiency and plant invasion in low-resource systems. Nature, 446; 1079–81.

Getzin S, Dean C, He F, Trofymow JA, Wiegand K, Ecography TW. 2006. Spatial patterns and competition of tree species in a chronosequence of Douglas-fir Forest on Vancouver Island. Ecography, 29; 671–682.

Gu L, Kevin LO, Wei-zhong L, Zhi-wen G. 2019. Spatial patterns and interspecific associations among trees at different stand development stages in the natural secondary forests on the Loess Plateau, China. Ecology and evolution, 9; 6410-6421.

Harms KE, Condit R, Hubbell SP, Foster RB. 2001. Habitat associations of trees and shrubs in a 50 ha Neotropical forest plot. Journal of Ecology, 89; 947–959.

Harpole WS, Sullivan LL, Lind EM, Firn J, Adler PB, Borer ET, Chase J, Fay PA. 2016. Addition of multiple limiting resources reduces grassland diversity. Nature, 537; 93-96.

Hautier Y, Niklaus PA, Hector A. 2009. Competition for light causes plant biodiversity loss after eutrophication. Science, 324; 636–8.

Holzapfel C, Tielborgerb K, Paragb HA, Kigelc J, Sternberga M. 2006. Annual plant–shrub interactions along an aridity gradient. Basic and Applied Ecology, 7; 268-279.

Hunter J, Jay A, Nicholson N, Nicholson H, Horton S. 1992. Species Recovery Plan: Acronychia littoralis. Australian National Parks & Wildlife Service.

Kéfi S, Rietkerk M, Alados CL, Pueyo Y, Papanastasis VP, ElAich A, de Ruiter PC. 2007. Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems. Nature**,** 449; 213–217.

Kershaw KA, Looney JHH. (Eds.), 1985. Quantitative and Dynamic Plant Ecology. Edward Arnold, Baltimore.

Khojasteh F, Zare Chahouki MA, Azarnivand H, Kikvidze Z. 2013. Life form and preference can drive spatial relationships among plant species in semi-arid rangelands of middle Iran. The Rangeland Journal, 35; 63-69.

Lawrence CR, Reynolds RL, Ketterer ME, Neff JC. 2013. Aeolian controls of soil geochemistry and weathering fluxes in high elevation ecosystems of the Rocky Mountains, Colorado. Geochimica et Cosmochimica Acta, 107; 27-46.

Lee JT, Yen LZ, Chu MY, Lin YS, Chang CC, Lin RS, Chao KH, Lee MJ. 2020.Growth Characteristics and Anti-Wind Erosion Ability of Three Tropical Foredune Pioneer Species for Sand Dune Stabilization. Sustainability, 12; 3353.

Lei L, Zhang K, Zhang X, Wang Y, Xia J, Piao S, Hui D, Zhong M, Ru J, Zhou Z, Song H, Yang Z, Wang D, Miao Y, Yang F, Liu B, Zhang A, Yu M, Liu X, Song Y, Zhu L, Wan S. 2019. Plant feedback aggravates soil organic carbon loss associated with wind erosion in northwest China. Journal of Geophysical Research: Biogeosciences, 124; 825-839.

Li P, Liu L, Wang J, Wang Z, Wang X, Bai Y, Chen S. 2018. Wind erosion enhanced by land use changes significantly reduces ecosystem carbon storage and carbon sequestration potentials in semiarid grasslands. Land Degradation & Development, 29; 3469-3478.

Li SL, Yu FH, Werger MJ, Dong M, During HJ, Zuidema PA. 2015. Mobile dune fixation by a fast-growing clonal plant: a full life-cycle analysis. Scientific reports, 5; 1-7.

Liu B, Liu Z, Lü X, Maestre FT, Wang L. 2014. Sand burial compensates for the negative effects of erosion on the dune-building shrub artemisia wudanica. Plant and Soil, 374; 263-273.

Maun MA. 1996. The effects of burial by sand on survival and growth of Calamovilfa longifolia. Ecoscience, 3; 93-100.

McIntire EJB, Fajardo A. 2009. Beyond description: the active and effective way to infer processes from spatial patterns. Ecology, 90; 46-56.

Mitchell SJ. 2013. Wind as a natural disturbance agent in forests: a synthesis. Forestry: An International Journal of Forest Research, 86; 147-157.

Nyatwere M, Mkabwa LKM, Zachariah KR. 2012. Distribution patterns of plant species around North Mara Gold Mine in Tanzania. International Journal of Agricultural Sciences, 2; 302–312.

Okin GS, Gillette DA, Herrick JE. 2006. Multi-scale controls on and consequences of aeolian processes in landscape change in arid and semi-arid environments. Journal of arid environments, 65; 253-275.

Soliveres S, García-Palacios P, Castillo-Monroy AP, Maestre FT, Escudero A, Valladares F. 2011. Temporal dynamics of herbivory and water availability interactively modulate the outcome of a grass–shrub interaction in a semi-arid ecosystem. Oikos, 120; 710-719.

Su SJ, Liu JF, He ZS, Zheng SQ, Hong W, Xu DW. 2015. Ecological species group and interspecific association of dominant tree species in Daiyun Mountain Natural Reserve. Journal of Mountain Science, 12; 637–646.

Su YG, Li XR, Zheng JG, Huang G. 2009. The effect of biological soil crusts of different successional stages and conditions on the germination of seeds of three desert plants. Journal of Arid Environments, 73; 931-936.

Sutomo S, Fardila D, Lily SEP. 2011. Species composition and interspecific association of plants in primary succession of Mount Merapi, Indonesia. Biodiversitas Journal of Biological Diversity, 12; 212-217.

Walker LR, Walker J, Del Moral R. (Eds.), 2007. Forging a new alliance between succession and restoration. Springer, New York.

Xu L, Huber H, During HJ, Dong M, Anten NP. 2013. Intra specific variation of a desert shrub species in phenotypic plasticity in response to sand burial. New Phytologist, 199; 991-1000.

Yang J, Vázquez L, Feng L, Liu Z, Zhao G. 2018. Climatic and soil factors shape the demographical history and genetic diversity of a deciduous oak (*Quercus liaotungensis*) in Northern China. Frontiers in Plant Science, 9; 1534.

Zhang S, Guofang L, Qingguo C, Zhenying H, Xuehua Y, Johannes HCC. 2021. New field wind manipulation methodology reveals adaptive responses of steppe plants to increased and reduced wind speed. Plant Methods, 17; 1-16.

Zheng M, Jian S, Jingyi R, Zhenxing Z, Mingxing Z, Lin J, Dafeng H, Shiqiang W. 2020. Effects of grazing, wind erosion, and dust deposition on plant community composition and structure in a temperate steppe. Ecosystems. Ecosystems, 24; 403-420.