ISSN (Print) 1225-9918
ISSN (Online) 2287-3406
Journal of Life Science 2018 Vol. 28. No. 11. 1262~1267
DOI : https://doi.org/10.5352/JLS.2018.28.11.1262

Spatial Distribution Patterns of *Oplismenus undulatifolius* var. *undulatifolius* on Mt. Hanwoo in Korea

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Received July 4, 2018 / Revised November 7, 2018 / Accepted November 17, 2018

The patchiness of local environments within a habitat is assumed to be a primary factor affecting the spatial patterns of plants. In this study, a randomization procedure was developed to test the null hypothesis that only spatial association with patches determines the spatial patterns of plants. *Oplismenus undulatifolius* (Ard.) P. Beauv. var. *undulatifolius* is an herbaceous plant and a member of the genus *Oplismenus* in the family Poaceae. *Oplismenus hirtellus* subsp. *undulatifolius* occurs in temperate, subtropical, and tropical areas of the world. The spatial pattern of *O. undulatifolius* var. *undulatifolius* was analyzed using dispersion indices in different sizes of plots according to several patchiness indexes, population uniformity, or aggregation . Population densities (D) at Mt. Hanwoo varied from 0.453 to 4.375, with a mean of 2.387. The small and mid-sized plots (2 m × 2 m, 2 m × 4 m, 4 m × 4 m, 4 m × 8 m, and 8 m × 8 m) of *O. undulatifolius* var. *undulatifolius* were aggregated in the forest community. However, *O. undulatifolius* var. *undulatifolius* was uniformly distributed in three large plots (8 m × 16 m, 16 m × 16 m, and 16 m × 32 m). The greatest mean crowding (*M**) and patchiness index (*PAI*) showed positive values. Aggregation is mainly caused by environmental factors. Many plants on Mt. Hanwoo are being disturbed by climbers, which is preventing these plants from inhabiting their realized niches on Mt. Hanwoo.

Key words : Mt. Hanwoo, *Oplismenus undulatifolius* var. *undulatifolius,* patchiness index, spatial distribution

Introduction

The spatial distribution of vegetation is commonly used by plant ecologists to determine relationships among plants and to better understand plant community dynamics [5]. Spatial statistics provides the quantitative description of natural variables distributed in space and time and now it is the most rapidly growing field in ecology [13]. Spatial analyses are commonly used in many disciplines, such as plant and animal ecology, geography, archeology or mining engineering. It has also found applications in forestry and forest science. Studying the spatial distribution of species according to their niche breadth would normally be addressed by studying spatial organization using, e.g. multivariate analysis, and trying to interpret observed associations according to the distance from an individual to its nearest neighbor, irrespective of direction.

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For any species, factors limiting its distribution include a combination of biotic and abiotic factors that may operate at different spatial and temporal scales [14].

Aggregated patterns of plants are often observed as spatial structures in a local population especially in a patchy habitat, and these are scale-dependent [17]. Aggregated patterns at the spatial scale corresponding to the size of patches would be the result of spatial variation in mortality and establishment of plants caused by the patchiness of the environment [9].

Structures and dynamics of a local population in a patchy habitat also depend on the structure of the habitat, which is called patch dynamics [8, 19], although it is usually applied to the large-scale dynamics of a regional population at landscape level [17]. However, spatially distribution determine at a local population in Korea has rarely been studied.

Oplismenus undulatifolius (Ard.) P. Beauv. var. *undulatifolius* is a species of perennial grass from the Poaceae family that is native to South Asia, East Asia, Southeast Asia, Australia, and Southern Africa. Thus the species can be found in temperate, subtropical, and tropical areas of the world such as Pakistan (Punjab and Kashmir), China, Japan, Korea, India, Australia, South Africa, Madagascar [15].

O. undulatifolius var. *undulatifolius* spreads rapidly through wooded natural areas, crowding out native herbaceous plants and preventing regeneration of native hardwood tree species. It forms dense carpets in the forest understory, at times creating a new layer of plant vegetation in habitats [18].

The aims of this study were to: (i) estimate plant density and population size of *O. undulatifolius* var. *undulatifolius* at Mt. Hanwoo in Korea, (ii) explore the spatial patterns of particular plot size variables and evaluate how these might be associated with the abundance and distribution of this species.

Materials and Methods

Study area

This study was carried out on the populations of *O. undulatifolius* var. *undulatifolius*, located at Mt. Hanwoo (835 m) (35°398′251′′N/128°188′601′′E) in Uiryeong-gun, Gyeongsangnam-do Province in Korea. The mountain is alpine mountain trail well maintained up to the mountain top. Especially, the place where this plant grows is the area where the mountain trail of Mt. Hanwoo is combined with the mountain trail of Mt. Jagul (897 m). The forest site comprised of rich vegetation which had not been disturbed for more than sixty years while the farming-land had almost no vegetation due to frequent human activities and interference. The elevation of *community of O. undulatifolius* var. *undulatifolius* ranges from 400 to 500 m. The site is characterized by a temperate climate with a little hot and long summer. The mean annual temperature is 13.0℃ with the maximum temperature being 25.4℃ in August and the minimum -0.5℃ in January. The mean annual precipitation ranges from 15.2 (December) to 294.5 mm (August) with 1275.6 mm. The rain is concentrated in rain falling period between June and August.

Sampling procedure

Spatial ecologists use artificial sampling units (so-called quadrats) to determine abundance or density of species. Many quadrats at Mt. Hanwoo were randomly chosen for each combination of site x habitat, so that, overall, 46 quadrats were sampled for the complete experiment. The quadrat sizes were 2 m × 2 m, 2 m × 4 m, 4 m × 4 m, 4 m × 8 m, 8 m × 8 m, 8 m × 16 m, 16 m × 16 m, and 16 m × 32 m.

Index calculation and data analysis

The spatial pattern of *O. undulatifolius* var. *undulatifolius* was analyzed according to the Neatest Neighbor Rule [3, 11] with Microsoft Excel 2016. The distance from an individual to its nearest neighbor, irrespective of direction, provides the basis for this measuring of spacing [3].

The mean observed distance (r_A) was calculated as follows:

$$r_A = \sum_{i=1}^{N} ri \,/\, N \;(i = 1,\ 2,\ 3\ \ldots\ N)$$

Where r_i is the distance from the individual to its nearest neighbor. N is the total number of individuals within the quadrat.

If this population were distributed at random, the expectation value of mean distance of individuals within a quadrat (r_B) was calculated as follows:

$$r_B = 1/2\sqrt{D}$$

Where D is population density and D is the number of individuals per plot size. The ratio R can be used as a measure of the degree to which the observed distribution approaches or departs from random expectation.

$$R = r_A \,/\, r_B$$

When $R > 1$, it is a uniform distribution and $R < 1$, it is an aggregated distribution. In a random distribution, $R = 1$ and under conditions of maximum aggregation, $R = 0$.

If the value of R is not randomly distributed, the significance of the deviation is calculated from the following formula [3].

$$C_R = \frac{r_A - r_B}{\delta_{rB}}$$

$$\delta_{rB} = 0.26136 \,/\, \sqrt{ND}$$

When $C_R > 1.96$, the level of the significance index of the deviation of R is 5%, and When $C_R > 2.58$, the level is 1%.

One test for spatial pattern and associated index of dispersion that can be used on random-point-to-nearest-organism distances was suggested by Eberhardt [4] and analyzed further by Hines and Hines [7]: $I_E = (s/m)^2 + 1$

Where I_E = Eberhardt's index of dispersion for point-to-organism distances, s = observed standard deviation of distances, m = mean of point-to-organism distances.

Many spatial dispersal parameters were calculated the degree of population aggregation under different sizes of plots by dispersion indices: index of clumping or the index of dispersion (*C*), aggregation index (*CI*), mean crowding (M*), patchiness index (PAI), negative binominal distribution index *K*, *Ca* indicators (*Ca* is the name of one index) [12] and Morisita index (*IM*) were calculated with Microsoft Excel 2016. The formulae are as follows:

Index of dispersion: $C = S^2 / m$

Aggregation index $CI = \frac{s^2}{m} - 1$

Mean crowding

$$M^* = m + \frac{s^2}{m} - 1 = m + CI = m + C - 1 - 1$$

Patchiness index $PAI = \frac{m}{\frac{s^2}{m} - 1} = \frac{M^*}{m}$

Aggregation intensity

$$PI = k = m^2 / (s^2 - m) = \frac{m}{CI} = \frac{m}{C-1}$$

Ca indicators $Ca = 1 / k$

$$IM = \frac{n\Sigma m\ (m-1)}{nm\ (nm-1)}$$

Where S^2 is variance and m is mean density of *O. undulatifolius* var. *undulatifolius*.

When C, M^*, $PAI > 1$, it means aggregately distributed, when C, M^*, $PAI < 1$, it means uniformly distributed, when CI, PA, $Ca > 0$, it means aggregately distributed, and when CI, PA, $Ca < 0$ it means uniformly distributed.

The mean aggregation number to find the reason for the aggregation of *O. undulatifolius* var. *undulatifolius* was calculated [1].

$\delta = mr / 2k$

Where r is the value of chi-square when $2k$ is the degree of freedom and k is the aggregation intensity.

Green index (GI) is a modification of the index of cluster size that is independent of n [6].

Results

The spatial pattern of individuals

Population densities (D) at Mt. Hanwoo varied from 0.453 to 4.375, with a mean of 2.387 (Table 1). The most individuals of *O. undulatifolius* var. *undulatifolius* were clustered and the distribution pattern of the *O. undulatifolius* var. *undulatifolius* was quadrat-sampling dependent. The values (*R*) of spatial distance (the rate of observed distance-to-expected distance) among the nearest individuals were higher than 1 and the significant index of C_R was > 2.58. If by this parameter, the small and middle plots (2 m × 2 m, 2 m × 4 m, 4 m × 4 m, 4 m × 8 m, and 8 m × 8 m) of *O. undulatifolius* var. *undulatifolius* were aggregative distributed in the forest community (Table 1). However, *O. undulatifolius* var. *undulatifolius* was uniformly distributed in three large plots (8 m × 16 m, 16 m × 16 m, and 16 m × 32 m).

The degree of population aggregation

The values dispersion index (*C*) were higher than 1 in the five plots (2 m × 2 m, 2 m × 4 m, 4 m × 4 m, 4 m x 8 m, and 8 m × 8 m) (Table 2). Thus aggregation indices (*CI*) in these plots were positive, which indicate aggregative distribution. Three values were lower than 1 in the three plots (8 m × 16 m, 16 m × 16 m, and 16 m × 32 m). Thus aggregation indices (*CI*) of these large plots were negative, which indicate a uniform distribution. The most mean crowding (*M**) and patchiness index (*PAI*) showed positive values. Three indices *C*, *M**, *PAI* at large plots (8 m × 16 m, 16 m × 16 m, and 16 m × 32 m) were <1 and their values of *PI* and *Ca* except three plots were also shown smaller than zero, thus it means uniform distributed. In *O. undulatifolius* var. *undulatifolius*, the two indices, *C*, *PAI* were >1 and their values of *PI* and *Ca* at small and middle plots (2 m × 2 m, 2 m × 4 m, 4 m × 4 m, 4 m × 8 m, and 8 m

Table 1. Spatial patterns of *Oplismenus undulatifolius* var. *undulatifolius* individuals at different sampling quadrat sizes in Mt. Hanwoo

Quadrat size (m × m)	No. Quadrat	Density	*R*	*CR*	I_E	Distribution pattern
2×2	14	4.250	0.885	-0.905	1.837	Aggregation
2×4	12	4.375	0.875	-1.416	2.127	Aggregation
4×4	8	3.688	0.944	-0.825	2.137	Aggregation
4×8	6	2.594	0.909	-1.587	2.866	Aggregation
8×8	4	1.672	0.865	-2.676	3.446	Aggregation
8×16	2	1.250	1.313	7.563	2.706	Uniform
16×16	2	0.813	1.056	1.549	2.681	Uniform
16×32	1	0.453	1.034	0.991	2.651	Uniform

Table 2. Changes in gathering strength of *O. undulatifolius* var. *undulatifolius* at different sampling quadrat sizes

Quadrat size (m × m)	Aggregation indices						
	C	*CI*	*M**	*PAI*	*PI*	*Ca*	*IM*
2×2	1.043	0.043	0.310	1.162	6.160	0.162	1.448
2×4	1.001	0.001	0.349	1.002	6.224	0.002	1.077
4×4	1.035	0.035	0.601	1.062	16.157	0.062	1.113
4×8	1.006	0.006	0.611	1.009	107.324	0.009	1.017
8×8	1.059	0.059	0.645	1.101	9.917	0.101	1.118
8×16	0.990	-0.010	0.544	0.983	-57.132	-0.018	0.994
16×16	0.925	-0.075	0.454	0.858	-7.065	-0.142	0.866
16×32	0.896	-0.104	0.436	0.808	-5.199	-0.192	0.814

× 8 m) were also shown greater than zero, thus it means aggregately distributed.

Iwao's method showed that Plot A had an overtly steep slope when the area was larger than 8 m × 8 m, which indicated that the degree of aggregation decreased significantly with increasing quadrat area (Fig. 1). Plot B had an overtly steep slope when the area was larger than 4 m × 8 m. while the patchiness indices of Plot C changed slightly with decreasing quadrat area.

The mean aggregation number (δ) analysis showed that the reasons for aggregation of *O. undulatifolius* var. *undulatifolius* differed in quadrats with different plot sizes. The values of δ were varied between 0.060 (8 m × 16 m) to 3.152 (2 m × 2 m) (Fig. 2). Four plots (2 m × 2 m, 2 m × 4 m, 4 m × 4 m, and 4 m × 8 m) except 8 m × 8 m plot had low δ < 2. The cluster was mainly determined by the *O. undulatifolius* var. *undulatifolius* themselves; the mean value of the aggregation index changed irregularly with the variation in plot sizes.

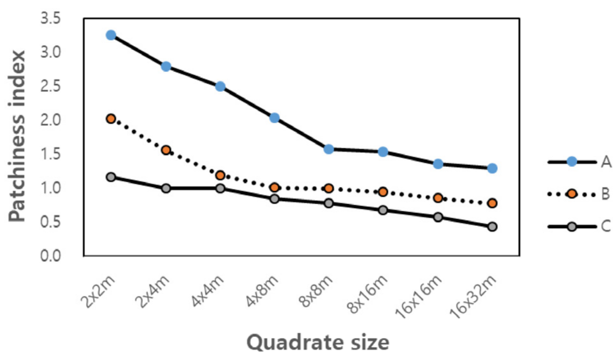

Fig. 1. The curves of the patchiness index. Plot A (—): D ≥ 10 individuals/m^2; Plot B (···): 10 individuals/m^2 > D ≥ 5 individuals/m^2; Plot C (– – –): D < 5 individuals/m^2. D represents the average density of *Oplismenus undulatifolius* var. *undulatifolius* in plots.

Discussion

When R = 1, it is a random distribution; R < 1, it is an aggregation; R > 1, it is a uniform distribution [11]. According to this rule, individuals within from 2 m × 2 m to 8 m × 8 m distance plots of *O. undulatifolius* var. *undulatifolius* at Mt. Hanwoo are aggregative distribution (Table 1). However, three large plots (8 m × 16 m, 16 m × 16 m and 16 m × 32 m) were R > 1 and those plots were shown uniform distribution. In only 8 m × 8 m plot, the two indices, *C* and *PAI* were >1, and *PI* and *Ca* > 0, thus it means aggregately distributed. Aggregation is mainly caused by the environmental factors [11]. Four plots (2 m × 2 m, 2 m × 4 m, 4 m × 4 m, and 4 m × 8 m) except 8 m × 8 m plot had low δ < 2 (Fig. 2). Previous studies on this plant have been reported in other areas (Huh, 2016). The small plots (2 m × 2 m, 2 m × 4 m, 4 m × 4 m, 4 m × 8 m, 8 m × 8 m, 8 m × 16 m, and 16 m × 16 m) of *O. undulatifolius* var. *undulatifolius* were uniformly distributed in the Mt. Ahop. However, *O. undulatifolius* var. *undulatifolius* was aggregately distributed in one large plot (16 m

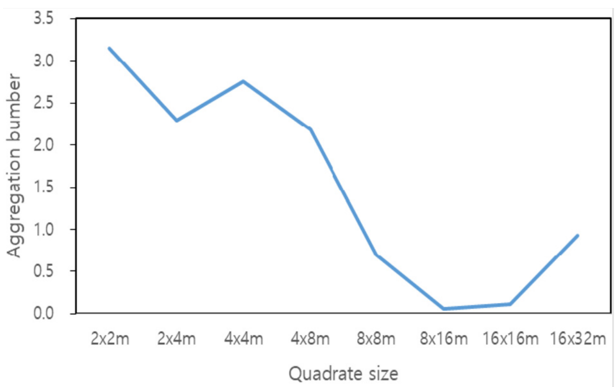

Fig. 2. The mean aggregation number to find the reason for the aggregation of *Oplismenus undulatifolius* var. *undulatifolius*.

$\times$ 32 m). When $\delta > 2$, the aggregation was mainly caused by both species characteristics and environmental factors [11]. *O. undulatifolius* var. *undulatifolius* grows in a steep mountain range of Mt. Ahop is not accessible to people. However, many plants of Mt. Hanwoo is distributed in mountain trail to Mt. Hanwoo and Mt. Jagul. Thus many plants is being interfered with by climbers. These plants cannot inhabit their realization niche in the Mt. Hanwoo.

Plants are limited by the external forces and substances affecting the growth and distribution, structure, and reproduction of that plant. Limiting factors are light, water, microclimate, soil nutrient, below-ground resources, neighbor competition which are responsible for the geography of plant distribution.

There have been several reviews of the theoretical alternatives to classical coexistence theory [2], but no comprehensive, recent review of progress made in the search for empirical evidence of niche separation in plants. The classical explanation, that each species occupies its own niche, seems at first unlikely because most plants require the same set of resources and acquire these in a limited number of ways. However, recent studies, although few in number and incomplete in many ways, do suggest that plants segregate along various environmental niche axes, including gradients of light, soil moisture and root depth, and that partitioning of soil nutrients occurs, possibly through the mediation of microbial symbionts, some of which are more species specific than was previously thought [16]. The aggregation pattern of the *O. undulatifolius* var. *undulatifolius* at Mt. Hanwoo may observed as a result of changes of the initial uniformed pattern caused by artificial interference.

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초록 : 한우산에 분포하는 주름조개풀의 공간적 양상

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국지적 환경에서 패치 분포 형태는 일차적으로 식물의 공간적 양상으로 나타나고, 임의화 과정은 패치를 결정하는 공간적 가설을 입증하는데 이용된다. 주름조개풀(*Oplismenus undulatifolius* (Ard.) P. Beauv. var. *undulatifolius*)은 Poaceae과 *Oplismenus* 속에 속하는 초본류이다. 이 종은 온대, 아열대, 열대에 분포한다. 이 지역의 주름조개풀이 일정한 분포인지 응집하는 분포인지 여러 패치 지표를 사용하여 분석하였다. 한우산의 집단 밀도는 0.453에서 4.375였으며 평균은 2.387이였다. 소형과 중형 프롯(2 m × 2 m, 2 m × 4 m, 4 m × 4 m, 4 m × 8 m, and 8 m × 8 m)에서 주름조개풀은 응집형태를 보였다. 반면에 대형 플롯(8 m × 16 m, 16 m × 16 m, and 16 m × 32 m)에서는 일정한 분포 양상을 나타내었다. 평균 응집 계수(*M**)와 패치 지표(*PAI*)는 양의 값을 보였다. 응집은 여러 환경적 요인에 기인하는데 등산객들에 의해 방해되고 있었다. 따라서 주름조개풀은 이 지역에서 본래의 기본 생태적 지위를 누리지 못하고 있음을 보여주었다.