STUDIA GEOBOTANICA
5: 127-142, 1985

SPATIAL AUTOCORRELATION ANALYSIS: COMPUTER PROGRAM AND EXAMPLES OF APPLICATION WITH DIFFERENT DATA OF GRASSLAND VEGETATION UNDER A NATURAL REFORESTATION PROCESS IN THE KARST NEAR TRIESTE

Paola GANIS

Keywords: autocorrelation, gradient, grasslands, grids, hierarchy, Karst, pattern, transects, vegetation.

Abstract. A program in FORTRAN 77 for spatial pattern based on the methods of nearest-neighbor and autocorrelation is presented. It has been used with the option for autocorrelation to analyse the spatial pattern of 120 species and other variables as life-growth forms, chorological elements and classes of environmental variables, along transects from open grasslands to groups of trees (NR) in the Karst area near Trieste. The results proved that both the species and the other variables show significant pattern. Particularly a high degree of significance has been found for the variables of higher hierarchical meaning than species and especially for the classes of environmental variables. The number of entities with significant pattern increases in function of the lenght of the transect. The results prove that along the transect there is a composite ecological gradient which produces significant changes of vegetation pattern at different hierarchical levels, both structural and chorological.

Introduction

Spatial pattern analysis of vegetation has been made by using several method considering simultoneaously many species as was suggested by David (1971a), Pielou (1975), Juhasz Nagy (1976), Feoli et al. (1980), Juhasz-Nagy & Podani (1983) or analysing single species (Goodall, 1974; Greigh-Smith, 1979; Galiano, 1982; Ford & Renshaw, 1984). It looks that the methods of autocorrelation, widely known in Geography (Ebdon, 1977), have been rarely applied in plant ecology (e.g. David, 1971b). A program in FORTRAN 77 for spatial pattern analysis, based on the method of nearest neighbor and the method of autocorrelation, has been developed. The listings are presented in the Appendix. The aim of the present paper is to show how to compare, by the program, the spatial pattern of species, life-growth forms, chorological elements and classes of environmental variables, as defined by the ecological indicator values of Landolt (1977), along transects in grasslands under a natural reforestation process in the Karst region near Trieste.

The process in such region has been studied by different points of view by Lausi, Pignatti & Poldini (1967), Feoli & Feoli Chiapella (1979), Feoli et al. (1980), Feoli & Scimone (1982), Poldini & Favretto (1985).

The use of variables of higher hierarchical meaning than species may allow to investigate into vegetation patterns at more general level than that of species. Notwithstanding biology is "a very hierarchical science" (see Thornley, 1979; Allen & Starr, 1982) the discussion on the hierarchical processes for vegetation analysis started only recently by Feoli (1984), Feoli & Scimone (1985) and Orlóci et al. (1986). In such processes the species are considered only as carrier of the biological information useful to understand the relationships between chorology, structure and ecology of vegetation (see Feoli & Ganis, 1985).

Program PATTERN

The program PATTERN consists of a root program calling four subroutines (PIUVIC, CORBIN, CORVAL and CORPUN) each performing a different technique for the measurement of pattern. PIUVIC analyses the pattern by the nearest-neighbour technique, CORBIN calculates the spatial autocorrelation for binary data and CORVAL for ordinal and continuous data related to areas, finally CORPUN computes the spatial autocorrelation for ordinal and continuous data related to points. The programm PATTERN is written in Fortran 77 for a Cyber 170-730.

a) Nearest-neighbour analysis (subroutine PIUVIC)

This technique has been developed by plant ecologists (Clark and Evans, 1954). It consists in calculating for each point of a set of points the distance to its nearest-neighbour and then in calculating the mean of the distances. It matters to underline that the number of nearest-neighbour distances is always the same as the number of the considered points. It means that if two points are each one the nearest-neighbour for the other one, their distance must be add up twice in the sum of all the distances. The mean nearest-neighbour distance is the observed index (D obs) that is compared with the expected mean nearest-neighbour distance for the different types of spatial arrangements of points.

For a random arrangement the theoretical mean nearest-neighbour distance (D ran) is given by the equation 1) calculated by Clark and Evans (1954) (symbolism follows Ebdon, 1981).

$$1) \quad D\,ran = \frac{1}{2\sqrt{p}}$$

where p is the density of points per unit area. We remember that the area calculated in the program is the one given by a rectangle which encloses all the points as closely as possible. The area is calculated in the same units as the distances between the points.

For a uniform pattern, where the greatest dispersion of the points is realized, the expected mean-nearest-neighbour distance (D dis) is given by the equation 2).

$$2) \quad D\,dis = \frac{1.07453}{\sqrt{p}}$$

Finally, in the third type of pattern (clustered) the points are as close as possible to the other points, and therefore superimposed. In this case the mean nearest-neighbour distance is zero. The random pattern type is considered to have intermediate values between the two extreme types: clustered and dispersed.

The nearest-neighbour index (R) is given by the following equation:

3) $R = D\ obs/D\ ran$

It can be seen that the index R is equal to 1.0, when the observed index is equal to the expected mean nearest-neighbour distance for a random arrangement of points; if the index R gets near the value zero, it indicates a clustered pattern and if it is getting near the value D dis/D ran it indicates a dispersed pattern.

It is possible to value how the pattern is significatly clustered or dispersed looking at the tables of critical values of nearest-neighbour index R (see Edbon 1976).

Another way to test the significance of results from nearest-neighbour analysis is to use the statistic test c given by equation 5) that is similar in form to Student' t and has a normal distribution. Also in this case, positive value of c indicate a dispersed pattern and negative values a clustered one.

The null hypothesis of random pattern can be rejected if the value c is greather or less then the appropriate critical value related to the chosen significance level deduced from the tables of critical values of a standard normal deviate.

4) $SE = \dfrac{0.26136}{\sqrt{n\ p}}$

5) $c = (D\ obs - D\ ran)/SE$

n = the number of the points.
SE = standard error of the mean nearest-neighbour distance.

The subroutine PIUVIC requires in input:
on tape 1 - a) the variable label
b) the numbers of the points and the number of the considered axes
c) for each point the cartesian co-ordinates relatives to two or more axes. The co-ordinates are given in free format, each point in a new row.

If the axes are more than two, the subroutine only computes for each point its nearest-neighbour distance. If the points are in a bi-dimensional surface, the subroutine completes the nearest-beighbour analysis calculating the index R and the test c too. Notwithstanding Clark & Evans (1979) extend the method to test C for more than 2 dimensions, the problems related to the definition of density suggest to use the Moran's I (CORPUN) for testing the pattern in n dimensional spaces.

b) Spatial autocorrelation

The spatial autocorrelation introduced by Cliff & Ord (1973, 1981) allows to measure the variation of a variable through space. In this analysis the basic idea is that if the values of a variable in adjacent areas are similar and if they are very dissimilar to those of distant areas then there is a high spatial autocorrelation and therefore a high heterogeneity.

Subroutine Corbin

This subroutine computes the spatial autocorrelation for binary data on areas. It is called to see if the spatial arrangement of areas with two different scores (a1, a2) is or not at random. In this case the observed index (I obs) is simply the number of joins between areas of different scores. This index is compared with the expected value for a random pattern. There are two forms of null hypothesis for the significance test. The former (free sampling) is applied only when the probability of the scores is known a priori; the latter (non-free sampling) is used when the probability is unknown.

For the first form the expected value (I exp) and the standard deviation (S) are given by 6) and 7), and, for the second form, the same values are given by 8) and 9).

6) $I\,exp = 2\,Jpq$

7) $S = \sqrt{[\,2\,J + \Sigma\,L\,(L-1)\,]\,p\,q - 4\,[\,J + \Sigma\,L\,(L-1)\,]\,p^2\,q^2}$

8) $I\,exp = \dfrac{2\,J\,a1\,a2}{n\,(n-1)}$

9) $$S = \sqrt{I\,exp + \frac{\Sigma\,L\,(L-1)\,a_1\,a_2}{n\,(n-1)} + \frac{4\,[\,J(J-1) - \Sigma\,L(L-1)\,a_1(a_1-1)\,a_2(a_2-1)}{n\,(n-1)\,(n-2)\,(n-3)} - I^2\,exp}$$

10) $z = (I\,obs - I\,exp)/S$

J = total number of joins in the study region
p = probability that an area will have the score a1
q = probability that an area will have the score a2 $(p + q = 1.0)$
a1 = the number of areas with a1
a2 = the numbers of areas with a 2
n = $a1 + a2$ = the total number of areas in the study region
L = the number of joins between an area and contiguous areas (L = 2J).

The statistic **z** is calculated by the equation 10) and is used as test. It follows a normal distribution, so as for the test c of the nearest-neighbour analysis, in order to test the sigificance, it needs to examinate the appropriate critical values of the tables of a standard normal deviate.

The areas must be labelled by different ordinal numbers. The subroutine CORBIN requires in input:

from tape 1 - a) for each join the numeric labels of the contiguous areas.
b) for each area, the number of joins between that area and all contiguous areas.
The inputs a) and b) are in free format.
c) the input format for the table of variables (enter by rows)
d) the output format for the variables. If missing the variables are not printed.

from tape 2 - the labels of the variables (up to 80 characters); if missing the subroutine numbers automatically the variables.

from tape 3 - for each variable its value inside each area.

from the keyboard - the numbers of the areas, the number of the joins, the option choosing the null hypothesis (1 = free-sampling, 2 = non-free sampling). If the null hypothesis of free sampling is selected, the a priori probability must be given in input.

Subroutine Corval

This subroutine calculates the spatial autocorrelation for ordinal or interval data on areas.

The observed index (I obs) has been proposed by Moran (1950). It is described in equation 11). Two forms of null hypothesis apply: the hypothesis of normality in which the observed values of the variables are drawn at random from a normally distributed population, and the hypothesis of randomization that does not consider any kind of distribution.

The equation for the expected value of index (I exp) is given by 12), and the ones for the standard deviation under the first and the second null hypothesis are presented in 13) and 14) respectively. In both cases the test z is the same as that used in the spatial autocorrelation for binary data (equation 10). It may be worth noting that negative values of the index indicate dispersion pattern, whereas positive value imply clustering.

11) $$I\,obs = \frac{n\,\Sigma_{(J)}\,(x_i - \bar{x})\,(x_j - \bar{x})}{J\,\Sigma\,(x - \bar{x})^2}$$

12) $$I\,exp = -\frac{1}{n-1}$$

13) $$S = \sqrt{\frac{n^2\,J + 3\,J^2 - n\,\Sigma\,L^2}{J^2\,(n^2 - 1)}}$$

14) $$S = \sqrt{\frac{n[J(n^2 + 3 - 3n) + 3J^2 - n\Sigma L^2 - k[J(n^2 - n) + 6J^2 - 2n\Sigma L^2]}{J^2 (n-1)(n-2)(n-3)}}$$

15) $$s = \sqrt{\frac{\Sigma (x - \bar{x})^2}{n}}$$

16) $$k = \frac{\Sigma (x - \bar{x})^4}{n s^4}$$

n = number of areas in the study region
J = number of joins
x = a ordinal or interval value for an area
$\bar{x}$ = the mean of all the values of the variable x
x_i and x_j = the values for two adjacent areas
L = number of areas to which an area is joined
k = kurtosis of the variable x.

The areas must be labelled by different ordinal numbers. The subroutine CORVAL requires in input:

from tape 1 - a) for each join the numeric labels of the adjacent areas.
b) for each area the number of joins between that area an all contiguous areas.
The inputs a) and b) are in free format.
c) the input format for the table of variables disposed in rows.
d) the output format for the variables; if missing the variables are not printed.

from tape 2 - the labels of the variables (up to 80 characters); if missing the subroutine numbers automatically the variables.

from tape 3 - for each variable its value inside each area.

from the keyboard - the numbers of areas, the numbers of joins, the option selecting the null hypothesi (1 = normality, 2 = randomization).

Subroutine Corpun

This subroutine calculates the spatial autocorrelation for variables in ordinal or interval, ratio scales associated to points.

It calculates the observed index (I obs) as a revised version of Moran' s one (equation n. 17) based on the distances between the points. For n points there will be p = n (n − 1)/2 possible pairs of points. If such distances are not given from external tape (tape 4), they are computed within the program as was done by Feoli & Ganis (1986). The expected value of index (I exp) is the same of the previous analysis (equation 12). In equation 18) and 19) the standard deviation under the hypothesis of normality and randomization are respectivaly given. The test z (equation 10) is the same of the one already described for the spatial autocorrelation for binary data.

17) $$I\ obs = \frac{n\ \Sigma_{(p)}\ w_{ij}\ (x_i - \bar{x})\ (x_j - \bar{x})}{(\Sigma_{(p)}\ w_{ij})\ \Sigma\ (x - \bar{x})^2}$$

18) $$S = \sqrt{\frac{n^2\ A + 3\ B^2 - n\ C}{(n^2 - 1)\ B^2}}$$

19) $$S = \sqrt{\frac{n[(n^2 + 3 - 3\ n)\ A + 3\ B^2 - n\ C] - k\ [(n^2 - n)\ A + 6\ B^2 - 2\ n\ C]}{(n - 1)\ (n - 2)\ (n - 3)\ B^2}}$$

w_{ij} = the reciprocal of the distance between the point i and j. It is a weight assigned to the relationship between two points.

k = kurtosis of the variable x

x_i and x_j = the values for the points i and j

$\bar{x}$ = the mean of all the values of the variable x

$A = \Sigma_{(p)}\ w^2_{ij}$

$B = \Sigma_{(p)}\ w_{ij}$

$C = \Sigma_i\ (\Sigma_j\ w_{ij})^2$

The subroutine CORPUN requires in input:

from tape 1 - a) for each point the cartesian co-ordinates relatives to two or more axes. This input is given in free format, each point in a new row.
b) input format for the table variables disposed in rows.
c) output format for the variables; if missing the variables are not printed.
If the lower triangular distance matrix is read from tape 4, these inputs from tape 1 are missing.

from tape 2 - the labels of the variables (up to 80 characters); if missing the subroutine numbers automatically the variables.

from tape 3 - for each variable, the value in each point.

from tape 4 - a) the input format for the lower triangular distance matrix.
b) the lower triangular distance matrix computed outside this program. In this case the subroutine does not read the point co-ordinates.
c) input format for the table variables disposed in rows.
d) output format for the variables; if missing the variables are not printed.

from the keyboard - the number of the points, the number of the axes, the option selecting the null hypothesis (1 = normality; 2 = randomization), the option (= 1) indicating the distance matrix coming from tape 4.

Examples

a) Data

The relevés for pattern description have been performed by a grid of 1 square

NR

8				
				7
3	3		3	
			25	12
1				
	5		7	10
30	30	7	5	18
30	30	8	25	15
10	7	5		25

z=7.527

Fig. 1a — Example of a transect of 3 relevés each one consisting of a grid of 1 square metre subdivided in 25 quadrats. The first grid is the nearest the NR. For each quadrat the percentage of cover values of the single specie Stachys officinalis ssp. serotina are reported. For this arrangement the test z has a very significant value: 7.527.

NR

18				
			7	7
		15	12	
	7		8	
3	3		11	11
			5	3
		4		10
			8	12
	10		15	34
1	8			10
13	10	7	14	30
30	48	25	22	28
35	46	28	45	23
23	18	30	25	46

$z = 10.308$

Fig. 1 b — Example of the arrangement of the European chorological element in the same transect as in Fig. 1 a. Inside the grids, the value represent the cover sum of all the european species in each quadrat. One of them is the Stachy officinalis ssp. serotina, the single arrangement of which is given in Fig. 1 a. For this pattern the test z has a higher value: 10.308.

metre subdivided into 25 quadrats with side of 20 cm. This size has been used because 20x20 cm is approximately the maximal surface occupied by a plant of *Bromus erectus* Huds., or *Carex humilis* Leys. in the grasslands under study. For each quadrat the percentage of cover values of all the species have been considered. The relevés have been made along transects, 24 in total, starting from the centre of the grasslands and running to the groups of trees and shrubs called nuclei of reforestation (NR, Feoli e Feoli Chiapella, 1979). In total 120 species, included in 17 life-growth forms, 15 chorological elements and 48 classes of environmental variables have been considered. The lenght of the transects varies from 1 to 5 metres depending on the degree of closeness of the NR around the grasslands: short transects correspond to short distances between the NR, while long transects have been possible only in open grasslands. The last releve of the transect is always close to the trees of NR (such as *Ostrya carpinifolia* Scop., *Fraxinus ornus* L., *Quercus pubescens* Willd., *Quercus petrea* (Matt.) Liebl., *Prunus mahaleb* L., *Acer campestre* L., *Acer monspessulanum* L.) or to the shrubs of *Crataegus monogyna* Jacq., *Juniperus communis* L. and *Cotinus coggygria* Scop.. These often form a sort of belt around the NR.

b) Methods

The transects have been divided in 4 groups depending on their lenght: the first group has only a single relevé, the second two, the third three, the fourth four or five relevés.

The autocorrelation method has been applied for each transect and for each relevé by considering the single species (Figure 1a), the single life-growth forms, chorological elements (Figure 1b) and the classes of ecological variables defined by indicator values following Landolt (1977). Program FUSAF (Ganis, 1985) has been used to condense the values of the species into the other variables of higher hierarchical meaning. The analysis of spatial pattern has been done by program AUTOCOR. Among the methods was selected the one based on Moran's (1950) index (option CORVAL).

The method has been described and widely commented by Cliff and Ord (1973, 1981). The hypothesis of randomization has been chosen for the significance of the Moran's index: the test z is significant at 0.05 level, or more, when equal or greater 1.960.

c) Results

The analysis has shown that life-growth forms, chorological elements and classes of environmental variables have on the average a more significant spatial pattern than that of the species. In Table 1 some statistics of the observed entities (species and other categories) are reported for each group of transects. It can be seen that all the values increase with the increasing of the lenght of the transect. The relationship may be expressed by a function of the type $y = a(1 - \exp{-bx})$, however also a linear function fits efficiently the relationship, at least within the lenght of 5 metres. The increment is higher for ecological classes followed in order by

Species	I	II	III	IV
1	23.0	34.0	34.1	39.3
2	5.8	13.5	19.8	24.3
3	25.9	41.8	57.3	61.3
4	8.8	4.8	9.4	7.8
5	2.843	3.780	4.658	5.299
Growth forms				
1	6.3	8.0	9.0	9.0
2	1.7	4.3	5.6	6.0
3	26.8	55.5	63.2	66.9
4	14.6	21.9	17.7	10.1
5	2.550	4.017	4.478	5.861
Chorological elements				
1	9.4	10.0	10.3	9.3
2	3.0	5.3	7.8	7.7
3	31.9	51.7	74.9	82.2
4	15.1	13.6	15.2	5.9
5	2.676	3.881	4.867	5.835
Classes of species on the basis of the ecological indicators values				
1	25.4	26.3	27.2	27.7
2	7.6	14.3	23.1	26.3
3	30.0	54.7	84.9	95.2
4	11.1	16.1	8.6	2.0
5	3.138	4.086	5.077	6.421

Tab. 1 — Relevant parameters for each considered entity (species or category of species) and for each of the 4 groups of transects (I, II, III, IV). The rows indicate: 1) the mean number of observed entities; 2) the mean number of entities with significant pattern; 3) the mean percentage of entities with significant pattern; 4) the standard deviation of 3); 5) the mean of significative values of z.

1) $y = 15.40\ x + 6.46$	3) $y = 20.74\ x + 6.60$
2) $y = 17.20\ x + 8.44$	4) $y = 24.53\ x + 3.90$

Tab. 2 — Equations of the regression lines for the percentages of the variables with significant pattern in function of the lenght of the transects.

chorological elements, life-growth forms and species. Table 2 presents the equations of the regression lines for the precentages of significant variables in function of the lenght of the transects. The slopes of the regression lines are significantly different at better than 5% for species and classes of environmental variables and for life-growth forms and again the classes of environmental variables.

The autocorrelation analysis applied for single releves has given similar results as the short transects of the first group: on the average, only few entities have proved a significant pattern.

This means that the effects of the compositional gradient along the transects are better detectable if at least the lenght of two metres of grassland are considered.

The fact that the variables of higher hierarchical meaning have shown more significant patterns than species, suggests that the randomness associated with the dispersion of the species on the ground is higher than that associated with the other variables.

This can be explained by the "rarity" of the great part of them; among the 120 species only about 25-30% may be considered abundant species. In other words, the idea that the spatial pattern is a matter of a phenomenon at higher hierarchical levels than species should be supported and furtherly investigated.

Also in this study the chorological elements resulted more sensitive with respect to environmental changes than the life-growth forms (see Feoli & Ganis, 1986). This fact suggests that, in studying the problem of coexistance of plant species (see Shmida & Ellner, 1984) the chorology should also be considered because carrier of those historical information which can contribute to explain the presence of a set of species in a given site.

EXAMPLE OF INPUT FOR SUBROUTINE PIUVIC

From Tape 1

A)	Prima variabile
B)	8,2
C)	1,7
	1,8
	2,9
	4,9
	6,8
	3,7
	5,9
	8,8
A)	SECONDA VARIABILE
B)	5,4
C)	3, 7, 9, 10
	5, 1, 7, 4
	0, 3, 6, 8
	5, 5, 1, 8
	6, 6, 3, 4

EXAMPLE OF INPUT FOR SUBROUTINE CORBIN OR CORVAL

	FROM TAPE 1	FROM TAPE 2	FROM TAPE 3
1)	1,2	BROMUS ERECTUS	90 90 80 95 80 00 00 00 00 00
	2, 3	CAREX HUMILIS	25 00 35 00 25 00 35 00 30 00
	3, 4	FESTUCA RUPICOLA	60 80 00 00 00 70 75 00 00 00
	4, 5		
	1, 6		
	2, 7		
	3,8		
	4, 9		
	5, 10		
	6, 7		
	7, 8		

8, 9
9, 10
1, 7
2, 6
2, 8
3, 7
3, 9
4, 8
4, 10
5, 9

B) 3, 5, 5, 5, 3, 3, 5, 5, 5, 3

C) (10F3.0)

D) ((10X, 5F4.0)/)

EXAMPLE OF INPUT FOR SUBROUTINE CORPUN

	FROM TAPE 1	FROM TAPE 2	FROM TAPE 3
A)	1, 7	BROMUS ERECTUS	90 90 80 10 10 10 15 20
	1, 8	CAREX HUMILIS	25 90 90 90 25 60 60 60
	2, 9	FESTUCA RUPICOLA	45 35 25 60 35 45 50 55
	4, 9		
	6, 8		
	3, 7		
	5, 9		
	8, 8		
B)	(8F3.0)		
C)	(10X, 8F4.0)		

EXAMPLES OF OUTPUTS

ANALISI DEL VICINO PIÙ PROSSIMO

LIVELLI DI SIGNIFICATIVITÀ		0.1	0.05	0.01	0.005	0.001
TEST A UNA CODA	Z =	1.282	1.645	2.326	2.576	3.090
TEST A DUE CODE	Z =	1.645	1.960	2.576	2.813	3.291

1 PRIMA VARIABILE
N. PUNTI = 8 N. ASSI = 2

PUNTO	PUNTO PIÙ PROSSIMO	DISTANZA
1	2	1.0000
2	1	1.0000
3	2	1.4142
4	7	1.0000
5	7	1.4142
6	1	2.0000
7	4	1.0000
8	5	2.0000

DISTANZA MEDIA OSSERVATA = 1.3536
DISTANZA ATTESA RANDOM = .6614
DISTANZA ATTESA DISPERSA = 1.4215
INDICE DEL VICINO PIÙ PROSSIMO R = 2.0464
TEST STATISTICO C = (D. OSS-D.RAN)/SE = 5.6619

2 SECONDA VARIABILE
N. PUNTI = 5 N. ASSI = 4

PUNTO	PUNTO PIÙ PROSSIMO	DISTANZA
1	3	6.1644
2	5	6.4807
3	1	6.1644
4	5	4.6904
5	4	4.6904

AUTOCORRELAZIONE SPAZIALE PER DATI BINARI SU AREE
N. AREE = 10 N. CONFINI = 21
IPOTESI NULLA NON VINCOLATA

LIVELLI DI SIGNIFICATIVITÀ		0.1	0.05	0.01	0.005	0.001
TEST A UNA CODA	Z =	1.282	1.645	2.326	2.576	3.090
TEST A DUE CODE	Z =	1.645	1.960	2.576	2.813	3.291

1 BROMUS ERECTUS
90. 90. 80. 95. 80.
0. 0. 0. 0. 0.

INDICE OSS.	INDICE ATT.	TEST Z
13.0000	11.6667	.7483

2 CAREX HUMILIS
25. 0. 35. 0. 25.
0. 35. 0. 30. 0.

INDICE OSS.	INDICE ATT.	TEST Z
13.0000	11.6667	.7483

3 FESTUCA RUPICOLA
60. 80. 0. 0. 0.
70. 75. 0. 0. 0.

INDICE OSS.	INDICE ATT.	TEST Z
4.0000	11.2000	−4.1451

AUTOCORRELAZIONE SPAZIALE PER DATI QUANTITATIVI SU AREE
N. AREE = 10 N. CONFINI = 21
IPOTESI NULLA DI RANDOMIZZAZIONE

LIVELLI DI SIGNIFICATIVITÀ		0.1	0.05	0.01	0.005	0.001
TEST A UNA CODA	Z =	1.282	1.645	2.326	2.576	3.090
TEST A DUE CODE	Z =	1.645	1.960	2.576	2.813	3.291

1 BROMUS ERECTUS
90. 90. 80. 95. 80.
5. 0. 5. 5. 0.
450.00 45.00 − .2388 − .1111 − .631

2 CAREX HUMILIS
25. 0. 35. 5. 25.
5. 35. 5. 30. 5.
SOMMA
MEDIA
INDICE OSS.
INDICE ATT.
TEST Z

SOMMA	MEDIA	INDICE OSS.	INDICE ATT.	TEST Z
170.00	17.00	− .2278	− .1111	− .582

3	FESTUCA RUPICOLA				
	60. 80. 5. 10. 5.				
	70. 75. 20. 10. 5.				
	SOMMA	MEDIA	INDICE OSS.	INDICE ATT.	TEST Z
	340.00	34.00	.5506	−.1111	3.310

AUTOCORRELAZIONE SPAZIALE PER DATI QUANTITATIVI PUNTIFORMI
N. PUNTI = 8 N. ASSI = 2
IPOTESI NULLA DI RANDOMIZZAZIONE

LIVELLI DI SIGNIFICATIVITÀ		0.1	0.05	0.01	0.005	0.001
TEST A UNA CODA	Z =	1.282	1.645	2.326	2.576	3.090
TEST A DUE CODE	Z =	1.645	1.960	2.576	2.813	3.291

1	BROMUS ERECTUS				
	90. 90. 80. 10. 10. 10. 15. 20				
	SOMMA	MEDIA	INDICE OSS.	INDICE ATT.	TEST Z
	325.00	40.63	.1740	−.1429	1.7573
2	CAREX HUMILIS				
	25. 90. 90. 90. 25. 60. 60. 60				
	SOMMA	MEDIA	INDICE OSS.	INDICE ATT.	TEST Z
	500.00	62.50	−.1812	−.1429	−.2157
3	FESTUCA RUPICOLA				
	45. 35. 25. 60. 35. 45. 50. 55				
	SOMMA	MEDIA	INDICE OSS.	INDICE ATT.	TEST Z
	350.00	43.75	−.0990	−.1429	.2489

Acknowledgements. The work has been supported by Italian CNR within the project "Structure and dynamics of forests". Thanks are due to prof. Enrico Feoli for reading and commenting the paper.

References

Allen T.F.H. & Starr T.B. (1982) - *Hierarchy. Perspectives for Ecological Complexity.* University of Chicago Press. Chicago and London.

Clark P.J. & Evans F.C. (1954) - *Distance to nearest neighbour as a measure of spatial relationship in populations.* Ecology 35: 445-453.

Clark P.J. & Evans F.C. (1979) - *Generalization of a nearest neighbor measure of dispersion for use in k dimensions.* Ecology 60: 316-317.

Cliff A.D. & Ord J.K. (1973) - *Spatial autocorrelation.* Pion, London.

Cliff A.D. & Ord J.K. (1981) - *Spatial processes.* Models and applications. Pion, London.

David F.N. (1971a) - *Measurement of diversity: multiple cell contents.* Proceedings of the Sixth Berkeley Symposium on Mathematical Statistics and Probability volume 4. University of California Press., Berkeley. 109-136.

David F.N. (1971b) - *Measurement of diversity.* Proceedings of the Sixth Berkeley Symposium on Mathematical Statistics and Probability volume 1. University of California Press, Berkeley. 631-648.

Ebdon D.S. (1976) - *On the underestimation inherent in the commonly-used formulae.* Area 8: 165-169.

Ebdon D. (1977) - *Statistics in Geography.* Basil Blackwell, Oxford.

Ellenberg H. and Mueller-Dombois D. (1965/66) - *A key to Raunkiaer plant life forms with revised subdivisions.* Ber. Geobot. Inst. ETH 37: 56-72.

Favretto D. & Poldini L. (1985) - *Extinction time of a sample of Karst pastures due to bush encroachment.* Ecological Modelling. (in press).

Feoli E. (1984) - *Some aspects of classification and ordination of vegetation data in perspective.* Studia Geobotanica 4: 7-21.

Feoli E. & Feoli Chiapella L. (1979) - *Changements of vegetation pattern towards reforestation.* VIII Colloque Phytosociologique International de Lille. Lille Septembre 1979.

Feoli E., Chiapella Feoli L., Ganis P. & Sorge A. (1980) - *Spatial pattern analysis of abandoned grasslands of the Karst region by Trieste and Gorizia.* Studia Geobotanica 1 (1): 213-221.

Feoli E. & Ganis P. (1985) - *Comparison of floristic vegetation types by multiway contingency tables.* An example of application of an integrated information system to some beech wood types of the Apennines. Abstracta Botanica 9: 1-15.

Feoli E. & Ganis P. (1986) - *Autocorrelation for measuring predictivity in community ecology. An example with structural and chorological data from mixed forest types of NE Italy.* Coenoses 1: 53-56.

Feoli E. & Scimone M. (1982) - *Gradient analysis in the spontaneous reforestation process of the Karst region.* Gortania. Atti Museo Friul. Storia Nat. 3: 143-162.

Feoli E. & Scimone M. (1984) - *Hierarchical diversity: an application to broad-leaved woods of the Apennines.* Giorn. Bot. Ital., 118: 1-15.

Ford D.E. & Renshow E. (1984) - *The interpretation of process from pattern using two-dimensional spectral analysis: modelling single species patterns in vegetation.* Vegetatio 56: 113-123.

Galiano E.F. (1982) - *Pattern detection in plant populations through the analysis of plant-to-all-plants distances.* Vegetatio 49: 39-43.

Ganis P. (1985) - *FUSAF.* Manuale per l'uso di programmi a integrazione della Banca Dati SBAFT. GEAD-EQ n. 2. Trieste. pp. 83.

Goodall D.W. (1974) - *A new method for the analysis of spatial pattern by random pairing of quadrats.* Vegetatio 29 (2): 135-146.

Greig-Smith P. (1979) - *Pattern in Vegetation.* J. Ecol. 67: 755-779.

Juhasz-Nagy P. (1976) - *Spatial dependence of plant populations.* Part I. Equivalence analysis (an outline for a new model). Acta Bot. Hung. 22 (1-2): 61-78.

Juhasz-Nagy P. & Podani J. (1983) - *Information theory methods for the study of spatial processes and succession.* Vegetatio 51: 129-140.

Landolt E. (1977) - *Okologische Zeigerwerte zur Schweizer Flora.* Ber. Geobot. Inst. ETH. 64: 64-207.

Lausi D., Pignatti S. & Poldini L. (1967) - *Statistiche uber die Wiederbewaldung auf dem Triester Karst.* Ber. Inst. Symp. Int. Ver. Vegetationskunde, Cramer, Vaduz.

Moran P.A.P. (1950) - *Notes on continuous stochastic phenomena.* Biometrika. 37: 17-23.

Pielou E.C. (1975) - *Ecological diversity.* Wiley, New York. pp. 165.

Pignatti S. (1982) - *Flora d'Italia.* Calderini. Bologna.

Shmida A. & Ellner S. (1984) - *Coexistence of plant with similar niches.* Vegetatio 58: 29-55.

Thornley J.H.M. (1979) - *Review of 'Life Cycles' by P. Calow. J. exp.* Bot. 30: 1285-1286.

Address of the Author:
Dipartimento di Biologia
dell'Università di Trieste
I - 34100 Trieste, via A. Valerio 30