

Spatial Distribution Pattern of Patches of *Erythronium japonicum* at Mt. Geumjeong in Korea

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The purpose of this paper was to describe a statistical analysis for the spatial distribution of geographical distances of *Erythronium japonicum* at Mt. Geumjeong in Korea. The spatial pattern of *E. japonicum* was analyzed according to the nearest neighbor rule, population aggregation under different plot sizes by dispersion indices, and spatial autocorrelation. Most natural plots of *E. japonicum* were uniformly distributed in the forest community. Disturbed plots were aggregately distributed within $5\text{ m} \times 5\text{ m}$ of one another. Neighboring patches of *E. japonicum* were predominantly 7.5~10 m apart on average. If the natural populations of *E. japonicum* were disturbed by human activities, then the aggregation occurred in a shorter distance than the 7.5~10 m distance scale. The Morisita index (*IM*) is related to the patchiness index (*PAI*) that showed the $2.5\text{ m} \times 5\text{ m}$ plot had an overly steep slope at the west and south areas when the area was smaller than $5\text{ m} \times 5\text{ m}$. When the patch size was one $2.5\text{ m} \times 5\text{ m}$ quadrat at the west distributed area of Mt. Geumjeong, the cluster was determined by both species characteristics and environmental factors. The comparison of Moran's *I* values to a logistic regression indicated that individuals in *E. japonicum* populations at Mt. Geumjeong could be explained by isolation by distance.

Key words : *Erythronium japonicum*, Moran's *I*, Mt. Geumjeong, patchiness index, spatial distribution

Introduction

Quantitative examination of spatially explicit data in ecology is broadly categorized as spatial analysis [13, 14]. Besides this emerging area of spatial analysis, the availability of modern computer hardware and software including geographical information systems have advanced our understanding of spatial relationships in ecology, including the construction of spatial ecology theory and spatially explicit models of ecological processes [11, 14].

Spatial statistics provides the quantitative description of natural variables distributed in space and time [8, 17]. Spatial analyses are commonly used in many disciplines, such as plant, animal, and microlgy ecology, geography, archeology or mining engineering [18, 22]. It has also found applications

in forestry and forest science.

Many ecologists have adopted several different major schools of spatial analysis from other disciplines. The first of these comes from geography, and its methods include the use of statistics (e.g., Moran's *I*) to measure spatial autocorrelation [3, 20, 21]. Other approaches to spatial analysis were dispersion indices and the methods were developed specifically for ecological applications [4]. In the late 1960s and 1970s a variety of methods were developed to infer spatial pattern from the frequency distribution of sample counts [12, 24]. Although these methods can be used to differentiate among some types of spatial patterns, they do not use information about the spatial location of samples and fall short in their abilities to differentiate between types of patterns [14]. Other methods developed for ecological applications were designed for specific types of data. Nearest neighbor and related statistics, for example, were developed for analysis of data consisting of exhaustive maps depicting the locations of all individuals (e.g., trees in a forest) [19].

In this study, the several statistical tools of percentage distribution and population structure of the geographical areas are used to study the spatial distribution of *Erythronium japonicum* Decaisne in Busan.

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E. japonicum is an herbaceous and belongs to the family, Liliaceae. The pink-flower is solitary, a spring ephemeral, and blooms April–June in woodlands. The species is native to Japan, Korea, the Russian Far East (Sakhalin Island, Kuril Islands) and northeastern China (Jilin and Liaoning). There is mixed reporting on whether it should be regarded as endangered in Japan. The species in Korea is also evaluated at "near threatened" *E. japonicum* is beautiful plants that can spread through seeds or be grown from bulbs, which is often done nowadays in gardens in Europe and North America where it is a popular ornamental species. The stem grows up to 10~20 cm long, although as much as 30% of the stem may be underground. Bulb is elongated, up to 6 cm long but rarely more than 1 cm wide.

Mt. Geumjeong locates in south of the Korean. A sample of a large (more than 1,600 individuals) natural population of wild species *E. japonicum* collected at this mountain was also used in this study. It is expected to provide useful experimental conditions because of the large undisturbed and isolated site.

The purpose of this paper was to describe a statistical analysis for detecting a species association, which is valid even when the assumption of within- species spatial randomness is violated. The purpose of this study is addressed: is there a spatial structure within four populations of *E. japonicum*? and if so, what is the spatial pattern and is it the same for all populations?

Materials and Methods

Study area

I conducted the spatial analysis in the communities of *Erythronium japonicum* at Mt. Geumjeong in Busan-si. The mountain (801.5 m) is highest in Busan. It has a temperate climate with a little hot and long summer. In this region the mean annual temperature is 14.7°C with the maximum temperature being 29.4°C in August and the minimum -0.6°C in January. Mean annual precipitation is about 1519.1 mm with most rain falling period between June and August.

Sampling procedure

I established nine plots with an area of 2.5 m × 20 m each around three areas at Sasong-ri, Dong-myeon in Yangsan-si and one area at Mt. Geumjeong in Busan-si, 2020. I randomly located quadrates in each plot which I established populations. The quadrat sizes were 2.5 m × 2.5 m, 2.5 m × 5 m, 5 m × 5 m, 5 m × 10 m, 10 m × 10 m, 10 m × 20 m, and 20 m

× 20 m. All plants of *E. japonicum* were mapped to estimate density per plot and geographic distances between plants.

Index calculation and data analysis

The spatial pattern of *E. japonicum* was analyzed according to the Nearest Neighbor Rule [2, 15] with Microsoft Excel 2016.

Average viewing distance (r_A) was calculated as follows:

$$r_A = \sum_{i=1}^N r_i / N \quad (i = 1, 2, 3 \dots N)$$

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

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.

$$R = r_A / r_B$$

When $R > 1$, it is a uniform distribution, $R = 1$, it is a random distribution, $R < 1$, it is an aggregated distribution.

The significance index of the deviation of R that departs from the number of "1" is calculated from the following formula [15].

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

$$\delta_{r_B} = 0.2613/\sqrt{ND}$$

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%.

The degree of population aggregation was calculated 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 binomial distribution index K , Ca indicators (Ca is the name of one index) [16] and Morisita index (IM) were calculated with Microsoft Excel 2010. The formulae are as follows:

$$\text{Index of dispersion: } C = S^2/m$$

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

$$\text{Mean crowding } M^* = m + \frac{S^2}{m} - 1 = m + CI = m + C - 1 - 1$$

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

$$\text{Aggregation intensity } PI = k = m^2 / (S^2 - m) = \frac{m}{CI} = \frac{m}{C-1}$$

$$\text{Ca indicators } Ca = 1/k$$

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

Where S^2 is variance and m is mean density of *E. japonicum*.

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 calculated to find the reason for the aggregation of *E. japonicum* [1].

$$\delta = mr / 2k$$

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

Spatial structure

Numerical simulations of previous analyses were performed to investigate the significant differences at various distance scales, i.e., 5.0, 10.0 m, and so on. However, no significant population structure was found within the 2.5 m distance classes by means of Moran's I , and a significant population structure was revealed beyond 2.5 m. Thus, the distance classes are 0-2.5 m (class I), 2.5-5.0 m (class II), 5.0-7.5 m (class III), 7.5-10.0 m (class IV), 10.0-12.5 m (class V), 12.5-15.0 m (class VI), 15.0-17.5 m (class VII), 17.5-20.0 m (class VIII), 20.0-22.5 m, 22.5-25.0 m (class IX), and 25.0-27.5 m (class X). The codes of classes are the same as in the distance classes and are listed Table 3.

The spatial structure was quantified by Moran's I , a coefficient of spatial autocorrelation (SA) [20]. As applied in this study, Moran's I quantifies the similarity of pairs of spatially adjacent individuals relative to the population sample as a whole. The value of I ranges between +1 (completely positive autocorrelation, i.e., paired individuals have identical values) and -1 (completely negative autocorrelation). Each plant was assigned a value depending on the presence or absence of a specific individual. If the i th plant was a homozygote for the individual of interest, the assigned p_i value was 1, while if the individual was absent, the value 0 was assigned [21].

Pairs of sampled individuals were classified according to the Euclidian distance, d_{ij} , so that class k included d_{ij} satisfying $k - 1 < d_{ij} < k + 1$, where k ranges from 1 to 7. The interval for each distance class was 20 m. Moran's I statistic for class k was calculated as follows:

$$I(k) = n \sum_i \sum_{j(i \neq j)} W_{ij} Z_i Z_j / S \sum Z_i^2$$

where Z_i is $p_i - p$ (p is the average of p_i); W_{ij} is 1 if the distance between the i th and j th plants is classified into class k ; otherwise, W_{ij} is 0; n is the number of all samples and S is the sum of W_{ij} $\{\sum_i \sum_{j(i \neq j)} W_{ij}\}$ in class k . Under the randomization hypothesis, $I(k)$ has the expected value $u_1 = -1/(n - 1)$ for all k . Its variance, u_2 , has been given, for example, in Sokal and Oden [20]. Thus, if an individual

is randomly distributed for class k , the normalized $I(k)$ for the standard normal deviation (SND) for the plant genotype, $g(k) = \{I(k) - u_1\} / u_2^{1/2}$, asymptotically has a standard normal distribution [3]. Hence, SND $g(k)$ values exceeding 1.96, 2.58, and 3.27 are significant at the probability levels of 0.05, 0.01, and 0.001, respectively.

Results

The spatial pattern of individuals

Population densities (D) varied from 1.890 to 5.760, with a mean of 3.780 (Table 1). The D value of eastern area (4.239) is higher than the western area (3.591). There was not shown significant difference between south and northern areas. The values (R) of spatial distance (the rete of observed distance-to-expected distance) among the nearest individuals were higher than 1 and the significant index of R (C_R) was > 2.58 . If by this parameter, the small plot (2.5 m \times 2.2 m) of *E. japonicum* was aggregated distribution in the forest community and the other plots of *E. japonicum* were uniformly distributed in the forest community (Table 1).

The degree of population aggregation

Dispersion index (were higher than 1 except four quadrats (2.5 m \times 2.5 m for west area, 10 m \times 20 m for east area, 2.5 m \times 2.5 m and 2.5 m \times 5 m for south area) (Table 2). Thus aggregation indices (were positive except negative plots which indicate a clumped distribution. The mean crowding (M^*) and patchiness index (PAI) showed that two plots had negative values (2.5 m \times 2.5 m for west and east areas). In only 8 of the 24 quadrat sizes, the three indices, C, M^*, PAI were > 1 and their values of PI and Ca were also shown greater than zero, thus it means aggregately distributed. The other 16 quadrat sizes showed that at least one index was < 1 , thus they were uniform distributed. Thus, the most individual s of *E. japonicum* were clustered and the distribution pattern of the *E. japonicum* was quadrat-sampling dependent. As the sizes of quadrat were greater, the PI values of *E. japonicum* showed high.

Morisita index (IM) is related to the patchiness index (PAI) showed that the plot 2.5 m \times 5 m had an overly steep slope at west and south areas when the area was smaller than 5 m \times 5 m, which indicated that the degree of aggregation increased significantly with increasing quadrat sizes, while the patchiness indices did not change from the plot 5 m \times 5 m to 10 m \times 20 m (Fig. 1). When the area was from 2.5 m \times 2.5 m to 2.5 m \times 5 m, IM of east and north areas the degree

Table 1. Spatial patterns of *Erythronium japonicum* individuals at four areas in Mt. Geumjeong

Location	Quadrat size (m × m)	Density	R	C _R	Distribution pattern
West	2.5 × 2.5	4.480	1.749	7.586	Aggregation
	2.5 × 5	4.640	3.409	35.111	Uniform
	5 × 5	4.240	3.240	47.846	Uniform
	5 × 10	3.680	3.462	63.914	Uniform
	10 × 10	2.570	3.417	74.127	Uniform
	10 × 20	1.935	3.757	103.764	Uniform
Mean		3.591	3.172	55.391	Uniform
East	2.5 × 2.5	5.600	2.334	15.103	Aggregation
	2.5 × 5	5.440	3.125	33.537	Uniform
	5 × 5	4.760	3.270	47.392	Uniform
	5 × 10	4.300	3.619	73.470	Uniform
	10 × 10	3.030	3.490	82.937	Uniform
	10 × 20	2.305	2.403	57.645	Uniform
Mean		4.239	3.040	51.681	Uniform
South	2.5 × 2.5	4.960	2.319	14.053	Aggregation
	2.5 × 5	4.720	2.618	23.783	Uniform
	5 × 5	4.080	2.753	33.870	Uniform
	5 × 10	3.740	3.409	63.048	Uniform
	10 × 10	2.880	3.447	79.456	Uniform
	10 × 20	2.005	3.619	100.349	Uniform
Mean	3.731	3.028	52.427	3.731	Uniform
North	2.5 × 2.5	5.760	2.519	17.436	Aggregation
	2.5 × 5	4.720	3.157	31.696	Uniform
	5 × 5	3.760	3.321	43.055	Uniform
	5 × 10	2.960	3.287	53.245	Uniform
	10 × 10	2.260	3.195	63.131	Uniform
	10 × 20	1.890	3.719	101.136	Uniform
Mean		3.558	3.200	51.617	Uniform

Table 2. Changes in gathering strength of *Erythronium japonicum* at different sampling quadrat sizes

Population	Quadrat size (m × m)	Sample size	Aggregation indices						
			C	CI	M*	PAI	PI	Ca	IM
West	2.5 × 2.5	28	0.529	-0.471	-0.058	-0.140	-0.877	-1.140	-0.153
	2.5 × 5	58	1.072	0.072	0.738	1.108	9.268	0.108	1.137
	5 × 5	106	1.117	0.117	0.949	1.140	7.149	0.140	1.153
	5 × 10	184	1.064	0.064	0.966	1.070	14.216	0.070	1.077
	10 × 10	257	1.063	0.063	1.129	1.059	16.847	0.059	1.063
	10 × 20	387	1.003	0.003	1.617	1.002	542.727	0.002	1.003
East	2.5 × 2.5	35	1.272	0.272	0.786	1.529	1.889	0.529	1.619
	2.5 × 5	68	1.068	0.068	0.559	1.138	7.243	0.138	1.173
	5 × 5	119	1.059	0.059	0.809	1.079	12.668	0.089	1.091
	5 × 10	215	1.102	0.102	0.975	1.117	8.529	0.117	1.123
	10 × 10	303	1.042	0.042	1.045	1.042	23.720	0.042	1.046
	10 × 20	461	0.818	-0.182	0.610	0.770	-4.351	-0.230	0.772
South	2.5 × 2.5	31	0.312	-0.688	-0.167	-0.321	-0.757	-1.321	-0.342
	2.5 × 5	59	0.842	-0.158	0.295	0.652	-2.870	-0.348	0.677
	5 × 5	102	1.085	0.085	0.928	1.101	9.920	0.101	1.107
	5 × 10	187	1.093	0.093	0.974	1.105	9.528	0.105	1.112
	10 × 10	288	1.036	0.036	1.052	1.036	28.007	0.036	1.039
	10 × 20	401	1.046	0.046	1.625	1.029	34.431	0.029	1.031
North	2.5 × 2.5	36	1.197	0.197	0.722	1.375	2.665	0.375	1.452
	2.5 × 5	59	1.101	0.101	0.626	1.193	5.181	0.193	1.233
	5 × 5	94	1.097	0.097	0.953	1.113	8.849	0.113	1.127
	5 × 10	148	1.293	0.293	1.248	1.307	3.262	0.307	1.316
	10 × 10	226	1.131	0.131	1.273	1.114	8.753	0.114	1.119
	10 × 20	378	1.055	0.055	1.710	1.033	30.275	0.033	1.035

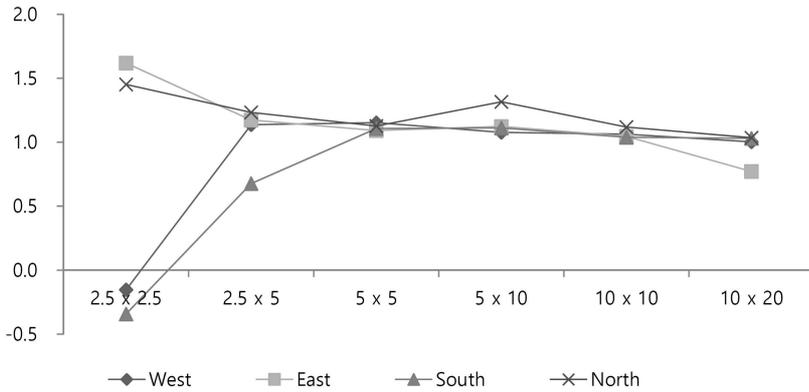


Fig. 1. The curves of patchiness in four areas of *Erythronium japonicum* using values of Green index. The *E. japonicum* patches must be more than 5 m × 5 m plot sizes to achieve effective populations.

of aggregation decreased with increasing quadrat sizes.

The mean aggregation number (δ) analysis showed that the reasons for aggregation of *E. japonicum* differed in quadrats with different plot sizes (Fig. 2). The most clusters at 25 quadrat was determined by environmental factors. When the patch size was one 2.5 m × 5 m quadrat at west, the cluster was determined by both species characteristics and environmental factors.

Analysis of spatial autocorrelation

The spatial autocoefficient, Moran's *I* is presented in Table 3. Separate counts for each type of joined individuals and for each distance class of separation were tested for significant deviation from random expectations by calculating

the SND. Moran's *I* of *E. japonicum* significantly differed from the expected value in only 16 of 40 cases (40%). Five of these values (31.3%) were negative, indicating a partial dissimilarity among pairs of individuals in the 10 distance classes. Eleven of the significant values (68.7%) were positive, indicating similarity among individuals in the first 4 distance classes, i.e., pairs of individuals can separate by more than 10 m. Namely significant aggregations were partially observed within IV classes. As a matter of course, the negative SND values at classes VI, VII, VIII, and X. Thus, dissimilarity among pairs of individuals could found by more than 15.5 m.

The comparison of Moran's *I* values to a logistic regression indicated that a highly significant percentage of in-

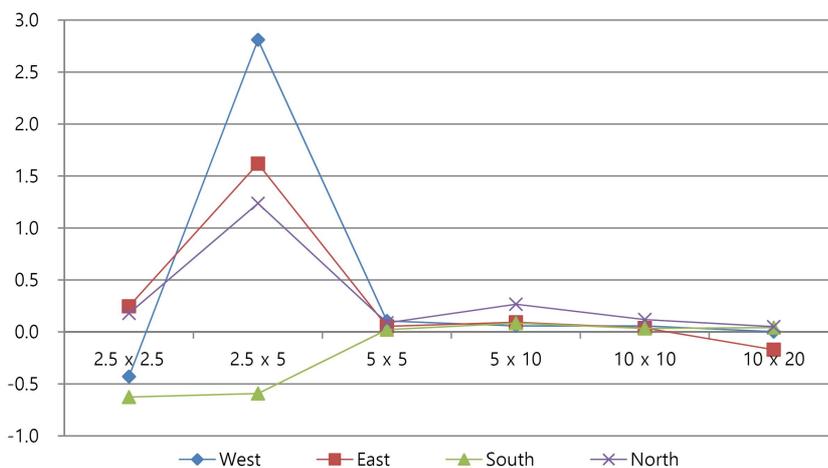


Fig. 2. The changes in the mean aggregation numbers for four areas. The small plot (2.5 m × 2.5 m) of *E. japonicum* was aggregated distribution in the four populations and the other plots of *E. japonicum* were uniformly distributed in the all populations. The four *E. japonicum* populations converged uniformly when it was more than 5 m × 5 m.

Table 3. Spatial autocorrelation coefficients (Moran's *I*) among four populations of *Erythronium japonicum* for ten distance classes

Population	I	II	III	IV	V	VI	VII	VIII	IX	X
West	0.187**	0.141*	0.172*	0.073	0.046	-0.006	-0.078	-0.092	-0.097	-0.148*
East	0.246***	0.150*	0.136	0.080	0.105	0.138	0.008	-0.272	-0.043	-0.157*
South	0.153*	0.152*	0.173*	0.148*	0.054	-0.034	-0.027	-0.142	0.066	-0.017
North	0.108	0.134	0.184*	0.248***	0.114	0.098	-0.037	-0.077	-0.115*	-0.253***

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

dividual dispersion in *E. japonicum* populations at Mt. Geumjeong could be explained by isolation by distance.

Discussion

When $R = 1$, it is a random distribution; $R < 1$, it is an aggregation; $R > 1$, it is a uniform distribution (Lian *et al.*, 2012). According to this rule, all plots and areas of *E. japonicum* at Mt. Geumjeong are uniform distribution (Table 1). However, according to dispersion indices of Lloyd [16], many plots are not uniform distribution (Table 2) and not consistent with the rule. $R = r_A / r_B$ [2]. N for r_A is total numbers of within the quadrat and r_B is concerned with plot size. Although, a large plot has large N , the plot size is not N . As D is the number of individuals per plot size, the nearest neighbor rule by Clark and Evans [2] is good for spatial pattern. 16 plots (66.7%) showed were uniform distributed. In only 8 plots (33.3%), the three indices, C , M^* , PAI were >1 , and PI and $Ca > 0$, thus it means aggregately distributed. Aggregation is mainly caused by the environmental factors [15]. When $\delta > 2$, the aggregation was mainly caused by both species characteristics and environmental factors [15]. Most 23 plots except one had low $\delta < 2$. I recognized that the important environmental factors might be considered competition, growth rate, little decomposition, light, and below-ground resources. The characteristics of the *E. japonicum* included primarily their life history, artificial disturbance, and population density. Life history theory seeks to understand the variation in traits such as growth rate, number and size of offspring and life span observed in nature, and to explain them as evolutionary adaptations to environmental conditions [23]. Ashmole's hypothesis interprets variation in clutch size as a consequence of seasonal changes in resource availability. More marked seasonality increases the discrepancy between the size of the breeding population and the breeding environment's carrying capacity [7]. Artificial disturbances are important environmental factors affecting *E. japonicum* such as constitutional roads at east area, temple construction at west area, and farming at south area. At the plots which had fewer *E. japonicum*, the cluster was mainly determined by *E. japonicum* themselves. Although the small proportion of seeds from mother removed by ants, 99% seeds in *E. japonicum* fell within 20 cm of the scape and 91% within 10 cm of the scape [10]. In addition, the mean value of the aggregation index changed irregularly with population growth rate.

A significant positive value of Moran's I indicated that pairs of individuals separated by distances that fell within

distance class V had similar individuals, whereas a significant negative value indicated that they had dissimilar individuals (Table 3). The overall significance of individual correlograms was tested using Bonferroni's criteria. The results revealed that patchiness similarity was shared among individuals within up to a scale of a 7.5 m ~ 10 m distance. Thus it was looked for the presence of dispersion correlations between neighbors at this scale.

The results from this study are consistent with the supposition that a plant population is subdivided into local demes, or neighborhoods of related individuals [5, 9]. Previous reports on the local distribution of genetic variability suggested that microenvironmental selection and limited gene flow are the main factors causing substructuring of alleles within a population [6].

E. japonicum is one of very important resources of East Asia. *E. japonicum* in Europe was brought from Asia. Europe and North America had already been cultivated.

In conclusion, *E. japonicum* populations within Mt. Geumjeong was observed a strong spatial structure. Neighboring patches of *E. japonicum* are predominantly 7.5 m to 10 m apart on average. The present study demonstrates that a spatial structure of *E. japonicum* in the Mt. Geumjeong populations could be explained by isolation by distance, limited gene flow, and topography. However, if the natural populations of *E. japonicum* were disturbed by human activities, the aggregation was occurred in more short distance than a scale of a 7.5 m ~ 10 m distance. The results of this study were used as systematic conservation planning which is an effective way to seek and identify efficient and effective types of reserve design to capture or sustain the highest priority biodiversity values and to work with communities in support of local ecosystems. Conservation biology is an objective science when biologists advocate for an inherent value in nature.

The Conflict of Interest Statement

The authors declare that they have no conflicts of interest with the contents of this article.

References

1. Arbous, A. G. and Kerrich, J. E. 1951. Accident statistics and the concept of accident proneness. *Biometrics* **7**, 340-342.
2. Clark, P. J. and Evans, F. C. 1954. Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology* **35**, 445-453.

3. Cliff, A. D. and Ord, J. K. 1971. *Spatial Autocorrelation*, pp. 1-178, Pion: London, UK.
4. Dale, M. R. T., Dixon, P., Fortin, M. J., Legendre, P., Myers, D. E. and Rosenberg, M. S. 2002. Conceptual and mathematical relationships among methods for spatial analysis. *Ecography* **25**, 558-577.
5. Ehrlich, P. R. and Raven, P. H. 1969. Differentiation of populations. *Science* **165**, 1228-1232.
6. Epperson, B. K., Chung, M. G. and Telewski, F. W. 2003. Spatial pattern variation in a contact zone of *Pinus ponderosa* and *P. arizonica* (Pinaceae). *Am. J. Bot.* **90**, 25-31.
7. Evans, K. L., Duncan, R. P., Blackburn, T. M. and Crick, H. Q. P. 2005. Investigating geographic variation in clutch size using a natural experiment. *Funct. Ecol.* **19**, 616-624.
8. Fortin, M. J. and Dale, M. R. T. 2005. *Spatial Analysis: A Guide for Ecologists*, pp. 1-365, Cambridge University Press: Cambridge, UK.
9. Garnier, L. K. M., Durand, J. and Dajoz, I. 2002. Limited seed dispersal and microspatial population structure of an agamosperous grass of west African savannahs. *Hyparrhenia diplandra* (Poaceae). *Am. J. Bot.* **89**, 1785-1791.
10. Guitian, P., Mefrano, M. and Guitian, J. 2003. Seed dispersal in *Erythronium dens-canis* L. (Liliceae): variation among habitats in a myrmecochorous plant. *Plant Ecol.* **169**, 171-177.
11. Hassell, M., Comins, H. and May, R. M. 1991. Spatial structures and chaos in insect population dynamics. *Nature* **353**, 255-258.
12. Iwao, S. 1972. Application of the $m-m^*$ method to the analysis of spatial patterns by changing the quadrat size. *Res. Popul. Ecol.* **14**, 97-128.
13. Legendre, P. and Fortin, M. J. 1989. Spatial pattern and ecological analysis. *Vegetatio* **80**, 107-138.
14. Liebhold, A. M. and Gurevitch, J. 2002. Integrating the statistical analysis of spatial data in ecology. *Ecography* **25**, 553-557.
15. Lian, X., Jiang, Z., Ping, X., Tang, S., Bi, J. and Li, C. 2012. Spatial distribution pattern of the steppe toad-headed lizard (*Phrynocephalus frontalis*) and its influencing factors. *Asian Herpetol. Res.* **3**, 46-51.
16. Lloyd, M. 1967. Mean crowding. *J. Anim. Ecol.* **36**, 1-30.
17. Pommerening, A. and Särkkä, A. 2013. What mark variograms tell about spatial plant interactions. *Ecol. Modell.* **251**, 64-72.
18. Reiczigel, J., Lang, Z., Rozsa, L. and Tothmeresz, B. 2005. Properties of crowding indices and statistical tools to analyze parasite crowding data. *J. Parasitol.* **91**, 245-252.
19. Ripley, B. D. 1979. Tests of "randomness" for spatial point patterns. *J. R. Stat. Soc. Series B.* **91**, 68-374.
20. Sokal, R. R. and Oden, N. L. 1978. Spatial autocorrelation in biology 1. Methodology. *Biol. J. Linn. Soc. Lond.* **10**, 199-228.
21. Sokal, R. R. and Oden, N. L. 1978. Spatial autocorrelation in biology 2. Some biological implications and four applications of evolutionary and ecological interest. *Biol. J. Linn. Soc. Lond.* **10**, 229-249.
22. Sone, K., Ohkubo, K., Matsudo, T. and Hata, K. 2013. Spatial distribution pattern of pine trees killed by pine wilt disease in a sparsely growing, young pine stand. *J. Plant Stud.* **2**, 36-41.
23. Souza, A. F. and Martins, F. R. 2004. Microsite specialization and spatial distribution of *Geonoma brevispatha*, a clonal palm in south-eastern Brazil. *Ecol. Res.* **19**, 521-532.
24. Taylor, L. R. 1961. Aggregation, variance and the mean. *Nature* **189**, 732-735.

초록 : 한국 금정산에 분포하고 있는 얼레지의 공간적 분포 양상과 집단 구조

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본 연구의 목적은 한국의 금정산 얼레지(*Erythronium japonicum*) 집단의 지리적 분포에 따른 공간적 분석을 기술한 것이다. 얼레지의 공간적 양상은 Nearest Neighbor Rule, 분산 척도에 의한 다양한 플롯 크기에 따른 집단 응집, 그리고 공간적 상관관계로 분석하였다. 교란된 플롯은 5 m × 5 m 내에서 응집되었다. 얼레지의 대부분 자연 플롯은 산림 군락에서 일정하게 분포되어 있었다. 얼레지의 이웃 패치는 평균 약 7.5 m에서 10 m 사이에서 이격되어 있었다. 얼레지 자연집단이 인간의 활동으로 교란되었다면 7.5 m~10 m 거리보다 짧은 크기에서 발생한다. 패치 지표(patchiness index, *PAI*)에 근거한 모리시타 지표(Morisita index, *IM*)는 금정산 서쪽 사면은 2.5 m × 5 m 플롯이었고 남쪽사면은 5 m × 5 m 이내에 나타났다. 금정산의 서쪽에서 패치 크기가 2.5 m × 5 m 방형구일 때 클러스터는 식물이 가진 종의 특성과 환경적 요인에 의해 결정되었다. 금정산 얼레지 집단은 Moran's *I* 값의 비교에서 로지스트 회귀로 분석었고, 거리에 의한 격리가 각 개체의 분산에 높은 유의성을 가지고 설명되었다.