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Spatial Distribution Pattern of the Populations of *Carex siderosticta* at Mt. Geumjeong and Mt. Ahop

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Data on the spatial distribution of a plant population among administrative areas is useful for various purposes. In this study, I analyzed the spatial distribution of the geographical distances of *Carex siderosticta* at Mt. Geumjeong and Mt. Ahop in Korea. The aim was to test a spatial structure within two populations of *C. siderosticta*. Most natural plots of *C. siderosticta* are not uniformly distributed in the forest community; for example, uniform plots were aggregately distributed within a space of 6.0 m × 6.0 m. When the sampling plots were larger than 6.0 m × 12.0 m, the individuals of *C. siderosticta* were aggregately distributed. The neighboring patches of *C. siderosticta* were predominantly 7.5 m to 9.0 m apart, on average; however, if the natural populations were disturbed by human activities, the aggregation occurred in shorter distances than a scale of 9.0 m. Moran's *I* of *C. siderosticta* significantly differed from the expected value in only 16 of 40 cases (40%). In conclusion, the geographical distribution of *C. siderosticta* is not even, with varying degrees of size in the plots, while human activities give rise to density effects in the plots at both Mt. Geumjeong and Mt. Ahop in Korea.

Key words : *Carex siderosticta*, Moran's *I*, neighboring patches, patchiness index, spatial autocorrelation

Introduction

Knowledge of specific habitats is also critical in the study of the distribution of plants. Habitats include a combination of physical factors that represent the environmental conditions in which organisms live [10]. Each plant community was considered as a discrete patch occupied by individuals of different species from a limited regional pool because all species were assumed to be in competition with each other. The spatial prediction of species distributions from survey data has recently been recognized as a significant component of conservation planning [8, 18].

Quantitative examination of spatially explicit data in ecology is broadly categorized as "spatial analysis" [13, 15]. The analysis of the spatial pattern of individuals of a particular species has long been a concern of ecologists [21].

Many ecologists have adopted several different major schools of spatial analysis from other disciplines [15]. The first of these comes from geography, and its methods include the use of statistics (e.g., Moran's *I*) to measure spatial autocorrelation [6, 19, 20]. It measures the degree to which the occurrence of an event in a real unit constrains, or makes more probable, the occurrence of an event in a neighboring areal unit.

Over the last decade, statistical ecologists have developed a number of elegant tools to incorporate spatial (or temporal) variables in analyses of multivariate ecological data sets. The presence of spatial (or temporal) autocorrelation in community composition data can be tested using multivariate Mantel correlograms. Variation partitioning [3, 17] provides a method for distinguishing the separate (and combined) influences of environmental, spatial, and temporal variables on the variability of multi-species distribution and abundance data.

Carex siderosticta Hance is an herbaceous and belongs to the family, Cyperaceae. The fruits are achene and yellow-flower blooms July - August in forests. Flowering culms and vegetative culms spaced; flowering culms clothed by bladeless sheaths at base, pale brown, without leaves. Leaf blades of vegetative culms are oblong-lanceolate, sometimes with white stripes. Flowering culms grow up to 30 cm tall. *C. siderosticta* is a species of sedge native to East Asia [23].

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

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Mt. Geumjeong and Mt. Ahop locate in south of the Korean. A sample of a large (more than 500 individuals) natural population of *C. siderosticta* collected at both mountains and was used in this study. It is expected to provide useful experimental conditions because of the large undisturbed and isolated site. Most temperate *Carex* species including *C. siderosticta* have shoots formed during the previous year, some emerging in autumn, others remaining below ground until spring [2]. The maximum shoot life span for temperate species appears to be approximately 24 months but mortality is very high; sometimes 90% of shoots do not live for the whole 2-year life span. Mortality is caused by differences in time of emergence, flowering, animal grazing, the age of the genet, and internal competition through the rhizome system. Thus, *C. siderosticta* is ideal species to study the spatial distribution pattern of the population levels.

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 two populations of *C. siderosticta*? and 2) 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 *Carex siderosticta* at Mt. Geumjeong in Busan-si. The mountain (801.5 m) is highest in Busan. Mt. Ahop (350.0 m) locates in Gijang-gun, Busan-si, Korea. Mt. Geumjeong and Mt. Ahop is about 20 km away. It has a temperate climate with a little hot and long summer. In this region the mean annual temperature is 14.7℃ with the maximum temperature being 29.4℃ in August and the minimum -0.6℃ in January. Mean annual precipitation is about 1519.1 mm with most 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. The number of events per unit area are counted and divided by area of each square to get a measure of the intensity of each quadrat. I established many 1.5 m × 1.5 m quadrats with an area of 12 m × 12 m each around one area at Mt. Ahop and Mt. Geumjeong. I randomly located quadrates in each plot which I established populations. The quadrat sizes were 1.5 m × 1.5 m, 1.5 m × 3 m, 3 m × 3 m, 3 m × 6 m, 6 m × 6 m, 6 m × 12 m, and 12 m × 12 m. I mapped all plants to estimate *C. siderosticta* density per plot.

Index calculation and data analysis

The spatial pattern of *C. siderosticta* was analyzed according to the Neatest Neighbor Rule [5, 15] with Microsoft Excel 2010.

Average viewing distance (r_A) was calculated as follows:

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

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

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 [14].

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

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

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%.

I 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) [16] and Morisita index (IM) were calculated with Microsoft Excel 2010. The formulae are as follows:

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

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

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

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 *C. siderosticta* 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.

Spatial structure

Numerical simulations of previous analyses were performed to investigate the significant differences at various distance scales, i.e., 1.0 m, 1.5 m, 2.0 m, and so on. However, no significant population structure was found within the 1.5 m distance classes by means of Moran's *I*, and a significant population structure was revealed beyond 1.5-m. Thus, the distance classes are 0-1.5 m (class I), 1.5-3.0 m (class II), 3.0-4.5 m (class III), 4.5-6.0 m (class IV), 6.0-7.5 m (class V), 7.5-9.0 m (class VI), 9.0-10.5 m (class VII), 10.5-12.0 m (class VIII), 12.0-13.5 m, 13.5-15.0 m (class IX), and 15.0-16.5 m (class X). The codes of classes are the same as in the distance classes and are listed Table 1.

The spatial structure was quantified by Moran's *I*, a coefficient of spatial autocorrelation (SA) [19]. 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 pi value was 1, while if the individual was absent, the value 0 was assigned [20].

Pairs of sampled individuals were classified according to the Euclidian distance, dij, so that class k included dij satisfying k - 1 < dij < k + 1, where k ranges from 1 to 10. The interval for each distance class was 1.5 m. Moran's *I* statistic for class k was calculated as follows:

$I\ (k) = n\Sigma i\Sigma j(i \neq j)WijZiZj/S\Sigma Zi^2$

where Zi is *pi* - p (p is the average of *pi*); Wij is 1 if the distance between the *i*th and *j*th plants is classified into class k; otherwise, Wij is 0; n is the number of all samples and S is the sum of Wij {ΣiΣj(i ≠j)Wij} in class k. Under the randomization hypothesis, *I* (k) has the expected value u1 = -1/(n - 1) for all k. Its variance, u2, has been given, for

Table 1. Spatial patterns of *Carex siderosticta* individuals at different sampling quadrat sizes in Mt. Geumjeong and Mt. Ahop

Location	Quadrat size (m × m)	Density	R	CR	Distribution pattern
Mt. Geumjeong	1.5×1.5	5.778	1.992	12.451	Uniform
	1.5×3	4.774	1.528	4.868	Uniform
	3×3	5.490	1.761	9.217	Uniform
	3×6	3.778	1.788	12.427	Uniform
	6×6	2.463	1.448	8.592	Uniform
	6×12	1.112	0.670	-7.496	Aggregation
	12×12	0.809	0.828	-4.743	Aggregation
	12×24	0.658	0.542	-11.514	Aggregation
Mt. Ahop	1.5×1.5	4.739	2.277	9.469	Uniform
	1.5×3	4.200	2.968	22.956	Uniform
	3×3	2.625	1.881	10.824	Uniform
	3×6	2.385	2.362	23.063	Uniform
	6×6	1.000	0.874	-0.874	Aggregation
	6×12	0.948	0.907	-1.685	Aggregation
	12×12	0.998	0.502	-0.603	Aggregation
	12×24	0.547	0.710	-6.731	Aggregation

example, in Sokal and Oden [19]. 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) - u1}/u2$^{1/2}$, asymptotically has a standard normal distribution [6]. 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 0.547 to 5.778, with a mean of 2.644 (Table 1). The D value of Mt. Geumjeong area (3.108) is higher than Mt. Ahop area (2.180). There was shown significant difference between both mountain areas. 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 R (Cr) was > 2.58. When this parameter was applied to two areas, the small plots (1.5 m × 1.5 m, 1.5 m × 3 m, 3 m × 3 m, and 3 m × 6 m) of *C. siderosticta* were uniformly distributed in the forest community (Table 1). However, *C. siderosticta* were aggregately distributed in large plots (6 m × 12 m, 12 m × 12 m, and 12 m × 24 m) (Table 1).

The degree of population aggregation

Dispersion index (*C*) were higher than 1 except two quadrats (1.5 m × 1.5 m and 1.5 m × 3 m for Mt. Geumjeong area) (Table 2). Thus aggregation indices (*CI*) were positive except two plots at Mt. Geumjeong which indicate a clumped distribution. The mean crowding (M*) and patchiness index (PAI) showed positive values. In Mt. Ahop, the three indices, *C*, *M**, *PAI* were >1 and their values of PI and Ca except two plots were also shown greater than zero, thus it means aggregately distributed. The most individuals of *C. siderosticta* were clustered and the distribution pattern of the *C. siderosticta* was quadrat-sampling dependent. As the sizes of quadrat were greater, the PI values of *C. siderosticta* showed high.

Morisita index (*IM*) is related to the patchiness index (*PAI*) and showed an overly steep slope at the plot 3 m x 3 m in Mt. Geumjeong and at the plot 1.5 m x 3 m in Mt. Ahop. When the area was smaller than 1.5 m x 3 m, the degree of aggregation increased significantly with increasing quadrat sizes, while the patchiness indices did not change from the plot 6 m × 6 m to 12 m × 24 m.

The mean aggregation number (δ) analysis showed that the reasons for aggregation of *C. siderosticta* differed in quadrats with different plot sizes. The most clusters at 25 quadrat was determined by environmental factors. When the size was one 2.5 m × 5 m plot 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 *C. siderosticta* significantly differed from the expected value in only 16 of 40 cases (40%). Five

Table 2. Changes in gathering strength of *Carex siderosticta* at different sampling quadrat sizes

Population	Quadrat size (m × m)	No. Quadrat	Aggregation indices						
			C	CI	M*	PAI	PI	Ca	IM
Mt. Geumjeong	1.5 × 1.5	18	0.758	-0.242	0.167	0.321	-0.610	-0.679	0.388
	1.5 × 3	12	0.785	-0.215	0.186	0.474	-4.317	-0.526	0.527
	3 × 3	10	1.007	0.007	0.433	1.014	7.185	0.014	1.047
	3 × 6	8	1.064	0.064	0.506	1.140	11.893	0.140	1.147
	6 × 6	6	1.035	0.035	0.485	1.077	13.205	0.077	1.105
	6 × 12	4	1.049	0.049	0.499	1.111	12.425	0.112	1.120
	12 × 12	2	1.025	0.025	0.541	1.050	20.803	0.050	1.059
Mt. Ahop	1.5 × 1.5	14	1.038	0.038	0.563	1.078	24.065	0.078	1.264
	1.5 × 3	10	1.067	0.067	0.445	1.159	1.134	0.159	1.250
	3 × 3	8	1.106	0.106	0.621	1.203	8.180	0.203	1.225
	3 × 6	6	1.079	0.079	0.571	1.162	12.427	0.162	1.168
	6 × 6	5	1.066	0.066	0.484	1.143	19.645	0.143	1.194
	6 × 12	3	1.040	0.040	0.538	1.073	21.683	0.073	1.080
	12 × 12	2	1.062	0.062	0.463	1.013	75.613	0.013	1.016

Table 3. Spatial autocorrelation coefficients (Moran's *I*) among two populations of *Carex siderosticta* for ten distance classes

Population	I	II	III	IV	V	VI	VII	VIII	IX	X
Mt. Geumjeong	0.449**	0.359*	0.333*	0.118	0.017	0.016	-0.103	-0.148	-0.206	-0.423
Mt. Ahop	0.405	0.347	0.319	0.240	0.021	0.134	-0.055	0.023	-0.162	-0.553

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

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 individual dispersion in *C. siderosticta* 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 [14]. According to this rule, all plots and areas of *C. siderosticta* at Mt. Geumjeong are uniform distribution (Table 1). However, According to dispersion indices of Llord [16], many plots are not uniform distribution (Table 2) and not consistent with the rule. R = r_A/r_B [5]. N for r_A is total numbers of within the plot 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 [5] 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 [14]. When δ > 2, the aggregation was mainly caused by both species characteristics and environmental factors [14]. Most 23 plots except one had low δ < 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 *C. siderosticta* concerned 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 [22]. Artificial disturbances are important environmental factors affecting *C. siderosticta* such as constitutional roads at east area, temple construction at west area, and farming at south area. At the plots which had fewer *C. siderosticta*, the cluster was mainly determined by *C. siderosticta* themselves. Although the small proportion of seeds from mother removed by ants, 99% seeds in *C. siderosticta* fell within 20 cm of the scape and 91% within 10 cm of the scape [12]. In addition, the mean value of the aggregation index changed irregularly with population growth rate [4].

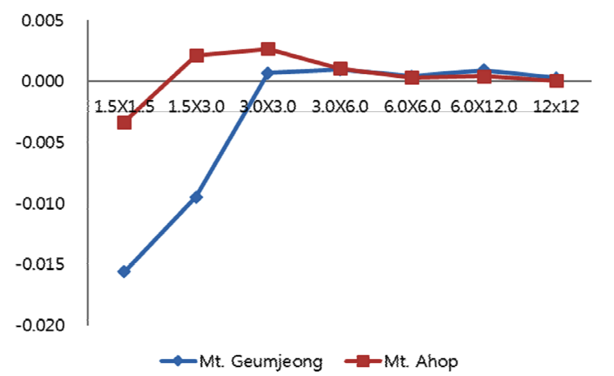

Fig. 1. The curves of patchiness according to geographic distances for two communities of *Carex siderosticta* using values of Green index. X axis is quadrat sizes (m × m).

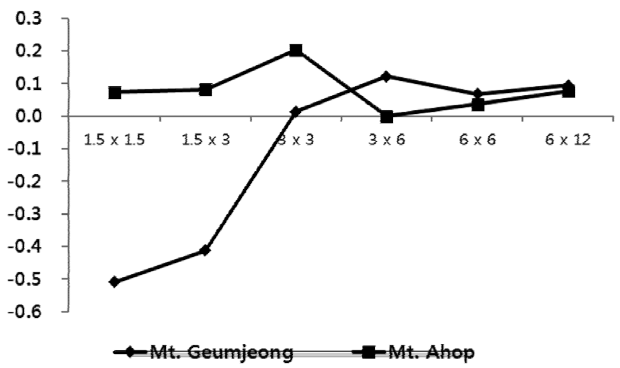

Fig. 2. The changes of the mean aggregation numbers for communities of *Carex siderosticta*. X axis is quadrat sizes (m × m).

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 [7, 11]. 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 [9].

In conclusion, *C. siderosticta* populations within Mt. Geumjeong was observed a strong spatial structure. Neighboring patches of *C. siderosticta* are predominantly 7.5 m to 10 m apart on average. The present study demonstrates that a spatial structure of *C. siderosticta* in the Mt. Geumjeong populations could be explained by isolation by distance, limited gene flow, and topography. However, if the natural populations 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.

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초록 : 금정산과 아홉산의 대사초 집단의 공간적 분포 양상

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식물 보존의 권고지역에서 식물 집단의 공간적 데이터는 여러 목적에서 중요하다. 부산광역시 금정산과 아홉산의 대사초(*Carex siderosticta*)의 지리적 거리에 따른 공간적 분포를 분석하였다. 공간적 양상의 분석 방법은 여러 패치 척도, 분산 척도에 의거한 plot(플롯)의 크기에 따라 집단의 균질성 또는 운집을 분석하였다. 대사초의 많은 자연 플롯은 산림군락에서 균질하지 않았다. 예를 들면 균질한 플롯은 6.0 m × 6.0 m 이내였다. 플롯의 크기가 6.0 m × 12.0 m 이상이면 운집되었다. 대사초의 이웃 패치는 평균 7.5 m에서 9.0 m사이였다. 그런데 자연집단이 인간의 활동에 의해 교란되면 운집은 9.0 m보다 짧은 거리에서 일어났다. 결론적으로 대사초의 지리적 분포는 플롯의 밀도에 균질하지 않았고 금정산과 아홉산 집단에서 집단 크기에 따라 다르며 인간의 간섭은 플롯에서 밀도 효과를 일으킨다.