Open Journal of Ecology, 2024, 14, 66-76
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

Effect of Quadrat Shape on Spatial Point Pattern Performance of *Haloxylon ammodendron*

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How to cite this paper: Wang, S.H. and Dai, L.W. (2024) Effect of Quadrat Shape on Spatial Point Pattern Performance of *Haloxylon ammodendron*. *Open Journal of Ecology*, **14**, 66-76.
https://doi.org/10.4236/oje.2024.141004

Received: December 25, 2023
Accepted: January 22, 2024
Published: January 25, 2024

Abstract

In this study, we investigated the natural growth of *Haloxylon ammodendron* forest in Moso Bay, southwest of Gurbantunggut Desert. Random sample analysis was used to analyze the spatial point pattern performance of *Haloxylon ammodendron* population. ArcGIS software was used to summarize and analyze the spatial point pattern response of *Haloxylon ammodendron* population. The results showed that: 1) There were significant differences in the performance of point pattern analysis among different random quadrants. The paired t-test for variance mean ratio showed that the *P* values were 0.048, 0.004 and 0.301 respectively, indicating that the influence of quadrat shape on the performance of point pattern analysis was significant under the condition of the same optimal quadrat area. 2) The comparative analysis of square shapes shows that circular square is the best, square and regular hexagonal square are the second, and there is no significant difference between square and regular hexagonal square. 3) The number of samples plays a decisive role in spatial point pattern analysis. Insufficient sample size will lead to unstable results. With the increase of the number of samples to more than 120, the *V* value and *P* value curves will eventually stabilize. That is, stable spatial point pattern analysis results are closely related to the increase of the number of samples in random sample square analysis.

Keywords

Spatial Point Pattern, Random Quadrat, Quadrat Analysis, Quadrat Shape

1. Introduction

Haloxylon is a plant, shrub or small tree of *Haloxylon ammodendron*, and the main distribution areas are mostly extremely desert areas. At the moment when the ecological environment of the desert areas is increasingly worsening, shuttles play an irreplaceable role in maintaining the fragile ecological balance of the desert areas, improving the ecological environment, curbing and fixing the movement of deserts, and guaranteeing people's daily agricultural production and life. However, since the middle of last century, a large number of desert vegetation dominated by *Haloxylon ammodendron* has been destroyed, resulting in the deterioration of the land environment in desert areas, increasingly serious sandstorms, rapid expansion of land desertification and serious deterioration of ecological environment. Therefore, taking effective measures to analyze and protect the desert shrub dominated by *Haloxylon ammodendron* is an important issue in the current ecological community [1] [2] [3] [4] [5].

Spatial point pattern analysis originated from plant ecology and was used to analyze the spatial distribution of plants at a certain distance scale. From the late 1950s to the early 1960s, this method was extended to other research fields. Since the 1970s, after the development of some scholars, this method has been perfected day by day. Its basic idea is: divide a certain area of research, mark all point events in this research area on a plan diagram, and analyze whether there is spatial aggregation of point events at a certain distance scale by a certain calculation method. In environmental epidemiology, spatial point pattern analysis is also used to explore the spatial variability of disease risk. Because point events are abstract generalizations of the study object, point events can represent plants, diseases, and social research propositions, such as deviant events and slum problems, which are very meaningful for sufficient sociological quantitative research [6] [7].

Identification and measurement of spatial distribution patterns has always been one of the hot spots in ecology, epidemiology and social science research [8] [9] [10] [11]. Quadrant analysis is a commonly used spatial point pattern analysis method [12] [13] [14] [15]. Spatial distribution patterns are scale-dependent, and distribution types are closely related to spatial scales. On small scales, they may be aggregated distribution, while on large scales, they may be random distribution or uniform distribution. In this paper, *Haloxylon ammodendron* stand in Mosuo Bay of Shihezi was used as the study object. The spatial point pattern of *Haloxylon ammodendron* stand was analyzed and determined by using circular, square and regular hexagonal random quadrats. The effects of quadrat shape and quadrat number on spatial point pattern performance of *Haloxylon ammodendron* were analyzed and discussed. The results showed that the influence of quadrat shape on spatial point pattern analysis performance was different under the condition of the same quadrat product and quadrat number.

2. Materials and Methods

2.1. Overview of the Study Area

The study area is located on the southern edge of Gurbantunggut Desert, located at 40˚01'68" - 45˚06'19"N, 85˚59'14" - 86˚18'04"E. Gurbantunggut Desert belongs to temperate arid desert because it is deep inland and far away from the sea. The landscape here is dominated by dendritic sand ridges and honeycomb sand dunes, which strike northwest and southeast. The height of sand dunes is generally 10 - 20 meters. The surface of inter-dune depression is soft and covered with rich desert vegetation. The plants are mainly xerophytic and desert shrubs, among which *Haloxylon ammodendron*, *Haloxylon ammodendron* and *Calligonum ammodendron* are the main species, and the natural vegetation rate can reach 25%. The research materials are wild *Haloxylon ammodendron* growing naturally in Mosuowan Desert.

2.2. Research Methods

According to the theory of statistics, when the number of random sample squares is sufficient, the spatial point pattern information of the study area can be accurately extracted. Therefore, this study adopts random sample square analysis, and the specific methods are as follows: Collect distribution data of *Haloxylon ammodendron* in desert *Haloxylon ammodendron* sample plot in Mosuo Bay, import collected data into ArcGIS to make spatial point pattern map, generate circular, square and regular hexagonal random sample squares by ArcToolbox function, then count target points in random sample squares, finally analyze the influence of different shape sample squares on point pattern, and judge spatial point pattern of *Haloxylon ammodendron* forest by using analysis data, as shown in **Figure 1**. Random sample square analysis method has strong representativeness, simple method, simple operation and easy observation of results, and random sample square analysis method can ensure that the information between samples will not be lost.

2.3. Quadrat Shape and Optimal Area

Sample square is the basis of spatial statistical sampling unit. Different shapes of sample square are used to sample the study area separately to obtain the information of the whole study area. There are many shapes of sample square, such as circle, regular hexagon, square, etc. Three kinds of sample square are used for analysis in this paper. The selection of sample size and range is very important for spatial point pattern analysis [16] [17]. The sample square is too large to lose detailed information easily. Taylor *et al.* studied the correlation problems such as the selection of sample size and range, and obtained the optimal size as Equation (1):

$$S = \frac{2A}{N} \tag{1}$$

In the above equation, A is the area of the entire study region, N is the number of points in the region, and S is the optimal area of the analysis sample of the spatial point pattern. From Equation (1), the radius R can be calculated as Equation (2) for the circular random sample:

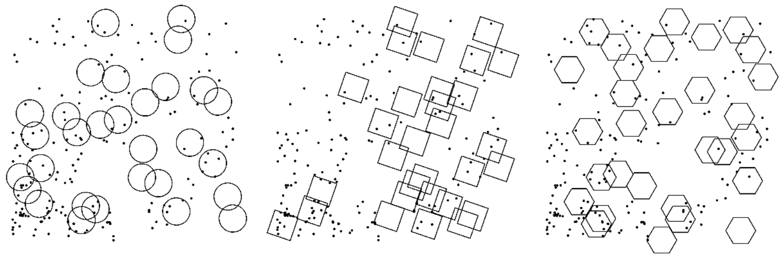

Figure 1. The random quadrat analysis method. (a) Random circular squares; (b) Random square squares; (c) Random hexagonal squares.

$$R=\sqrt{\frac{S}{\pi}}=\sqrt{\frac{2A}{\pi N}} \tag{2}$$

where R is the radius of a circular random sample. According to Equation (1), regarding a square random sample, its side length a is Equation (3), and for regular hexagonal random sample, its side length r is Equation (4).

$$a=\sqrt{S}=\sqrt{\frac{2A}{N}} \tag{3}$$

$$r=\sqrt{\frac{4A}{3\sqrt{3}N}}=0.877\sqrt{\frac{A}{N}} \tag{4}$$

2.4. Determination of Spatial Point Pattern Patterns by Variance Mean Ratio Method and Chi-Square Distribution

The mean in this study is the average density obtained by dividing the sum of the number of plants in the sample square by the number of plants in the sample square, and the variance is the average sum of the squares of the differences between the number of plants in each sample square and its mean. The variance mean ratio method is based on the assumption of Poisson distribution. The population of Poisson distribution has the property that the variance and mean are equal. Let the ratio of variance to mean be $V = s^2/x$. The spatial point pattern of the study area is random distribution pattern; if $V > 1$, it deviates from Poisson distribution and the spatial point pattern of the study area is cluster distribution; if $V < 1$, the spatial point pattern of the study area is uniform distribution. Usually, instead of directly judging the spatial distribution pattern by the variance mean ratio V, a statistic is introduced to judge the spatial pattern. The statistic quantity is shown in Equation (5) below:

$$\chi^2_{n-1}=\frac{\sum_{i=1}^{n}\left(x-\bar{x}\right)}{\bar{x}}=\frac{s^2}{\bar{x}}\left(N-1\right)=V\times\left(N-1\right) \tag{5}$$

where N is the number of quadrants. If the significance level is between 0.025 and 0.975, the spatial point pattern is random; if the significance level is above 0.975, the spatial point pattern is aggregated; if the significance level is below 0.025, the spatial point pattern is uniform.

3. Results and Analysis

3.1. Calculation of Optimal Area of Different Shape Quadrature

The experimental data are the coordinate data of *Haloxylon ammodendron* in a sample plot of Mosuo Bay desert, with a total of 171 plant data. The size of the sample plot is 100 m × 100 m. The distribution map of *Haloxylon ammodendron* points is shown in **Figure 2**.

According to formula (1), the optimal area *S* of the sample can be calculated as 116.959 m^2. According to formulas (2), (3) and (4), the side length and radius of the circular random sample, the regular hexagonal random sample and the square random sample are calculated respectively, and the results show that the optimal radius of circular quadrat is 6.102 meters, the optimal side length of hexagonal quadrat is 6.707 meters, and the optimal side length of square quadrat is 10.815 meters.

3.2. Analysis of *Haloxylon ammodendron* Point Pattern in Circular Random Quadrat, Regular Hexagonal Random Quadrat and Square Random Quadrat

In the study area, 30, 60, 90, 120, 150, 180, 210 and 240 circular, regular hexagonal and square quadrats are randomly generated independently according to the random quadrat shape parameters. When there are 30 quadrats as shown in **Figure 3**, the random distribution diagram of circular quadrats; when there are 30 quadrats as shown in **Figure 4**, the random distribution diagram of square quadrats; **Figure 5** shows a random distribution plot of regular hexagonal quadrants for 30 quadrants.

The spatial point pattern parameters of circular random sample, regular hexagonal random sample and square random sample under this *Haloxylon ammodendron* sample were calculated respectively, and the results are shown in **Tables 1-3**.

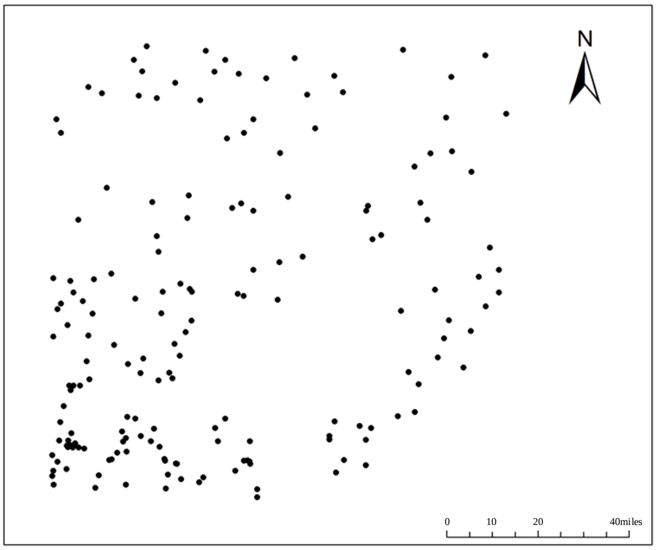

Figure 2. The map of surveys *Haloxylon ammodendron* point.

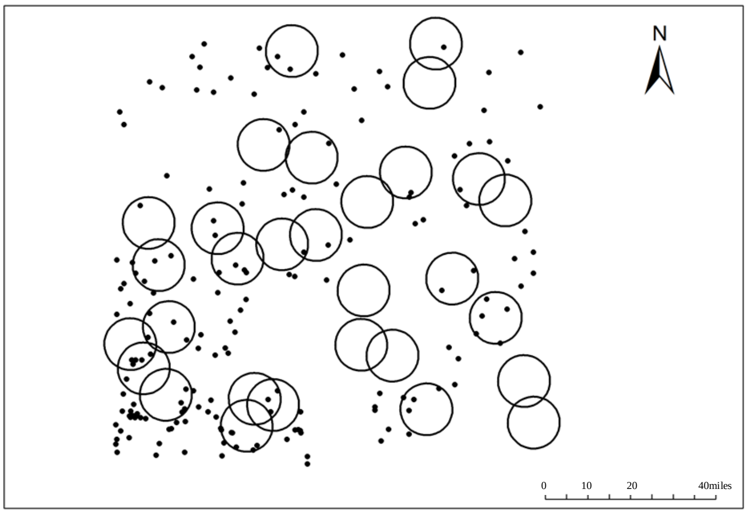

Figure 3. The distribution by random round quadrat method.

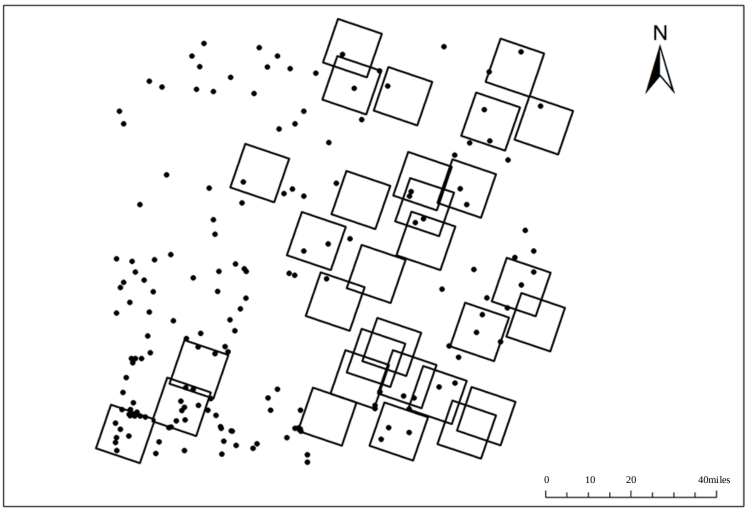

Figure 4. The distribution by random square quadrat method.

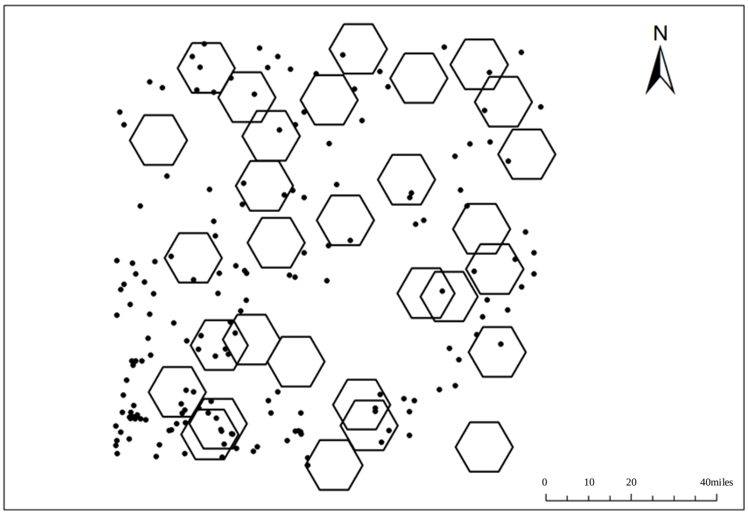

Figure 5. The distribution by random square quadrat method.

Table 1. The parameter of spatial point pattern by round quadrat method.

Number of quadrants	$\overline{x}$	s^2	V	χ^2	significance level P
30	1.300	2.810	2.162	20.400	0.1199
60	1.567	2.779	1.774	37.300	0.0122
90	1.811	3.664	2.203	80.200	0.2636
120	1.742	4.858	2.789	154.167	0.9834
150	1.833	4.752	2.592	204.640	0.9983
180	1.806	4.468	2.474	249.244	0.9995
210	1.786	4.797	2.686	346.114	1.0000
240	1.767	4.529	2.564	390.700	1.0000

Table 2. The parameter of spatial point pattern by hexagon quadrat method.

Number of quadrants	$\overline{x}$	s^2	V	χ^2	significance level P
30	2.000	3.733	1.867	16.667	0.0329
60	1.967	3.299	1.677	37.600	0.0135
90	1.956	3.909	1.999	78.000	0.2088
120	1.908	4.483	2.349	177.200	0.9996
150	1.827	4.050	2.217	222.320	0.9999
180	1.861	4.053	2.178	255.467	0.9998
210	1.919	4.760	2.480	334.517	1.0000
240	1.867	4.457	2.388	394.725	1.0000

Table 3. The parameter of spatial point pattern by square quadrat method.

Number of quadrants	$\overline{x}$	s^2	V	χ^2	significance level P
30	1.600	3.573	2.233	22.267	0.1910
60	1.750	4.388	2.507	63.900	0.6915
90	1.800	3.804	2.114	77.800	0.2041
120	1.800	3.577	1.987	99.000	0.0912
150	1.807	3.609	1.998	123.600	0.0636
180	1.706	3.286	1.926	164.400	0.2242
210	1.681	3.074	1.829	194.657	0.2465
240	1.600	3.573	2.233	22.267	0.1910

It can be seen from the results in **Table 2** that the minimum value of the mean square deviation ratio V of the circular sample is 1.774, the maximum value is 2.789, and the average value is 2.383. Each group of data is greater than 1. The significance level P is greater than 0.975 when the number of samples increases to more than 120 and gradually converges to 1. The mean square deviation ratio V of regular hexagon samples has a minimum value of 1.677 and a maximum value of 2.480, and the mean value of 2.144. Each group of data is greater than 1. The significance level P is greater than 0.975 and converges to 1 gradually when the number of samples increases to more than 120. The mean variance ratio of square square samples was 1.829 and 2.507, and the mean variance ratio of square samples was 2.059. The significance level *P* increased continuously when the number of quadrants increased to more than 120. The mean variance ratio of circle was the largest among the three quadrants, followed by regular hexagon and square. Plot variance mean ratio line graph 6 and significance level *P* line graph 7 with the number of quadrants as the horizontal axis and variance mean ratio and significance level *P* in **Tables 1-3** as the vertical axis.

From **Figure 6** and **Figure 7**, it can be concluded that when the number of samples is small, the results of random sample point pattern analysis are unstable because of insufficient sample size, but with the gradual increase of the number of samples to more than 120, the variance mean ratio *V* and *P* tend to be stable and the variance mean ratio *V* is greater than 1, and the circular sample and regular hexagonal sample *P* converge to 1. It can be seen from **Tables 1-3** that when the number of sample squares is greater than 120, the *P* value in the study area is greater than 0.975 and the variance mean ratio *V* is greater than 1, indicating that the *Haloxylon ammodendron* in this area is distributed in spatial clusters. It can be clearly that under the premise of the same random sample number and sample area, the probability *P* of the paired t-test for the comparison of the shape performance of circular and square, circular and regular hexagon and square and regular hexagon is 0.048, 0.004 and 0.301 respectively, indicating that the analysis efficiency of circular sample is significantly different from square and regular hexagon sample. There is no significant difference between square and regular hexagonal quadrants in spatial point pattern analysis efficiency; meanwhile, it can be seen from **Figure 3** that the analysis efficiency of circular quadrants is higher than regular hexagonal and square quadrants.

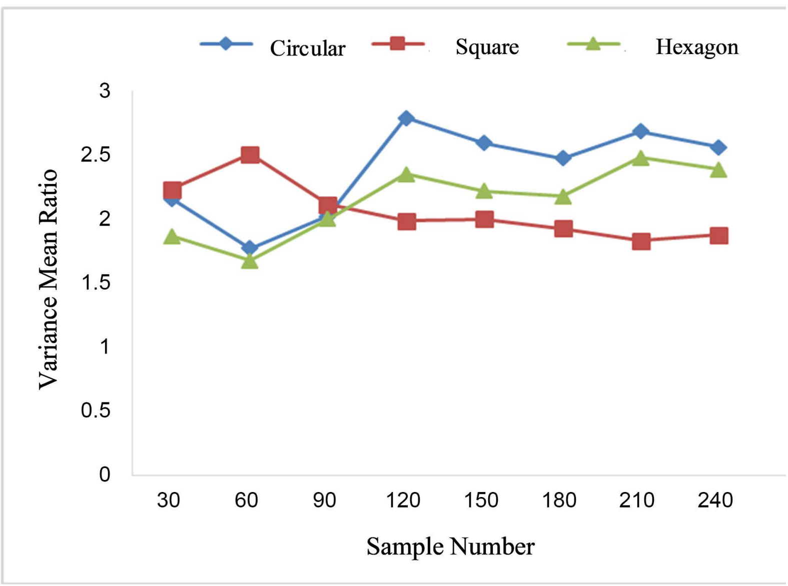

Figure 6. Ratio of variance means of spatial distribution pattern of different shape quadrats.

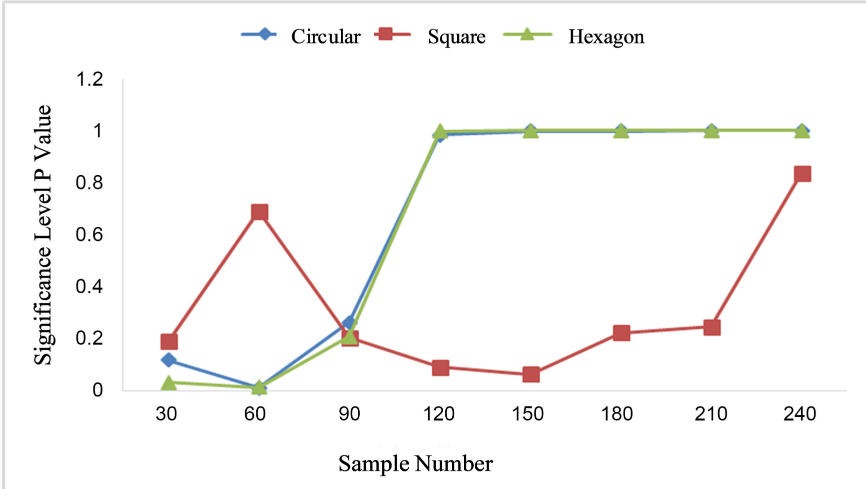

Figure 7. Significance level *P* of spatial distribution pattern of different shape quadrats.

4. Conclusions and Discussion

The spatial point pattern of *Haloxylon ammodendron* stand in Mosuowan, Shihezi was studied. The spatial point pattern of *Haloxylon ammodendron* stand in circular, square and regular hexagonal random quadrats was analyzed. The following conclusions were obtained by analyzing the influence of random quadrat shape and quantity on spatial point pattern performance: 1) The probability *P* of variance mean ratio of the response of different random quadrat shapes to *Haloxylon ammodendron* was 0.048, 0.004 and 0.301 respectively, which indicated that the influence of quadrat shapes on the performance of point pattern analysis was significantly different under the condition of the same optimal quadrat size. 2) The results of square shape contrast analysis show that circular square shape is the best, square square and hexagonal square shape are the second, and there is no significant difference between square and hexagonal square shape. 3) The number of samples plays a decisive role in spatial point pattern analysis. Insufficient sample size will lead to unstable results. With the increase of the number of samples to more than 120, the *V* value and *P* value curves will eventually stabilize. That is, stable spatial point pattern analysis results are closely related to the increase of the number of samples in random sample square analysis.

When the number of samples is small, the result of random sample analysis is unstable due to insufficient sample size, but when the number of samples is gradually increased to more than 90, the *V* value and *P* value tend to be stable, indicating that increasing the number of samples in random sample analysis can obtain stable spatial point pattern. This study also has a lot of shortcomings, only taking the *Haloxylon ammodendron* survey plot in Mosuowan, Xinjiang as an example, analyzed the influence of random quadrat shape, quadrat number and other factors on the performance of spatial point pattern analysis; the influence of other factors such as survey area, plant species type, species data amount and their interaction on the performance of spatial point pattern analysis needs further study.

Funds

This research was funded by Hunan University of Arts and Sciences Doctoral Research Initiation Project (no. 20BSQD04); Hunan Provincial Natural Science Foundation (no. 2023JJ60168).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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