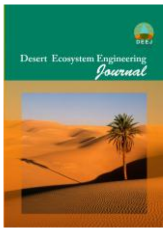
DEEJ (2018) 7 (2) 55-66

University of

Desert Ecosystem Engineering Journal

Journal homepage: http://deej.kashanu.ac.ir



The spatial association between *Halocnemum strobliaceum* and Nebkas in North of Golestan Province, Iran

Mohsen Hosseinalizadeh*[1], Narges Kariminejad[2], Mohammad Alinejad[3], Ali Mohammadian Behbahani[4]

Received: 10/04/2018 Accepted: 17/09/2018

Abstract

Investigating the distribution of *Halocnemum strobliaceum* (*H. strobliaceum)* has an important role in spatial patterns of Nebka. In order to compare the indices efficiency of *H. strobliaceum.* and Nebkas' spatial patterns and their interactions, a semi-arid region with 27.3 ha was selected in Golestan Province, Iran. The analysis of the collected samples was performed using univariate and bivariate summary statistic methods. Then, the maps of 119 *H. strobliaceum* and 322 Nebkas locations were prepared using Leica TCR407 Total Station Reflectorless. In the next step, detailed field studies were carried out to investigate the patterns and interactions between *H. strobliaceum* and Nebkas spatial locations in the selected region. The univariate (L, g, and O-ring functions) and bivariate (L_{12}, g_{12}, and O_{12} functions) summary statistics were used to separately investigate spatial patterns of *H. strobliaceum* and Nebkas as well as their interaction. The results of the univariate summary statistics showed that the *H. strobliaceum* had a dispersed distribution pattern up to scales of 17 m and this pattern was a significant departure from random labeling at scales of 0-7 m. In this regard, the pattern of Nebkas showed a higher tendency to dispersed pattern at scales 0-18 m and after that the random pattern at scales 18-50 m. The bivariate summary statistics showed that *H. strobliaceum* and Nebkas locations had a highly significant positive relationship, suggesting their facilitation effects. In general, it is concluded that the spatial pattern of *H. strobliaceum* is a strong predictor of the Nebkas point pattern.

Keywords: *Halocnemum Strobilaceum*, Nebka, Spatial analysis, Summary statistics, Golestan Province.

1. Assistant Professor, Department of Watershed and Arid Zone Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, IRAN
2. PhD Candidate, Phd Student, Arid Zone Management, Gorgan University of Agricultural Sciences and Natural Resources
3. M.Sc Student, Arid Zone Management, Gorgan University of Agricultural Sciences and Natural Resources
4. Assistant Professor, Department of Watershed and Arid Zone Management, Gorgan University of Agricultural Sciences and Natural Resources

DOI: 10.22052/jdee.2018.126753.1032

1. Introduction

Natural systems inherently tend to get stability and are flexible against disturbances (Farrell *et al*., 2000; Walker & Del Moral, 2003; Stringham *et al*., 2003; Bodin & Wiman, 2007). Rangelands as a natural ecosystem seem to be very simple biotic communities all over the world. However, at the same time complex ecological interactions occur among and with their environment. Understanding the ecological interactions of *H. strobliaceum* in these regions is essential for sustainable management of vegetation. According to the wide distribution of plant communities and their role in preventing desertification trend (Abd El-Wahab *et al*., 2014; Erfanifard and Sheikholeslami, 2017), an investigation about plant intraspecific interactions is important for better understanding the ecological structure and function of these ecosystems. Therefore, recognition of indicators that can easily be applied as pulses for managers to discover alarms is the crucial key for managing the desertification trend in rangelands.

Degradation of ecosystems and loss of biodiversity are considered global challenges with serious implications for the sustainable use of the natural environment particularly in arid and semi-arid regions (UNDP, 2012). The main features of degradation in arid ecosystems include a reduction in vegetation productivity, decrease in species diversity, and increase in aeolian processes such as the erosion, transportation, and deposition of sand (Brown, 2003). In areas with degraded vegetation and human activities, these aeolian processes lead to the creation of Nebkas (Tengberg, 1995) around the base of perennial *H. strobliaceum* such as *Haloxylon Strobilaceum* (Abd El-Wahab and AlRashed, 2010). Nebkas, also referred to as Nabkhas, phytogenic hillocks, phytogenic mounds, and coppices or vegetated dunes, are distributed extensively throughout desert with vegetation cover (El-Sheikh *et al*., 2010; Abd El-Wahab *et al*., 2014). Moreover, *H. strobliaceum* is one of the halophyte plant species in the rangelands of Golestan Province, which grows in areas of saline and alkaline soils with the shallow water table. This species, which belongs to the Chenopodiaceae family, is called Cheraton by the local people. It covers 167,000 ha of the province area and is typical of vast areas of saline flats with high salinity and high ground-water level. This desert-plant species is tolerant to abrasion and burial by sand (Quets *et al*., 2014). When fine wind-borne sediment, organic matter, and litter are deposited around it, nutrient-rich Nebkas are formed (El-Bana *et al*., 2002; Zhao *et al*., 2007; Quets *et al*., 2014). So, the distribution and formative process of Nebkas significantly located next to the *H. strobliaceum* make an important part of the study of eco-geomorphic relations in the arid environments.

Evaluation of eco-geomorphic processes based on the natural system requires a thorough knowledge of quantitative characterization of spatial pattern and continuous measurement of them (Navarro-Cerrillo *et al*., 2013; Erfanifard and Sheikholeslami, 2017). In this regard, studying the characteristics of plant patterns, their effects on the geological features, and learning efficient methods to collect and analyze data on these characteristics appear to be of great importance, since their spatial pattern in these areas will affect the performance of the used methods (Koh *et al*., 2006 ؛Cipriotti *et al*., 2012). Moreover, given the importance of the arid region, the fragility of this ecosystem, and also increased destruction process going on the area, taking management measures and implementing programs based on rational and scientific process seem to be inevitable. Thus, appropriate strategies need to be provided for planning and evaluation of the existing circumstances to preserve the crucial role of this area in the protection of water and soil. Also, as the recognition of different changes of the spatial pattern of *H. strobliaceum* is considered as the most important part in the study of ecological function of plant cover, the first effective measure in this regard would be to understand the trend of changes and access to accurate statistics and information (Han *et al*., 2008). In this relation, the use of reliable methods of gathering information about a pattern with minimum cost and quantitative expression of the spatial pattern and its interaction with the other phenomena, especially in the erodible region, seem to of great necessity (Li & Zhang, 2007; Han *et al*., 2008).

In general, to determine the spatial pattern, spatial statistical techniques need to be measured. The results of this analysis can provide information not only in little-known regions but also for the management objectives of other regions (Lopez *et al*., 2010; Carrer *et al*., 2013). Each of these summary statistics has different efficiency and positive features, which prevent recommending only one of them for all the analyses. Therefore, evaluating the performance of methods related to each group seems to be necessary so that the users will apply each method with being ensured of its accuracy. In addition to these methods, another issue focused on the researchers is to select the proper estimator in each method. Several studies have been also conducted in this area in which each of these estimators has been investigated and compared as case and limited. Comparing the results of various studies show that among the estimators used, each of them had provided the necessary performance in the relevant area of research. Thus, it seems necessary to achieve efficient methods and estimators with acceptable performance in analyzing the spatial pattern.

Moreover, a majority of studies have focused on the sediment characteristics of Nebkas (e.g., Brown and Porembski, 2000; El-Sheikh *et al*., 2010) and spatial vegetation patterns using refined spatial statistical techniques [McIntire and Fajardo, 2009; Quets *et al*., 2014]. This approach has been used for disentangling ecological processes in various ecosystems (Barbier *et al*., 2010; Fedriani *et al*., 2010; Pillay and Ward, 2012), but rarely in Nebka landscapes (Du *et al*., 2010, Quets *et al*., 2013, Quets *et al*., 2014). In the present study, we applied this approach to a vegetation pattern of *H. strobliaceum* (a widespread Nebka-forming shrub) in Sufikam plain of Aq Qala in Golestan Province, eastern north of Iran. We evaluated hypotheses on recruitment and establishment of the Nebkas using modified point pattern analyses. So, we used the number of summary characteristics to capture the bio-geomorphologic spatial features and interaction of *H. strobliaceum* and Nebkas' locations. The main difference between the proposed studies and the previously mentioned studies is the complication of ecology and geomorphology sciences for finding the Halocnemum-Nebkas structures and their formative processes.

2. Study area

The Golestan Province is located in the northeast of Iran on the south-eastern shore of the Caspian Sea. The study area, the Aq Qala, as a part of the Sufikam plain, Golestan Province, located between 55° 35′ 39″ to 55° 36′ 10″ eastern longitude and 37° 16′ 8″ to 37° 16′ 26″ northern latitude, comprises a region of 27.3 ha (Fig. 1). The mean elevation of the study area is 7 m above sea level. Based on Iranian Meteorological Organization, the average annual rainfall and temperature in the region are 250-300 mm and 17℃, respectively. An area completely covered with Halocnemum shrubs was selected for this study (Fig. 2).

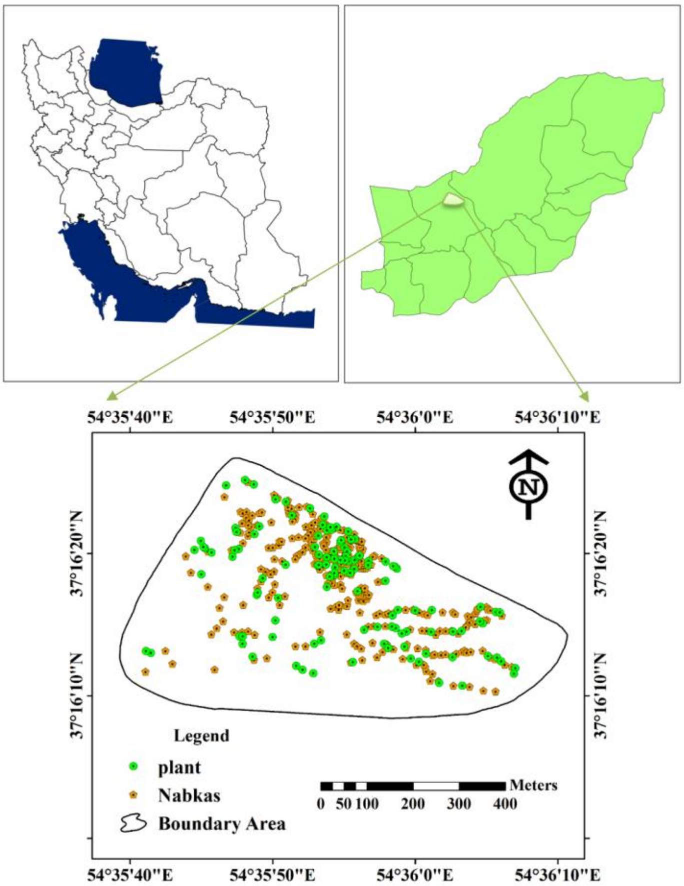


Figure 1: The study area in Sufikam plain of Aq Qala in Golestan Province, eastern-north of Iran

Figure 2. The study area covered by *H. strobilaceum* and a widespread Nebka-forming shrub

3. Methodology

3.1 Field measurements

Since the correctness and precision of the point pattern analysis of the plants depend on their correct recording, Leica TCR407 Total Station Reflectorless (Leica-TCR407) with an accuracy of 2 mm ± 2 ppm was used for obtaining the map of 129 *H. strobliaceum* and 322 Nebkas locations in the study area.

3.2. Univariate summary statistics

The Ripley *K*-function is a second-order summary statistics based on the distances between all pairs of points such as the location of *H. strobliaceum* or Nebkas. Thus, the location of every *H. strobliaceum* or Nebkas retreat was used as a point and accordingly their spatial pattern was analyzed. The current method provides information about the distances between all points in different patterns, which can be used to analyze the spatial patterns of points at different scales. Therefore, the distributed, random, or clustered patterns of points can be determined at the special scales from the central point. A modification *K*-function, called "*L* function" was used to normalize its hyperbolic behavior (Besag, 1977). From a statistical point of view, the expected value of the univariate *L* function is zero under complete spatial randomness (CSR). *L* function reflects the dispersed pattern if it is lower than the confidence envelopes while it indicates the clustered pattern when it is above the confidence envelopes (Eq. 1).

$$L(r) = \left(\frac{L(r)}{\pi}\right)^{0.5} - r \qquad (1)$$

The pair correlation function *g*(*r*) is a spatial correlation function that analyzes the change in point density in various scales (Stoyan and Stoyan, 1994). Based on inter-point distances, the g function describes the spatial pattern of points at a given radius r (Getzin *et al*., 2011; Getzin *et al*., 2011). Moreover, the pair correlation function – related to Ripley's *K* function – provides a formal measure for describing spatial patterns of points such as aggregation and dispersion (Eq. 2).

$$g(r) = \frac{1}{2\pi r}\frac{\mathrm{d}K(r)}{\mathrm{d}r} \qquad (2)$$

The *O*-ring statistics, which are based on the *K* function, implement a ring instead of a circle. Thus, the spatial relationship between the locations of two phenomena can be related to a certain scale in the ring (Wiegand and Moloney, 2004). The accumulative *L* function is able to focus on aggregation or regularity up to a given distance r and is appropriate only up to a certain distance although the *O*-ring statistics can detect aggregation or regularity at a given distance r in a ring. Another advantage related to the *O*-ring statistics is a probability density function with the interpretation of a neighborhood density, which is more intuitive than an accumulative measure (Stoyan and Pettinen, 2000). In this case, if the *O*-ring statistics exceeds the upper confidence envelope, a spatial aggregation of two phenomena is observed at a scale of *r*. However, the spatial regularity is observed between two phenomena (Eq. 3) if the statistic is below the lower confidence envelope. Further, the distribution does not deviate from the assumption of the selected null model at that scale if the statistic is placed between both envelopes (Benot *et al*., 2013; Pillay and Ward, 2012).

$$O(r) = \lambda\, g(r) \qquad (3)$$

3.3. Bivariate summary statistics

Based on the bivariate summary statistics, the spatial pattern analysis has been commonly used in structurally different ecosystems (Churchill *et al*., 2013; Illian *et al*., 2008; Wiegand and Moloney, 2013). Although univariate second-order summary statistics like pair correlation function *g*(*r*) have been widely implemented to study the spatial patterns of mapped points, few researchers have addressed bivariate second-order summary statistics in order to describe the spatial interactions between two patterns (Churchill *et al*., 2013; Erfanifard *et al*., 2014; Pommerening and Stoyan, 2008). Therefore, after using univariate summary statistics, the spatial patterns of *H. strobliaceum* and Nebkas are emphasized by using bivariate correlation function in order to see how they interact in the Sufikam plain region spatially.

Bivariate summary statistic L_{12} was utilized to study the interactions between *H. strobliaceum* and Nebkas, as well as their association, considers intervals among different points. For a marked point pattern, $L_{12}(r)$ can be used to estimate the number of points in Pattern 2 (Nebkas), which are expected to occur up to the radius *r* in the points related to Pattern 1 (*H. Strobilaceum*). $L_{12}(r)$ is expressed as follows (Law *et al*., 2009) (Eq. 4):

$$L_{12}(r) = \left(\frac{K_{12}(r)}{\pi}\right)^{0.5} - r \qquad (4)$$

g_{12} is regarded as a spatial correlation function that analyses the density changes of points in different scales and is used to examine the interaction between points and their association. This function considers the distances between different points or the point distance of one point with different dimensions in the study area. Based on the distance between the points, the bivariate g function calculates aggregation, dispersion, and uniformity of radius *r* using the normal density. Moreover, the bivariate distribution function g_{12}(r) of the distance *r* can be used to describe the relationship between *H. strobliaceum* and Nebkas (Getzin *et al*., 2011)

(Eq. 5).

$$g_{12}(r) = \frac{1}{2\pi r}\frac{\mathrm{d}K(r)}{\mathrm{d}r} \quad (5)$$

Further, the pair correlation function was used in the form of test statistics and random labeling as the null model to assess the spatial patterns of *H. Strobilaceum*-Nebkas relationship (Illian *et al*., 2008). Three test statistics were applied to detect the spatial interactions of two important erosional facies that allow assessing the potential departures from random labeling (Jacquemyn *et al*., 2010; Wiegand and Moloney, 2014; Svatek and Matula, 2015). The summary statistic $g_{22}(r) - g_{11}(r)$ was used to test the clustering pattern of *H. strobliaceum* compared to the Nebkas and $g_{12}(r) - g_{11}(r)$ was implemented to evaluate the neighborhood density of *H. strobliaceum* around Nebkas $g_{12}(r)$ compared to *H. strobliaceum* $g_{11}(r)$. In the latest part of bivariate pair correlation function, the statistics $g_{1,1+2} - g_{2,1+2}$, compared to the neighborhood density of joined *H. Strobilaceum*-Nebkas erosion, was denoted by subscript 1+2 around *H. strobliaceum* (pattern 1) with the density of H. Strobilaceum-Nebkas erosion around Nebkas (pattern 2) (Getzin *et al*., 2008; Castilla *et al*., 2012). Under random labeling, this function is equal to zero while the value of $g_{1,1+2} - g_{2,1+2} > 0$ indicates that *H. strobliaceum* occurs preferably in the areas with higher *H. Strobilaceum*-Nebkas density (Yu *et al*., 2009).

The bivariate *O*-ring statistic for a bivariate analysis is similar to the univariate function although it considers the number of points in Pattern 2 in a ring of distance *r* from an arbitrary point of Pattern 1. In the bivariate analysis, the values above the upper confidence envelope indicate a significant relationship between the two-point patterns (Point Type 1 relative to Point Type 2) on a particular scale. However, the values below the lower confidence envelope indicate a significant repulsion at that scale (Eq. 6). Like the univariate case, the values within the two confidence envelopes are not significantly different from the null model (Pillay and Ward, 2012).

$$O_{12}(r) = \lambda_2\, g_{12}(r) \quad (6)$$

3.4. Confidence envelopes

A deliberately stating from a null model (completely spatially random (*CSR)* pattern or heterogeneous Poisson process, depending on the spatial distribution of *H. strobliaceum* or Nebkas in the study area) was estimated using 199 Monte Carlo simulations. The null model is necessary to assess the observed pattern. Approximately, 95% confidence envelopes were built by the 5th lowest and 5th highest values of these simulations at each spatial scale *r* (Nguyen *et al*., 2014). All statistical computations and graphics were conducted using *Programita* Software (http://programita.org/) and Microsoft Excel (2013).

4. Results

4.1 Univariate summary statistics

The results of $L(r)$ explored the dispersed pattern of 119 *H. Strobilaceums* at scales of 0-6 m and the random pattern at scales of 6-50 m. This function was not a significant departure from random labeling at a level of 5% (Fig. 3A). Also, the results of 322 Nebkas showed that there was not a significant departure from the null hypothesis at any of the scales and the Nebkas pattern was random at these scales (Fig. 3B).

As shown by the test statistic $g(r)$, the spatial pattern of *H. Strobilaceums* (Fig. 3C) and Nebkas (Fig. 3D) were dispersion at scales 0–17 m. The significant departure of these distributions was confirmed at scales of 0-7 m (α=0.05) because at these distances, the functions values were out of range of Monte Carlo simulation. Hence, the distribution of *H. Strobilaceums* and Nebkas in the other scales were random and their random patterns statistically confirmed.

O-ring statistic results indicated that the spatial pattern of *H. strobliaceum* (Fig. 3E) and Nebkas (Fig. 3F) was dispersion at scales of 0-18 m. Also, the functions values were out of Monte Carlo simulation envelope at mentioned distances indicating that the dispersed patterns of *H. Strobilaceums* and Nebkas were statistically significant (α=0.05). The results of the *O*-ring functions showed the random pattern of *H. strobliaceum* and Nebkas locations at all other scales (Fig. 4F).

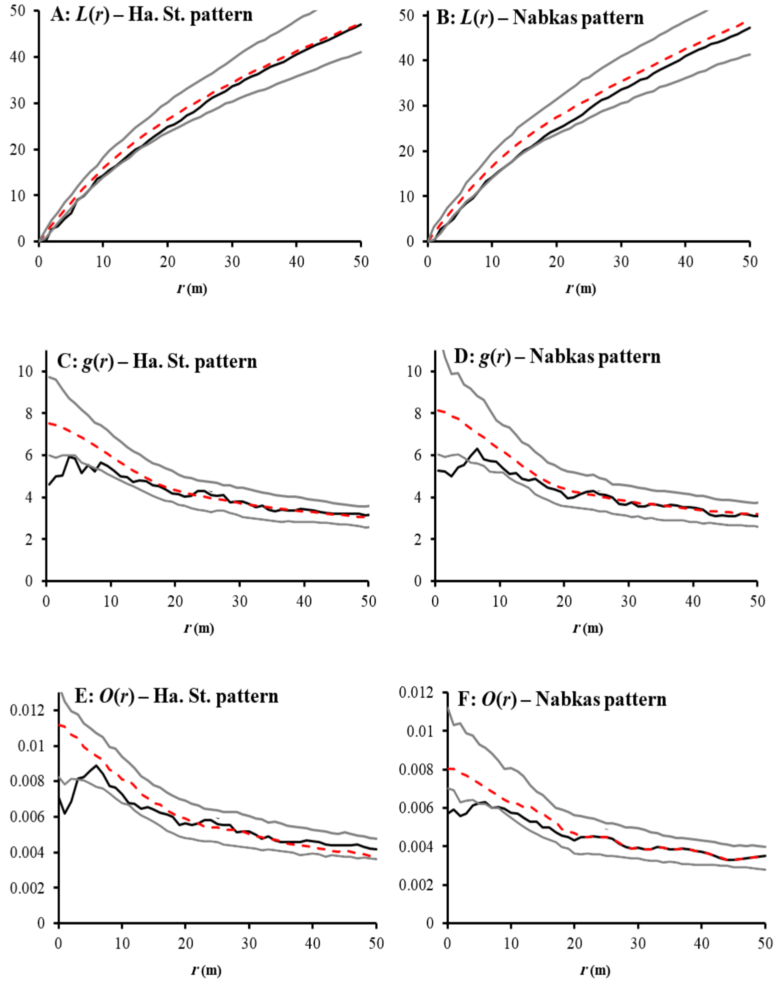


Figure 3: Spatial pattern analysis of *Halocnemum Strobilaceum* and Nebkas based on the univariate summary. As can be seen, the *L*(*r*), the results of the pair correlation function *g*(*r*), and the test statistic O-ring (c) were investigated. Approximately, 95% of the simulation envelopes were selected using the 5th lowest and 5th highest value of 199 Monte Carlo simulations of the null model of homogeneous complete spatial randomness. The observed summary statistics are presented by black lines, the simulation envelopes by gray lines, and the expectation of the null model by a red dotted line

4.2 Bivariate summary statistics

The results of bivariate functions revealed different aspects of *H. Strobilaceum*-Nebkas associations in the study area. The results of bivariate correlation function $L_{12}(r)$ for *H. strobliaceum* and Nebkas were significant departures from random labeling; *H. strobliaceum* and Nebkas presented positive associations in all scales (Fig. 4A). The results showed that in all scales, the degree of spatial dispersion and the importance of facilities between *H. strobliaceum* and Nebkas were positively linked, with significance at a level of 5%. In other words, this investigation showed that *H. strobliaceum* and Nebkas were located highly close to each other.

Studying the relationship between all *H. strobliaceum* and Nebkas with $g_{12}(r)$ showed that they had a significant correlation with each other. In addition, the amount of the function at all distances revealed that the positive relationship between the two patterns was significant due to the function line was out of the Monte Carlo simulation envelope (Fig. 4B). This investigation, therefore, showed that *H. Strobilaceums* and Nebkas were located highly close to each other.

The results of the bivariate *O*-ring correlation function showed that *H. strobliaceum* and Nebkas had a positive interaction with each other in the study area at all scales (Fig. 4C). Also, the bivariate relationship between *H. Strobilaceums* and Nebkas showed departures from random labeling. Furthermore, they had a positive interaction and the degree of spatial dispersion and the importance of facilities were positively linked.

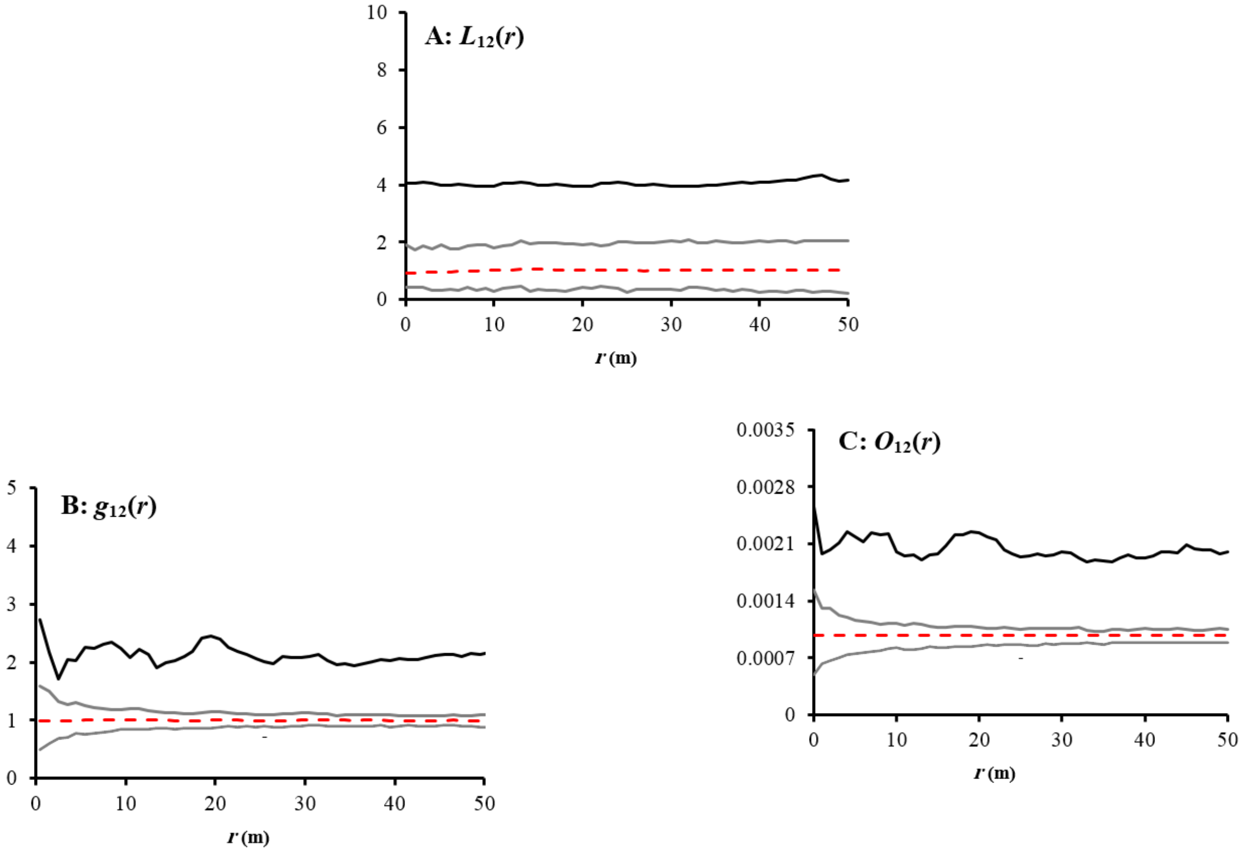


Figure 4: Spatial association analysis of *Halocnemum Strobilaceum* and Nebkas location based on the bivariate summary statistics. As can be seen, the test statistic L_{12}, $g_{12}(r)$, and $o_{12}(r)$ were investigated. About, 95% of simulation envelopes were selected using the 5th lowest and 5th highest value of 199 Monte Carlo simulations of the null model of homogeneous complete spatial randomness. The observed summary statistics are denoted by black lines, the simulation envelopes by gray lines, and the expectation of the null model by a red dotted line

5. Discussion

The spatial pattern of *H. strobliaceum* can be analyzed using point pattern processes. Accordingly, the interpretation of the results was conducted using univariate functions (*L*, *g*, and *O*-ring). The spatial pattern of *H. strobliaceum* using all functions showed dispersed pattern at small distances and random pattern at large scales. The use of different distribution functions in the study area showed that the *H. Strobilaceums* have not been able to facilitate conditions for the establishment of each other. Each of the methods used to determine the spatial pattern provided the possibility to determine the absolute spatial pattern at different scales and showed the behavioral changes of the *H. Strobilaceums* in the community in different scales. It can be concluded that at entire distances, *H. Strobilaceums* had not provided appropriate conditions for the establishment of each other. Moreover, as a result of this behavior, their spatial patterns showed dispersions and were statistically significant. The performance of each function that was used to determine the spatial pattern of *H. strobliaceum* and to investigate quantitative neighbourly relations are confirmed in other studies such as Getzin *et al*. (2008), Lan *et al*. (2009), Sher *et al*. (2010), and Erfanifard and Khosravi, (2015).

The spatial pattern of Nebkas locations using all functions showed in the dispersed pattern at small scales Nebkas were not able to facilitate conditions for the establishment of each other. Matching exactly with the pattern of *H. strobliaceum*, the Nebkas pattern showed a higher tendency toward dispersed pattern at scales 0-18 m and after that the random pattern at scales 18-50 m. In other words, the plant existence is the cause of Nebkas formations. As a first step toward the analyses, the present study aimed to disperse pattern of *H. strobliaceum* in the region. Despite the relatively homogeneous conditions including soil conditions, landform, and the structure of vegetation cover of the study area, the small-scale environmental changes, such as salinity and aridity as two favorite factors in the establishment of *Halocnemum*, might be the reasons for their dispersed and competitive distribution (e.g., Cisz *et al*., 2013; Nguyen *et al*., 2014, Erfanifard and Khosravi, 2015). Accordingly, this dispersed pattern occurs for Nebkas locations. The results of this study also demonstrate that the region is often prone to soil erosion and land degradation, especially under climate change and man-made affecting eastern-north of Iran. Our results are in agreement with the results of Du *et al*. (2010) and Quets *et al*. (2014), who showed that the presence of Nebkas may be an indicator of land degradation in the dry area.

Bivariate correlation functions – a distance-dependent correlation function – were used for the analysis of completely mapped point patterns. The results of the bivariate relationship between Nebkas and *H. strobliaceum* locations showed that they had a positive interaction with each other. Moreover, the results of summary statistics relating to the bivariate function, such as L_{12}, $g_{12}(r)$, and $o_{12}(r)$, confirmed that *H. Strobilaceums* and Nebkas had a positive interaction with each other. So, the *H. Strobilaceums* have been able to make proper conditions for establishing of Nebkas. In general, the results of the bivariate summary statistics (L_{12}, g_{12}, and O_{12}) showed *H. strobliaceum* and Nebkas had a positive influence on each other. A noteworthy point in this regard is that vegetation cover processes impacting the Nebkas' formation caused the similarly Nebkas pattern. Therefore, according to our findings, by recognizing the pattern of *H. strobliaceum*, which can easily be evaluated, the spatial pattern of Nebkas can be determined correctly. For this purpose, analyzing the interspecific and intraspecific interactions of plant and Nebkas, which are significantly influenced by their spatial patterns, probably are the best indicator for evaluation of environmental sustainability. It means that regions in which *H. strobliaceum* grow naturally have a special interaction with themselves and their environment. Furthermore, the formation of *H. strobliaceum* strongly effects on Nebkas formations and restoration activities. According to the wide distribution of *H. strobliaceum* in rangeland and their role in preventing desertification, investigation of inter- and intraspecific interactions of these *H. strobliaceum* and Nebkas are of great importance for a better understanding of its eco-geological structure and function in ecosystems. Finally, to the best of our knowledge, no research has been done on the interaction between *H. strobliaceum* and Nebkas locations using bivariate functions. Nevertheless, in previous studies like Law *et al*. (2009), Sher *et al*. (2010), Getzin *et al*. (2011), Burns *et al*. (2013), and Svatek and Matula (2015) the researchers used bivariate functions and approved the performance of bivariate functions in the study of the relationships between *H. Strobilaceum*. Our findings suggest that in an apparently homogeneous environment, more experiment-based research is essential to help uncover the specific processes underlying.

6. Conclusion

Nebkas are common sand dunes in arid ecosystems that are associated with *H. Strobilaceum*. Assessment of vegetation pattern has been considered as an important indicator of the Nebkas pattern (El- Bana *et al*., 2003; Abd El-Wahab *et al*., 2014).

Moreover, *H. strobliaceum* is one of the most important factors of arid and semi-arid ecosystems that influence restoration and stable development of these ecosystems. Understanding the ecological interactions of *H. strobliaceum* with the other ecosystem's fraction in arid regions is required for sustainable management of vegetation. The aim of this study is to model the spatial distribution of *H. strobliaceum* and Nebkas locations to find out their eco-geological interactions and improve the knowledge of inter- and intraspecific interactions of this important species with a wide distribution in Iran. To address this objective, we used the point pattern analysis via uni- and bivariate summary statistics in order to investigate inter- and intraspecific interactions of *H. strobliaceum* and Nebkas. The results of univariate functions ($L(r)$, $g(r)$, and $O(r)$) showed that the distribution of *H. strobliaceum* and Nebkas locations was significantly dispersed at small scales and random patterns were confirmed at large scales. Despite the relatively homogeneous conditions (e.g., landform, soil conditions, and the structure of vegetation cover) of the study area, the small-scale environmental changes (e.g., salinity and aridity as two favorite factors in the growth of *H. Strobilaceum*) might be the reasons for their competitive interaction in the appropriate condition.

The bivariate summary statistics used in this study (the heterogeneous $L_{12}(r)$, $g_{12}(r)$, and $O_{12}(r)$) described different aspects of the intraspecific interactions of *H. strobliaceum* and Nebkas in the study area. These functions demonstrate the positive interactions at scales 0-50 *m*, which were significant in all scales.

In conclusion, the summary statistics applied to model the spatial distribution of *H. strobliaceum* and Nebkas patterns revealed the significant dispersion in the study area at small scales and the positive eco-geological interactions of the *H. strobliaceum* with Nebkas.

References

1. Besag, J.E. 1977. Comments on Ripley’s paper, Journal of the Royal Statistical Society B, vol 39-2: 193-195
2. Brown, G. and Porembski, S. 2000. Phytogenic hillocks and blow-outs as safe sites for Halocnemum Strobilaceum in an oil contaminated area of northern Kuwait. Environ. Conserv,vol 27: 242-249
3. Barbier, N., Couteron, P., Planchon, O. and Diouf, A., 2010. Multiscale comparison of spatial patterns using two-dimensional cross-spectral analysis: application to a semi-arid (gapped) landscape. Landscape ecology,vol 25-6: 889-902.
4. Benot, M.L., Bittebiere, A.K., Ernoult, A., Clement, B. and Mony, C., 2013. Fine- scale spatial patterns in grassland communities depend on species clonal dispersal ability and interactions with neighbours. Journal of Ecology. Vol 101: 626-636.
5. Brown, G. 2003. Factors maintaining plant diversity in degraded areas of northern Kuwait. J. Arid Environ. vol 54: 183-194.
6. Burns, S.L., Goya, J.F., Arturi, M.F., Yapura, P.F. and Perez, C.A., 2013. Stand dynamics, spatial pattern and site quality in Austrocedrus chilensis forests in Patagonia, Argentina. Forest Systems. vol 22: 170-178.
7. Cipriotti, P.A., Aguiar, M.R., Wiegand, T. and Paruelo, J.M., 2012. Understanding the long-term spatial dynamics of a semiarid grass-shrub steppe through inverse parameterization for simulation models. Oikos.vol 121: 848-861.
8. Carrer, M., Soraruf, L. and Lingua, E., 2013. Convergent space-time tree regeneration patterns along an elevation gradient at high altitude in the Alps. Forest Ecology and Management. vol 304: 1-9.
9. Cisz, M.E., Falkowski, M.J. and Orr, B., 2013. Small-scale spatial pattern of Copernicia alba morong near Bahia Negra, Paraguay. Natural Resources. vol 4: 369-377.
10. Churchill, D., Larson, A., Dahlgreen, M., Franklin, J., Hessburg, P. and Luts, J., 2013. Restoring forest resilience: from reference spatial patterns to silvicultural prescriptions and monitoring. Forest Ecology and Management. Vol: 291: 442-457.
11. Du, J., Yan, P., and Dong, Y., 2010. The progress and prospects of nebkhas in arid areas. Journal of Geographical Sciences.vol 20: 712–728.
12. El-Bana, M.I., Nijs, I. and Kockelbergh,

F., 2002. Microenvironmental and vegetational heterogeneity induced by phytogenic nebkhas in an arid coastal ecosystem. Plant and Soil.vol 247-2: 283-293.

13. El-Wahab, R.H.A. and Al-Rashed, A.R., 2010. Vegetation and soil conditions of phytogenic mounds in Subiya area northeast of Kuwait. Catrina. vol 5-1: 87-95.
14. El-Sheikh, M.A., Abbadi, G.A., Bianco, P.M. 2010. Vegetation ecology of phytogenic hillocks (nabkhas) in coastal habitats of Jal Az-Zor National Park, Kuwait: Role of patches and edaphic factors. Flora. vol 205: 832-840.
15. El-WAHAB, R.H.A., Al-RASHED, A.R. and Al-HAMAD, Y., 2014. Conservation condition of Haloxylon salicornicum (Moq.) Bunge ex Boiss. in degraded desert habitats of northern Kuwait. Int. J. Curr. Microbiol. App. Sci. vol 3-10: 310-325.
16. Erfanifard, Y. and Khosravi, E., 2015. Modeling the Spatial Distribution of Eshnan (seidlitzia Rosmarinus) Shrubs to Exploring Their Ecological Interactions in Drylands of Central Iran. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences. vol 40-1: 163.
17. Erfanifard, Y., and Sheikholeslami, N., 2017. Competitive interactions of Persian oak coppice trees (Quercus brantii var. persica) in a pure dry woodland revealed through point pattern analysis. Folia Geobotanica. Vol 1-15.
18. Fedriani, J.M., Wiegand, T. and Delibes, M., 2010. Spatial pattern of adult trees and the mammal-generated seed rain in the Iberian pear. Ecography. 33-3: 545-555.
19. Getzin, S., Wiegand, K., Schumacher, J. and Gougeon, F.A., 2008. Scale-dependent competition at the stand level assessed from crown areas. Forest Ecology and Management. vol 255: 2478-2485.
20. Getzin, S., Worbes, M., Wiegand, T. and Wiegand, K., 2011. Size dominance regulates tree spacing more than competition within height classes in tropical Cameroon. Journal of Tropical Ecology. vol 27: 93-102.
21. Koh, L., M., Magnussen, S. and Marchetti, M. 2006. Sampling methods, remote sensing and GIS multiresource forest inventory. Springer. vol 388.
22. Li, F. and Zhang, L. 2007. Comparison of point pattern analysis methods for classifying the spatial distributions of spruce-fir stands in the north-east USA. Journal of forestry. vol 3: 337-349.
23. Law, R., Illian, J., Burslem, D.F.R.P., Gratzer, G., Gunatilleke, C.V.S. and Gunatilleke, I.A.U.N., 2009. Ecological information from spatial patterns of Halocnemum Strobilaceum: insights from point process theory (ESSAY REVIEW). Journal of Ecology. vol 97: 616-628.
24. Lopez, R.P., Larrea-Alcazar, D. and Zenteno-Ruiz, F., 2010. Spatial pattern analysis of dominant species in the Prepuna: Gaining insight into community dynamics in the semi-arid, subtropical Andes. Journal of Arid Environments. vol 74: 1534-1539.
25. Lan, G., Hu, Y., Cao, M. and Zhu, H., 2011. Topography related spatial distribution of dominant tree species in a tropical seasonal rain forest in China. Forest Ecology and Management. Vol 262: 1507-1513.
26. McIntire, E.J.B., Fajardo, A., 2009. Beyond description: the active and effective way to infer processes from spatial patterns. Ecology. vol 90: 46–56.
27. Navarro-Cerrillo, R., Manzanedo, R., Bohorque, J., Sanchez, R., Sanchez, J., Miguel, S., Solano, D., Qarro, M., Griffith, D. and Palacios, G., 2013. Structure and spatio-temporal dynamics of cedar forests along a management gradient in the Middle Atlas, Morocco. Forest Ecology and Management. Vol 289: 341-353.
28. Nguyen, H., Wiegand, K. and Getzin, S., 2014. Spatial patterns and demographics of Streblus Macrophyllus trees in a tropical evergreen forest Vietnam. Journal of Tropical Forest Science. vol 26-3: 309-319.
29. Quets, JJ., Temmerman, S., El-Bana, MI., Al-Rowaily, SL. and Assaeed, AM., 2013. Unraveling landscapes with phytogenic mounds (nebkhas): An exploration of spatial pattern. Acta Oecologica-

International Journal of Ecology. vol 49: 53–63.

30. Quets, JJ., Temmerman, S., El-Bana, MI., Al-Rowaily, SL. and Assaeed, AM., 2014. Use of Spatial Analysis to Test Hypotheses on Plant Recruitment in a Hyper-Arid Ecosystem. PLoS ONE. vol 9-3: 91184
31. Pommerening, A. and Stoyan, D., 2008. Reconstructing spatial tree point patterns from nearest neighbour summary statistics measured in small subwindows. Canadian Journal of Forest Research 38, 1110–1122.
32. Pillay, T., and Ward, D., 2012. Spatial pattern analysis and competition between Acacia karroo trees in humid savannas. Plant Ecol. vol 213: 1609–1619.
33. Stoyan, D. and Stoyan, H., 1994. Fractals, random shapes and point fields: methods of geometrical statistics. John Wiley & Sons Inc., England. vol 387.
34. Stoyan, D. and Penttinen, A., 2000. Recent application of point process methods in forest statistics. Statistical Science. vol 15: 61-78.
35. Sher, A.A., Wiegand, K. and Ward, D., 2010. Do Acacia and Tamarix trees compete for water in the Negev desert? Journal of Arid Environments. vol 74: 338-343.
36. Svatek, M., Matula, R., 2015. Fine-scale spatial patterns in oak sprouting and mortality in a newly restored coppice. Forest Ecology and Management. vol 348: 117–123.
37. Tengberg, A. 1995. Nebkha dunes as indicators of wind erosion and land degradation in the Sahel zone of Burkina Faso. J. Arid Environ. vol 30: 265-282.
38. UNDP, 2012. The Future We Want: Biodiversity and Ecosystems Driving Sustainable Development. United Nations Development Programme Biodiversity and Ecosystems Global Framework Pp. 20122020. New York.
39. Wiegand, T. and Moloney, K.A., 2004. Rings, circles, and null-models for point pattern analysis in ecology. Oikos. vol 104: 209-229.
40. Wiegand, T. and Moloney, K.A., 2014. Handbook of spatial point-pattern analysis in ecology. CRC Press, New York. vol 538.
41. Zhao, W.Z., Li, Q.Y. and Fang, H.Y., 2007. Effects of sand burial disturbance on seedling growth of Nitraria sphaerocarpa. Plant and soil. vol 295-1: 95-102.