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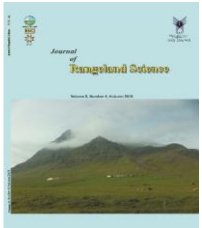

Research and Full Length Article:

Evaluation of Distance and Quadratic Indices for Determination of Plant Species Distribution Pattern in Khoosef Rangelands, Birjand, Iran

Reza Yari[A], Atefeh Gholami[B], Masoud Jafari Shalamzari[C]*, Gholamali Heshmati[D]
[A]Assistant Prof. Faculty of Agriculture, University of Sarayan, Birjand, Iran.
[B]Ph.D. Candidate, Arid Zone Management, Department of Arid Zone Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran
[C]Ph.D. Student in Remote Sensing, University of Chinese Academy of Sciences, Institute of Remote Sensing and Digital Earth (RADI), * (Corresponding Author), Email: msdjafari@radi.ac.cn
[D]Professor, Department of Range Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

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Abstract. One of the major issues examined in the quantitative ecology is the spatial distribution pattern of plant species. Knowledge of the spatial distribution patterns is essential to measure the level of uniformity in the surrounding environment, plant reproduction, and distribution of the seedlings, plant behavioral patterns, coexistence, allelopathic relations, and competition. Therefore, the aim of the present research is to select suitable indicators to determine the spatial distribution of three plant species namely *Seidlitzia rosmarinus*, *Cornulaca monacantha* and *Stipagrostis plumosa* and to evaluate their accuracy in arid and semi-arid rangelands of Birjand. Sampling was taken in the key area of each site with four transects of 100 m using quadrates (with their size proportional to the vegetative form of the plant species) by a stratified random sampling technique in 2014-2015. At each point, the distance from the nearest neighbors, the closest species and species richness were recorded. *S. plumosa* and *S. rosmarinus* produced the largest and smallest values as 6.6 and 0.24 plant/m^2, respectively. Our results suggested that *S. rosmarinus*, *C. monacantha* and *S. plumosa* follow regular and uniform distribution patterns. The results of the statistical analysis also showed the positive binomial distribution for these species, which further confirm our finding. In total, it has been found that quadratic indicators provide more accurate results regarding plant species distribution patterns as compared with the distance indicators.

Key words: Richness, Diversity, Uniformity, Distribution

Introduction

One of the major issues examined in quantitative ecology is the spatial distribution of plant species. Spatial distribution refers to the growing condition of species and their distribution in a given site or community (Malhado and Petrere, 2004). On the other hand, spatial distribution of plants is a very important measure against the adverse effects of environmental stresses (Fu-Cheng *et al.*, 2012). Knowledge of the spatial distribution patterns is essential to measure the level of uniformity in the surrounding environment, plant reproduction, and distribution of seedlings, plant behavioral patterns, coexistence, allelopathic relations and competition (Krebs, 1999). It is important to select accurate methods for measuring the quantitative characteristics of plant communities such as canopy cover, density, etc. Thus, knowledge of distribution pattern could be of great help (Johnson and Zimmer, 1985; Krebs, 1999; Legendre, 2002; Myers, 1978).

The distribution pattern and abundance of plant species in arid and semiarid environments might be attributed to the impact of physical factors, soil chemistry and human interventions (Ebrahimi *et al.,* 2015). Generally, distribution patterns of plant species include regular (uniform), cluster and random categories. In the random distribution pattern, each plant is independently established in a uniform area and in a non-selective pattern (Odum, 1999; Pielou, 1997). In the regular (uniform) distribution pattern, plants grow at regular intervals from each other (Moghadam, 2005). This could be the outcome of competition among species and the existence of allopathic relations, and the fact that each plant has also its own ecological niche. Cluster distribution pattern occurs when most or all of the populations tend to spread out in certain parts of the environment (Moghadam, 2005; Odum, 1999; Pielou, 1997). In case of the heterogeneity of a habitat, plants tend to grow in areas where the environmental conditions match their needs (Ardakani, 2003). Most plant species opt a cluster distribution pattern unless communities encounter disturbances (Basiri *et al.*, 2003).

The distance and quadratic indicators have been developed to identify different distribution patterns (Ludwing and Reynolds, 1988). A large body of literature exists for the application and the implication of these indices. Borhani *et al.* (2004) studied the distribution pattern of *Artemisia sieberi* in three regions in Isfahan province, Iran. They found that plant species were distributed in uniform and cluster forms. Fasheng and Lianjun (2006) investigated the distribution patterns of *Picea excelsa* in the North East USA. From total 50 quadrates, 24 (48%) had a random pattern, 17 (24%) had a regular pattern and 9 (18%) had a cluster pattern. Jahantab *et al.* (2012) by the identification of the distribution pattern of dominant plant species in the central Zagros mountainous ranges, Iran found that the spatial pattern of the *Kelussia odoratissima* and *Prangos ferulacea* tended to be random to cluster while that of *Artemisia aucheri* was usually uniform to random. Mohebi *et al.* (2012) by comparing the performance of distance and counting indices in the identification of the distribution pattern of *Artemisia sieberi* and *Astragalus ammodendron* in Markazi province, Iran found a random distribution pattern for *A. sieberi* and a uniform to cluster pattern for *A. ammodendron*. Pielou (1997) concluded that the standard Morista index had the highest accuracy in identifying the distribution pattern of *Anadenanthera peregrina*. Desheng *et al.* (2007) found that oak tree seedlings were distributed in a cluster pattern. Sharifi Najafabadi *et al.* (2015) in a study on the distribution of *Crataegus monogyna* in Bazoft Forest of Chaharmahal Bakhtiari province, Iran found that the most plant communities follow a cluster pattern. In a study, Jouri *et al.* (2011) evaluated the diversity and richness indices in the highlands of the Alborz Mountains, Iran. Their findings suggested that the diversity and richness might decline in the exclosures. They prescribed a light grazing for the area to maintain high levels of richness and diversity. Davari *et al.* (2011) conducted a study to investigate the biodiversity in riparian and neighboring areas in Javaherdeh rangeland of Ramsar, Iran. Their floristic list included 66 species belonging to 19 families and 56 genera. Their results showed that richness index in riparian areas and diversity index in neighboring areas are linked to the rangeland condition. Sharafatmandrad *et al.* (2014) analyzed plant richness and diversity data from 75 sampling plots located in five bioclimatic zones of the Khabr National Park, Kerman, Iran and identified a total of 73 plant species. They investigated the effects of grazing on plant species diversity and Plant Functional Types (PFTs) in an arid and semi-arid rangeland and concluded that the analyses on PFTs level possibly give more insight into the grazing response of plant community than those acting on species level.

S. rosmarinus is a bunch shrub belonging to the Chenopodiaceae family and endemic to the harsh hot and dry conditions. This plant prefers normally deep soils with light to moderate textures and can be found in arid regions. *S. rosmarinus* has a high nutritional value, especially for camels and protects the soil against wind erosion (Moghimi, 2005).

C. monacantha as a xerophyte-psammophyte shrub belonging to the Chenopodiaceae family is found mainly in the saline plains with high permeability and deep groundwater level. This plant is palatable to camel and can be used for sand stabilization and for feeding the animals (Abd EI-Ghani, 1998).

S. plumosa with high nutritional value and resistance to wind erosion belongs to the Poaceae family and thrives mostly in shallow to mid-deep soils with sandy or pebbly surfaces, good permeability, fairly fast drainages and medium to light textures (Moghimi, 2005).

Yet, little research has been done in the arid and semi-arid rangelands of Birjand rangelands, Iran and the applicability of the above mentioned indices is still not clear to rangeland managers. Given the importance and the value of rangeland plant species in rangeland restoration, resistance to wind erosion, and sand stabilization in Birjand rangelands, the aim of this study is to evaluate the applicability of the distance and quadratic indicators to identify the distribution patterns of *S. rosmarinus*, *C. monacantha* and *S. plumosa* in arid and semi-arid rangelands of Sarchah Amari, district, Birjand, Iran.

Material and Methods

Study area

The study area with a total area of 14503 ha is located in Ghalezari rural district in the vicinity of Khoosf district, 70 km Birjand city in South Khorasan province, Iran. The study area lies between 59˚59′ to 58˚50′ E and 32˚10′ to 32˚23′ N. The maximum and minimum elevation ranges between 1420 – 1240 m a.s.l. The average slope is 0-5% with mean annual precipitation of 93.6 mm, and an average annual temperature of 20.89˚C. January and June are respectively the wettest and driest months of the year. The rangeland is geologically located in the Iranian Central Plateau, and suffers from severe precipitation anomalies and high temperatures. The climate is characterized by hot and warm summers and fairly cold winters. Vegetation community of the area is mostly comprised of *Artemisia sieberi*, *Salsola tomentosa*, *Seidlitzia rosmarinus*, *Calligonum polygonoides*, and *Stipagrostis plumosa*. A sketch of the location of study area is provided in Fig. 1.

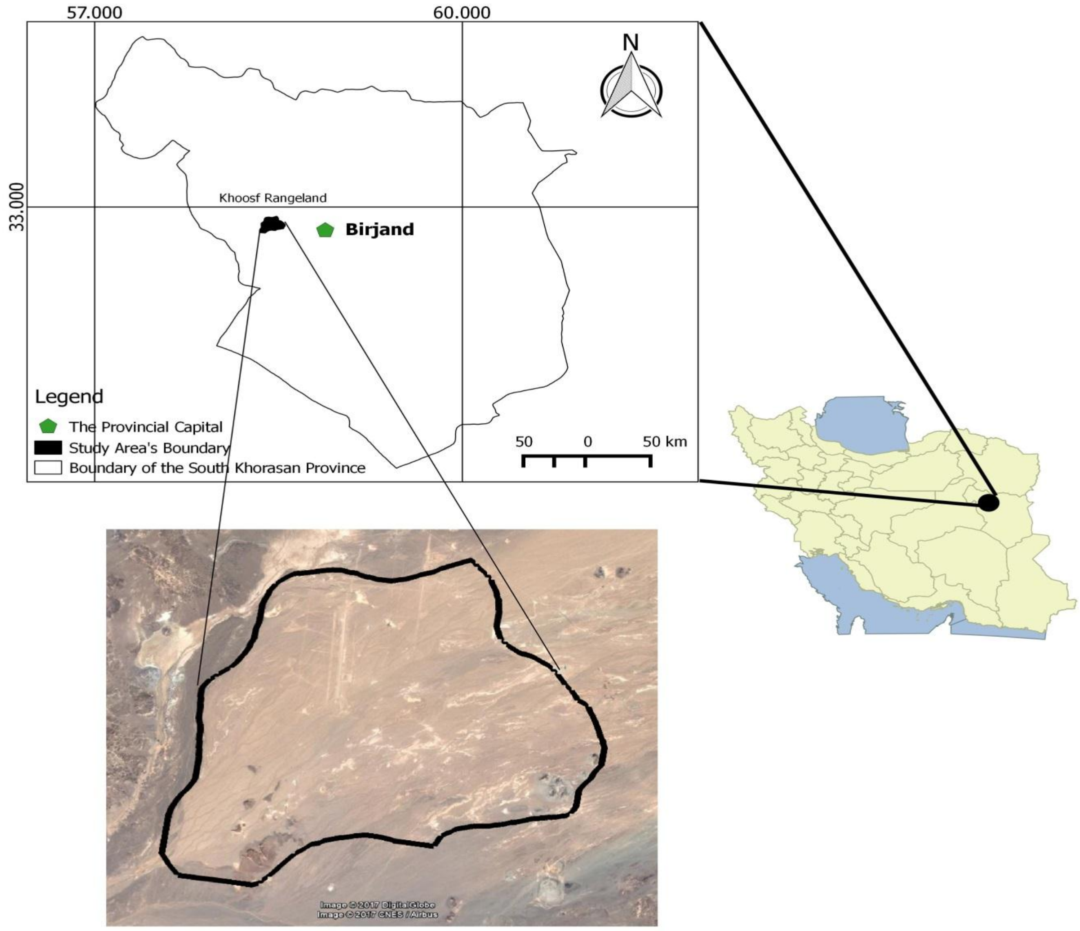

Fig. 1. Location of study area in Southern Khorasan Province relative to the boundary of Iran

Research methodology

This study was conducted from December 2014 until March 2015. After visiting the area and identifying the location of the species, sampling was carried out in the key area of each habitat in a random-systematic manner along 4 transects of 100 m. Transects were randomly established and along each transect, 5 points at 20 m intervals were selected with the first point randomly selected (Fig. 2). Next, distance indices (Johnson and Zimmer, 1985, Eberhart, Pielou, 1997 and Holgate indices) were measured (for more information on the indices and their numerical range, readers can refer to MacArthur (1965)). Quadrats with their level tailored to plants' growth form and density were established, the number of plants was recorded and the distribution patterns were determined using the quadratic indices (variance to mean index, Greene, Lloyd, Morisita and standard Morisita) (see Pielou, 1997; Ludwig & Reynolds, 1998). According to the growth form, canopy cover and density of *S. rosmarinus*, *C. monacantha* and *S. plumosa*, plot sizes of 9, 3, and 1 m^2 were used.

Statistical methods

In order to calculate the distance and quadratic indices as well as negative binomial and Poisson statistical distribution, Excel and Ecological Methodology software were used. In this case, the density of each species was initially determined and classified and the distribution of each species was then determined. Eventually, significance of the results was tested via statistical analysis. Significance of the analysis was subsequently used as a principle to distinguish between different distribution patterns. In this case, the Poisson, Positive Binomial, and Negative

Binomial distributions give the indications of random, uniform and cluster distribution patterns, respectively. As statistical frequency distributions provide a more accurate sign of plant distribution patterns, they have been used to determine the accuracy of distance and quadratic indicators for the three species of interest in this research.

Fig. 2. Transect establishment and a general outlook of the studied rangelands

Results

Table 1 provides detailed results of plant species, density, average distance of the nearest neighbor as well as variance and standard deviation of the measured distances in the three species of *S. rosmarinus*, *C. monacantha* and *S. plumosa* in dry pastures of Sarchah Amari in Khoosf district. The highest and lowest densities per unit area pertain to *S. plumosa* and *S. rosmarinus* by 6.6 and 0.24 m^2.

Table 1. Plant species, density, average distance to nearest neighbors, variances and standard deviations of the measured distance

Plant Species	Density per (m^2)	Distance from the nearest species (cm)	Distance from the nearest neighbor (cm)	Variance	SD
Seidlitzia rosmarinus	0.24	84.5	89.65	1906.19	43.66
Cornulaca monacantha	0.56	134	139.5	4641.69	68.13
Stipagrostis plumosa	6.6	30.6	36.55	376.36	19.4

Table 2 provides detailed analysis of the distance and quadratic indicators, and the distribution pattern of *S. rosmarinus* calculated in Microsoft Excel. According to Table 2, Holgate and Johnson and Zimmer's distance index shows a cluster pattern while Holgate and Pielou index gives the indication of a uniform distribution pattern. The variance to mean quadratic index tends to show a uniform to cluster pattern. However, quadratic indices of Green, Lloyd, Morisita and standard Morisita found a uniform distribution pattern.

Table 2. Distance and quadratic indices, and the identified spatial pattern for *S. Rosmarinus*

Distance Indices	Estimated Value	Distribution Pattern
Johnson and Zimmer	2.14	Cluster
Eberhart	1.6	Uniform
Pielou	0.49	Uniform
Holgate	1.64	Cluster

Quadrate Indices	Estimated Value	Distribution Pattern
Variance to mean	0.45	Uniform with cluster tendency
Green	-0.01	Uniform
Loyd	0.74	Uniform
Mourista	0.75	Uniform
Standard Mourista	-1.23	Uniform

Table 3 provides detailed analysis of the distance and quadratic indices, and the spatial pattern of *C. monacantha* (calculated in Microsoft Excel). According to Table 3, Johnson, Eberhart and Zimmer distance indices show a uniform distribution pattern while Holgate and Pielou indices indicated a cluster pattern. The variance to mean quadratic index tends to show a uniform to cluster pattern. However, quadratic indices of Green, Lloyd, Morisita and standard Morisita found the distribution pattern to be uniform.

Table 3. Distance and quadratic indices, and the identified spatial pattern for *C. monacantha*

Distance Indices	Estimated Value	Distribution Pattern
Johnson and Zimmer	1.25	Uniform
Eberhart	1.8	Uniform
Pielou	3.19	Cluster
Holgate	1.12	Cluster

Quadrate Indices	Estimated Value	Distribution Pattern
Variance to mean	0.31	Uniform with cluster tendency
Green	-0.02	Uniform
Loyd	0.59	Uniform
Mourista	0.6	Uniform
Standard Mourista	-0.98	Uniform

Table 4 provides detailed analysis of distance and quadratic indices, and the spatial pattern of *S. plumosa*. According to Table 4, Pielou and Eberhart distance indices show the distribution pattern of *S. plumosa* as uniform while Holgate, Zimmer and Pielou indices have estimated a cluster pattern. The variance to mean quadratic index tends to show a uniform cluster pattern. However, quadratic indices of Green, Lloyd, Morisita and standard Morisita found a uniform distribution pattern.

Table 4. Distance and quadratic index indices and the identified spatial patterns for *S. plumose*

Distance Indices	Estimated Value	Distribution Pattern
Johnson and Zimmer	2.46	Cluster
Eberhart	1.7	Uniform
Pielou	0.64	Uniform
Holgate	1.69	Cluster

Quadrate Indices	Estimated Value	Distribution Pattern
Variance to mean	0.58	Uniform with cluster tendency
Green	-0.003	Uniform
Loyd	0.93	Uniform
Mourista	-0.97	Uniform
Standard Mourista	-0.97	Uniform

Table 5 shows plant species, and statistical distributions. According to Table 5 and the given p-values<0.05 with respect to the Poisson and positive binomial distribution identified by the Ecological Methodology Software, the statistical distribution of the three species could be considered as a positive binomial distribution. This indicates a uniform and regular distribution pattern for the three species of interest.

Table 5. Plant species, degrees of freedom, p-values and the recognized frequency distributions

Plant Species	df	Distribution	p-value
Seidlitzia rosmarinus	3	Negative Binary	0.004
		Poisson	0.001
Cornulaca monacantha	3	Negative Binary	0.004
		Poisson	0.001
Stipagrostis plumosa	3	Negative Binary	0.003
		Poisson	0.001

Discussion

S. rosmarinus, C. monacantha and *S. plumosa* are valuable drought-tolerant forage species for camels grazing to protect the soil against wind erosion in arid and semi-arid environments. *S. rosmarinus* and *C. monacantha* are distributed mainly in similar areas and largely depend on water Table and soil texture (light sandy soils), which have to remain unchanged in the whole habitat (Yari, 2010). Distribution of *S. plumosa* as another valuable species depends mainly on edaphic factors (higher sand percentage, reduction of Na and EC values) and slope gradient. The results of the studies of Yari (2010) and Moghimi (2005) also testify the findings of this research.

The distribution pattern of the three species in the Sarchah Amari area (Birjand, Iran) was recognized as regular and uniform according to the quadratic indices and distance indices as well as positive binomial distribution. As stated in Moghadam (2005), in the uniform distribution pattern, species grow at regular intervals as the result of factors such as competition for moisture and nutrients and overlapping ecological niches.

The competition for water is more pronounced among species in arid and semi-arid environments. Jahantab *et al.* (2012) and Basiri and Mosesaei Sanjarehi (2007) studied the distribution patter of *Artemisia* sp. in an arid and semi-arid area using quadratic and distance indices. In the two studies, all quadratic and distance indices indicated a regular and uniform distribution pattern. If the restrictions of the quadratic indices are obviated (such as appropriate shape, number, size and sampling method), these indices could be considered more accurate compared with the distance indicators. The application of the quadratic indices resulted in regular and uniform distribution patterns due to small changes in species population size and the variations between plants. On the other hand, since in the most measured distances, the distance to the nearest species and neighbor were fairly similar (*S. rosmarinus*: 84.5-89.65 cm, *C. monacantha*: 134-139.5 cm, *S. plumosa*: 30.6-36.66 cm), the distance indices often showed uniform distribution patterns.

Meanwhile, the Eberhart distance index showed a similar pattern for three plant species, functioning similar to the quadratic indices. Therefore, the Eberhart indicator was selected as the best distance indicator which agrees to the findings of Janat Rostami *et al.* (2009). Likewise, Mohebbi *et al.* (2012) evaluated applicability of the quadratic and distance indicators in determining the distribution pattern of *Artemisia sieberi* and found a cluster pattern. The results showed that when the distribution pattern of a given species tends to be regular, there would be a convergence between the quadratic and distance indicators, which agrees to the findings of this study. Jahantab *et al.* (2012) with the identification of the distribution pattern of dominant plant species in the central Zagros mountainous ranges, Iran found that the spatial pattern of the *Kelussia odoratissima* and *Prangos ferulacea* tended to be random to cluster while that of *Artemisia aucheri* was usually uniform to random. They also illustrated that quadratic indices are more accurate than distance indices in identifying the distribution pattern of plant species.

Conclusion

In ecological studies, identification of the distribution pattern of species mostly drought-tolerant and resistant to wind erosion is important for restoring, improving and planting pastures, especially in arid and semi-arid areas. The distribution pattern of the three species in this study was identified as uniform and regular. Generally, quadratic indices and the Eberhart distance indicator were more accurate in the identification of the distribution patterns in arid and semi-arid areas which can be considered for further applications in the rangeland improvement and restoration endeavors. Thus, we concluded that the quadratic indicators are comparatively more accurate in identifying rangeland plant species distribution patterns.

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ارزیابی شاخص‌های فاصله‌ای و کوادراتی برای تعیین پراکنش گونه‌های مرتعی در مراتع خوسف شهرستان بیرجند

رضا یاری[الف]، عاطفه غلامی[ب]، مسعود جعفری شلمزاری[ج]*، غلامعلی حشمتی[د]
[الف] استادیار دانشکده کشاورزی سرایان، دانشگاه بیرجند، ایران
[ب] دانشجوی دکتری بیابان زدایی، گروه مدیریت مناطق خشک، دانشگاه کشاورزی و منابع طبیعی گرگان، گرگان، ایران
[ج] دانشجوی دکتری سنجش از دور، موسسه سنجش از دور دانشگاه آکادمی علوم چین، پکن *(نگارنده مسئول)، پست الکترونیک:
msdjafari@radi.ac.cn
[د] استاد گروه مرتعداری، دانشگاه کشاورزی و منابع طبیعی گرگان، گرگان، ایران

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چکیده. یکی از موضوعات اساسی و مهم در اکولوژی کمی الگوی پراکنش گیاهان است. آگاهی از الگوی پراکنش گیاهان برای ارزیابی یکنواختی و عدم یکنواختی محیط، نوع تکثیر و تولیدمثل گیاهان و همچنین برای تعیین روش مناسب اندازه‌گیری خصوصیات کمی گیاهان و روش نمونه برداری ضروری است. هدف از تحقیق حاضر انتخاب شاخص مناسب برای تعیین الگوی پراکنش و ارزیابی دقت این شاخص برای سه گونه گیاهی *Seidlitzia rosmarinus*، *Cornulaca monacantha* و *Stipagrostis plumosa* در مراتع خشک و نیمه خشک سرچاه‌عماری شهرستان خوسف می‌باشد. نمونه‌برداری در سال ۹۴-۱۳۹۳ در منطقه معرف هر رویشگاه در امتداد ۴ ترانسکت ۱۰۰ متری و در پلات‌هایی که سطح آن متناسب با فرم رویشی گونه گیاهی بود، به روش تصادفی- سیستماتیک انجام گرفت. در هر نقطه فاصله نزدیکترین گونه و نزدیک‌ترین همسایه و هم‌چنین در پلات‌ها فراوانی گونه‌ها برآورد گردید. بیشترین و کمترین تراکم در واحد سطح به‌ترتیب مربوط به نسی (*S. plumosa*) و اشنان (*S. rosmarinus*) و مقادیر ۶/۶ و ۰/۲۴ پایه در متر مربع برآورد گردید. نتایج نشان داد که سه گونه *S. rosmarinus*، *C. monacantha* و *S. plumosa* از الگوی پراکنش منظم و یکنواخت تبعیت می‌کند و همچنین نتایج تعیین نوع توزیع آماری نیز، این مورد را تصدیق و نوع توزیع آماری دوجمله ای مثبت و الگوی پراکنش منظم و یکنواخت را نشان داد. علاوه بر این نتایج نشان داد که شاخص‌های کوادراتی نسبت به شاخص‌های فاصله‌ای، الگوی پراکنش گونه‌ها را دقیق‌تر نشان می‌دهند.

کلمات کلیدی: غنا، تنوع، یکنواختی، پراکنش