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SPATIAL DISTRIBUTION PATTERN OF THE POPULATIONS OF *OPLISMENUS UNDULATIFOLIUS* VAR. *UNDULATIFOLIUS* AT MT. AHOP

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ABSTRACT

Oplismenus undulatifolius var. *undulatifolius* is a shallow rooted perennial with stolons. Spatial distribution of this species was studied in an established 16 m x 32 m plot at Mountain Ahop in Korea during 2015. The spatial pattern of *O. undulatifolius* var. *undulatifolius* was analyzed according to several patchiness indexes, population uniformity or aggregation under different sizes of plots by dispersion indices, and spatial autocorrelation. Most natural plots of *O. undulatifolius* var. *undulatifolius* were not uniformly distributed in the forest community. The small and middle plots (2 m x 2 m, to 16 m x 16 m) of *O. undulatifolius var. undulatifolius* were uniformly distributed in the forest community and one large plot (16 m x 32 m) was aggregately distributed. Significant aggregation by Moran's *I* of *O. undulatifolius* var. *undulatifolius* was partially observed within IV classes (8 m). Significant dissimilarity among pairs of individuals could found by more than 16.0 m. In conclusion, the geographic distribution of *O. undulatifolius* var. *undulatifolius* is not even with varying degrees of size of plots and human activities give rise to density effects in the plots at Mt. Ahop in Korea.

Keywords: *Oplismenus undulatifolius* var. *undulatifolius,* spatial distribution, patchiness indexes, Moran's *I*.

INTRODUCTION

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 (Elith and Burgman, 2002; Scott et al., 2002). Analysis of the spatial distribution pattern of a plant population is helpful to determine the population's ecological preferences, biological characteristics and relationships with environmental factors (Zhang *et al*., 2012). Therefore, the analysis of the spatial distribution pattern of plant populations has always been a major focus for ecological research (Haase, 1995; Baskent and Keles, 2005). 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. Individuals of a population can be distributed in one of three basic patterns; uniform, random, or clumped (aggregation). In a uniform distribution, individuals are equally spaced apart, as seen in negative allelopathy where chemicals kill off plants surrounding sages. In a random distribution, individuals are spaced at unpredictable distance from each other, as seen among plants that have wind-dispersed seeds. In a clumped distribution, individuals are grouped together, as seen elephants at a watering hole. The spatial distribution pattern of plant populations exhibits scale dependence, e.g. a species may show an aggregated distribution at one spatial scale and may change to a random or uniform distribution at a different scale.

Aggregated patterns of plants are often observed as spatial structures in a local population especially in a patchy habitat, and these are scale-dependent (Suzuki et al., 2005). The primary focus is on spatial pattern from two perspectives. One is to determine what spatial pattern a population shows in the field. The spatial pattern of a population has consequences for the estimation of abundance and the construction of confidence intervals for these estimates. The other is the methods include the use of statistics (e.g., Moran's *I*) to measure spatial autocorrelation (Sokal and Oden, 1978a). It measures the extent 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.

Oplismenus undulatifolius (Ard.) P. Beauv. var. *undulatifolius* is a shallow rooted perennial with stolons and a member of the genus *Oplismenus* in the family Poaceae. *O. undulatifolius* var. *undulatifolius* is species of perennial grass from the Poaceae family that is native to South Asia, East Asia, Southeast Asia, Australia, and Southern Africa. It can be found in countries such as Pakistan (Punjab & Kashmir), China, Japan, Korea, India, Australia, South Africa, Madagascar. *Oplismenus undulatifolius* may grow to several feet in length. The leaves of overwintering plants become brown and dead, but in the spring, new growth begins at the upper nodes of the stolons. Methods that are commonly used to describe dispersion of *O. undulatifolius* var. *undulatifolius* populations are no reported similar researches.

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 *O. undulatifolius* var. *undulatifolius* in Mt. Ahop locate in south of the Korean. A sample of a large (more than 300 individuals) natural population of *O. undulatifolius* var. *undulatifolius* collected at mountain and was used in this study. It is expected to provide useful experimental conditions because of the large undisturbed and isolated site.

METHODOLOGY
Study area

The present study was carried out in two adjacent areas of forest and farming ecosystems in Kijang village under Busan district, Korea which lies at *35°16′* North latitude and *129°11′* (E) longitude. The forest site comprised of rich vegetation which had not been disturbed for more than thirty-five years while the farming-land had almost no vegetation due to frequent human activities and interference. 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

Many quadrats at Mt. Ahop were randomly chosen for each combination of site x habitat, so that, overall, 55 quadrats were sampled for the complete experiment. 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 randomly located quadrates in each plot which I established populations. The quadrat sizes were 2 m x 2 m, 2 m x 4 m, 4 m x 4 m, 4 m x 8 m, 8 m x 8 m, 8 m x 16 m, 16 m x 16 m, and 16 m x 32 m. I mapped all plants to estimate *O. undulatifolius* var. *undulatifolius* density per plot.

Index calculation and data analysis

The spatial pattern of *O. undulatifolius* var. *undulatifolius* was analyzed according to the Neatest Neighbor Rule (Clark and Evans, 1954; Lian et al., 2012) with Microsoft Excel 2014.

The distance from an individual to its nearest neighbor, irrespective of direction, provides the basis for this measuring of spacing (Clark and Evans, 1954). The mean observed distance (r_A) was calculated as follows:

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

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 (Clark and Evans, 1954).

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

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

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%.

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) (Lloyd, 1967) and Morisita index (*IM*) were calculated with Microsoft Excel 2014. 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 (Arbous and Kerrich, 1951).

$$\delta = mr/2k$$

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* (Green, 1966).

Spatial structure

When a plant population or community is sampled, the samples have a spatial relationship with each other. To a certain extent, samples that are close to each other are more likely to be similar. 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 2.0 m distance classes by means of Moran's *I*, and a significant population structure was revealed beyond 2.0 m. Thus, the distance classes are 0-2.0 m (class I), 2.0-4.0 m (class II), 4.0-6.0 m (class III), 6.0-8.0 m (class IV), 8.0-10.0 m (class V), 10.0-12.0 m (class VI), 12.0-14.0 m (class VII), 14.0-16.0 m (class VIII), 16.0-18.0 m (class IX), and 18.0-20.0 m (class IX). The spatial structure was quantified by Moran's *I*, a coefficient of spatial autocorrelation (SA) (Sokal and Oden, 1978a). 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 (Sokal and Oden, 1978b). 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:

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

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 $\{\sum i\sum j(i \neq j)Wij\}$ 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 example, in Sokal and Oden (Sokal and Oden, 1978a). 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 (Cliff and Ord, 1971). 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) at Mt. Ahop varied from 0.469 to 8.500, with a mean of 2.770 (Table 1). 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 plots (2 m x 2 m, 2 m x 4 m, 4 m x 4 m, 4 m x 8 m, 8 m x 8 m, 8 m x 16 m, and 16 m x 16 m) of *O. undulatifolius* var. *undulatifolius* were uniformly distributed in the forest community (Table 1). However, *O. undulatifolius* var. *undulatifolius* was aggregately distributed in one large plot (16 m x 32 m). The most individuals of *O. undulatifolius* var. *undulatifolius* were clustered and the distribution pattern of the *O. undulatifolius* var. *undulatifolius* was quadrat-sampling dependent.

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

Quadrat size (m x m)	Density	*R*	C_R	Distribution pattern
2 x 2	8.500	3.855	22.527***	Uniform
2 x 4	3.750	3.033	21.303***	Uniform
4 x 4	2.938	2.236	16.216***	Uniform
4 x 8	2.531	1.706	12.155***	Uniform
8 x 8	1.813	1.713	14.702***	Uniform
8 x 16	1.297	1.889	21.916***	Uniform
16 x 16	0.863	1.746	21.227***	Uniform
16 x 32	0.469	0.988	0.344	Aggregation

***: p < 0.001.

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

Quadrat size (m x m)	No. Quadrat	Aggregation indices						
		C	*CI*	*M**	*PAI*	*PI*	*Ca*	*IM*
2 x 2	15	0.207	-0.793	-0.132	-0.200	-0.834	-1.200	-0.219
2 x 4	12	0.555	-0.445	0.338	0.432	-1.761	-0.568	0.452
4 x 4	10	0.658	-0.343	0.310	0.475	-1.905	-0.525	0.491
4 x 8	7	0.720	-0.280	0.322	0.535	-2.151	-0.465	0.540
8 x 8	5	0.723	-0.287	0.349	0.549	-2.216	-0.451	0.556
8 x 16	3	1.018	0.018	0.847	1.022	46.143	0.022	1.029
16 x 16	2	1.031	0.031	1.034	1.031	32.071	0.031	1.036
16 x 32	1	0.769	-0.232	0.476	0.673	-3.057	-0.327	0.677

Table 3. Spatial autocorrelation coefficients (Moran's *I*) among populations of *Oplismenus undulatifolius* var. *undulatifolius* for ten distance classes

I	II	III	IV	V	VI	VII	VIII	IX	X
0.632***	0.375***	0.349**	0.277**	0.099	-0.081	-0.159	-0.239*	-0.210*	-0.148

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

The degree of population aggregation

The values dispersion index (C) were lower than 1 except three large plots (8 m x 16 m, and 16 m x 16 m) (Table 2). Thus aggregation indices (CI) were negative, which indicate a uniform distribution. The most mean crowding (*M**) and patchiness index (*PAI*) showed positive values. Only small plot (2 m x 2 m) was negative *M** and *PAI*. Three indices $C,\ M^{*},\ PAI$ were <1 and their values of *PI* and *Ca* except two 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* except two plots (8 m x 16 m and 16 m x 16 m) were also shown greater than zero, thus it means aggregately distributed.

Morisita index (*IM*) is related to the patchiness index (*PAI*) and showed an overly steep slope at the plot 8 m x 16 m in Mt. Ahop. Green index varied between -0.005 (2 m x 2 m) to 0.003 (16 m x 16 m) (Fig. 1). 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 0.599 (16 m x 32 m) to 3.452 (16 m x 32 m) (Fig. 2).

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 *O. undulatifolius* var. *undulatifolius* significantly differed from the expected value in only 6 of 10 cases (60%). Four of the significant values (40.0%) were positive, indicating similarity among individuals in the first 4 distance classes, i.e., pairs of individuals can separate by more than 8.0 m. Namely, significant aggregations were partially observed within IV classes. Four of these values (40.0%) were negative, indicating a partial dissimilarity among pairs of individuals in the 10 distance classes. As a matter of course, the significant negative SND values at classes VIII and IX. Thus, dissimilarity among pairs of individuals could found by more than 16.0 m.

The comparison of Moran’s *I* values to a logistic regression indicated that a highly significant percentage of individual dispersion in *O. undulatifolius* var. *undulatifolius* populations at Mt. Ahop could be explained by isolation by distance.

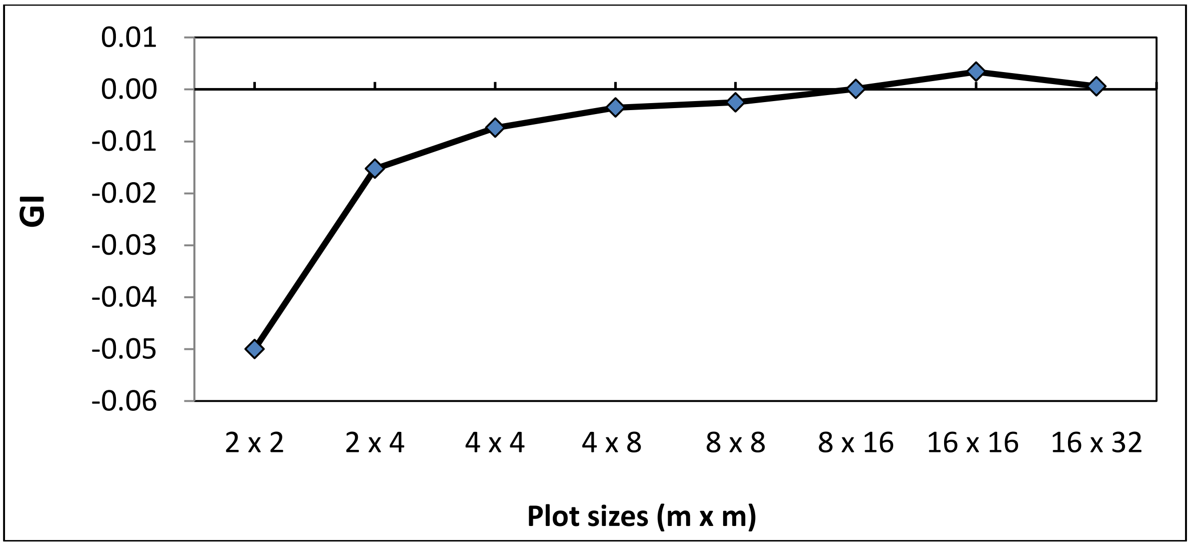

Fig. 1. The curves of patchiness in two areas of *Oplismenus undulatifolius* var. *undulatifolius* using values of Green index.

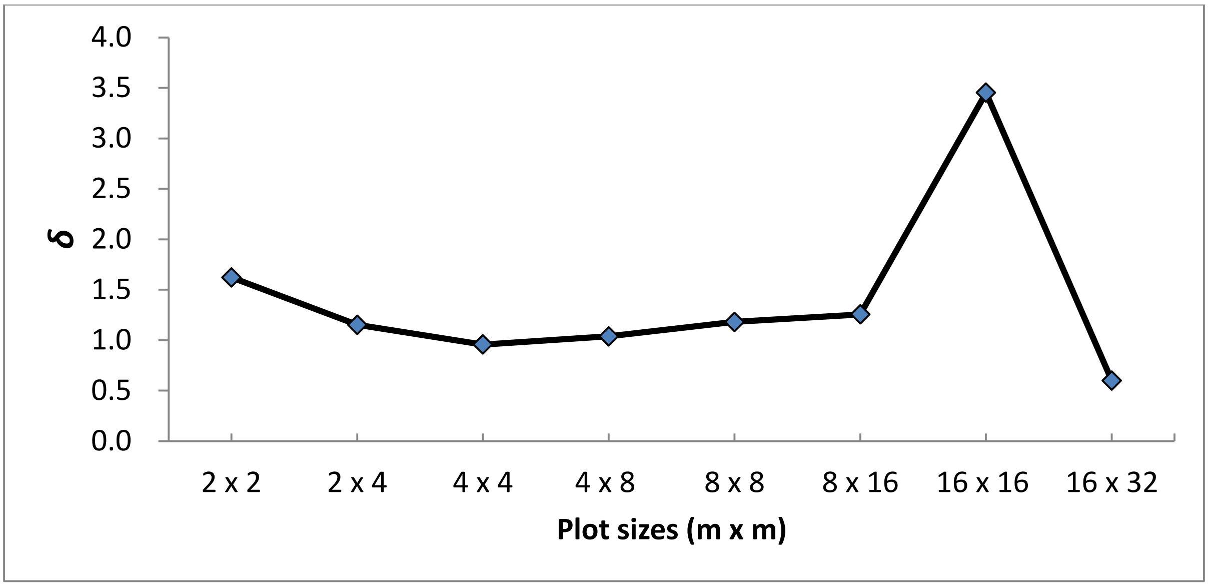

Fig. 2. The mean aggregation number to find the reason for the aggregation of *Oplismenus undulatifolius* var. *undulatifolius* in Busan.

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, individuals within from 2 m x 2 m to 16 m x 16 m distance plots of *O. undulatifolius* var. *undulatifolius* at Mt. Ahop are uniform distribution (Table 1). However, 16 m x 16 m distance plot was an aggregation distribution. In only 16 m x 16 m plot, 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 (Lian et al., 2012). Most plots except 16 m x 16 m plot had low δ < 2. When δ > 2, the aggregation was mainly caused by both species characteristics and environmental factors (Lian et al., 2012). Plant growth and distribution are limited by the environment. Limiting factors are also responsible for the geography of plant distribution. I recognized that the important environmental factors might be considered competition, growth rate, little decomposition, light, and below-ground resources. The characteristics of the *O. undulatifolius* var. *undulatifolius* concerned included primarily their life history, artificial disturbance, and population density. Essential plant nutrients that are needed for higher plants to complete all life functions, and that the deficiency can be corrected only by the application of the specific element causing the deficiency. 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 (Souza and Martins, 2004). Artificial disturbances are important environmental factors affecting *O. undulatifolius* var. *undulatifolius* such as constitutional roads at east area and farming at south area. At the plots which had fewer *O. undulatifolius* var. *undulatifolius*, the cluster was mainly determined by *O. undulatifolius* var. *undulatifolius* themselves. The Moran's *I* measures spatial autocorrelation based on both feature locations and feature values simultaneously. Given a set of features and an associated attribute, it evaluates whether the pattern expressed is clustered, dispersed, or random. A significant positive value of Moran's *I* indicated that pairs of individuals separated by distances that fell within distance class III had similar individuals, whereas a significant negative value indicated that they had dissimilar individuals (Table 3). The results revealed that patchiness similarity was shared among individuals within up to a scale of a 6.0 m distance. The results from this study are consistent with the supposition that a plant population is subdivided into local demes, or neighborhoods of related individuals

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(Ehrlich and Raven, 1969; Garnier et al., 2002). Clonal propagation was detected in many of plots and clonal ratio in each plot varied depending on the site environments. These results suggest that clonal propagation is popular in *O. undulatifolius* var. *undulatifolius* natural forest. Patterns of spatial structure without repeated clones showed significant positive autocorrelation ($P < 0.05$) over short distances (Brewer et al., 2012).

CONCLUSIONS

In conclusion, the present study demonstrates that a spatial structure of *O. undulatifolius* var. *undulatifolius* in the Mt. Ahop 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 16.0 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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