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Anna GAZDA

Department of Forest Botany and Nature Conservation, Agricultural University
al. 29-Listopada 46, 31–425 Cracow, Poland, rlgazda@cyf-kr.edu.pl

THE DISTRIBUTION OF BLACKBERRY (*RUBUS HIRTUS* W. K.) IN DIFFERENT SCALES: THE FRACTAL ANALYSIS

ABSTRACT: The scale dependence of natural patterns provides an opportunity to apply fractal geometry to diverse problems in "spatial" ecology so as to integrate the spatial and temporal characteristics of complex environments. In this paper I attempt to explore the scaling dependency of in an autecological study on blackberry across a range of scales by applying fractal theory.

The fractal dimension of: the blackberry (*Rubus hirtus* W. K.) distribution within its geographical range is 1.44 $\pm$ 0.02; the pattern in the Gorce National Park (5908 ha) is 1.47 $\pm$ 0.05; the pattern for Łopuszna Valley (49°34'N, 20°08'E) (185.86 ha) is 1.30 $\pm$ 0.09 and 1.32 $\pm$ 0.05 for the Ratanica watershed (49°51'N, 20°02'E) (121.76 ha) (Fig. 1); the distribution of blackberry within the six plots located within the Ratanica watershed has values: 1.21 $\pm$ 0.09 to 1.45 $\pm$ 0.06.

On the gap plot, located within Ratanica watershade, created in 1987, year the fractal dimension of blackberry distribution increased from 1.21 $\pm$ 0.16 to 1.60 $\pm$ 0.04 during 5 successive years (Fig. 2). In the same region, on plot located under the dense forest, D of blackberry distribution has not changed and reached value 1.28 $\pm$ 0.05.

This study demonstrates that the distribution pattern is heavily influenced by scale. There are no possibilities to detect any breakpoint at scale intervals within the range of spatial scales studied, because the study of pattern was carried out on a noncontinuous scale (Fig. 4).

KEY WORDS: The fractal dimension, blackberry.

1. INTRODUCTION

A critical problem in ecology is to answer the following question: in which way do different processes and environmental conditions determine the distribution and abundance of species? There are three main approaches to the study of these problems. One is to focus on one or a few species in attempt to make it easier to observe the process or pattern of the objects of interest. Another way is to study ecological problems at large-scales, in an attempt to detect the interaction between different processes and patterns at a broad scale. The third way is to study natural patterns and phenomena at many different spatial scales, thereby combining the advantages and disadvantages of two previous approaches (Wiens 1989, Kolasa 1989).

Patterns of many natural systems differ in details at different scales (they change gradually and continuously as a function of scale) but remain statistically self-similar (Mandelbrot 1983). The fractal dimension D (Mandelbrot 1983) characterises the scale-dependency of the pattern. Mandelbrot (1983) defined a fractal as "a set for which the Hausdorff Besicovitch dimension strictly exceeds the topological dimension". In Euclidean geometry the dimension of any object is characterized by integer values. In the fractal theory the fractal dimension of an object is non-integer, and depends on object's complexity. The fractal geometry is focused on objects which are self-similar, it does mean that each portion can be considered as a reduced-scale image of the whole. Statistical self-similarity of patterns (constant D) occurs when processes at smaller scales are the same as at larger scales (fractal geometry assumes that the same pro- cesses repeatedly act from one scale to another scale as so-called "cascades"). A change in the fractal dimension of an object is an indication of the differentiation of processes occurring at various temporal and spatial scales because the dynamics of different systems follow different trajectories (Bradbury 1984, Gutierrez and Almirall 1989, Sugihara and May 1990).

It is well known that the distribution of organisms is patchy. The landscape thus contains a mosaic of niches. The composition of the niches is determined by the differential responses of species to the biotic and abiotic factors. The spatial distribution of organisms thus describes their strategies of space occupation. This patchiness or aggregated distribution in space is hierarchical (May 1989). To understand the dependence of nesting niches within space, we should examine the phenomena and theirs geometry. This scale dependence of natural patterns provides an opportunity to apply fractal geometry to diverse problems in "spatial ecology" so as to integrate the spatial and temporal characteristics of complex environments. As Palmer (1988) proposes, vegetation is a very good example of a fractal in nature because it "exhibits variation over a continuum of scale".

In this paper I attempt to explore and understand the scaling dependency of in an autecological study on blackberry (*Rubus hirtus* W. K.) across a range of scales by applying fractal theory. It is interesting to see the pattern of spatial distribution of this species from the small unit (the pattern of distribution of individuals (Rabotnov 1950) within a small plot) to the largest one (the geographical range) and test if it has the same pattern of scale-dependency at different scales (Fig. 1).

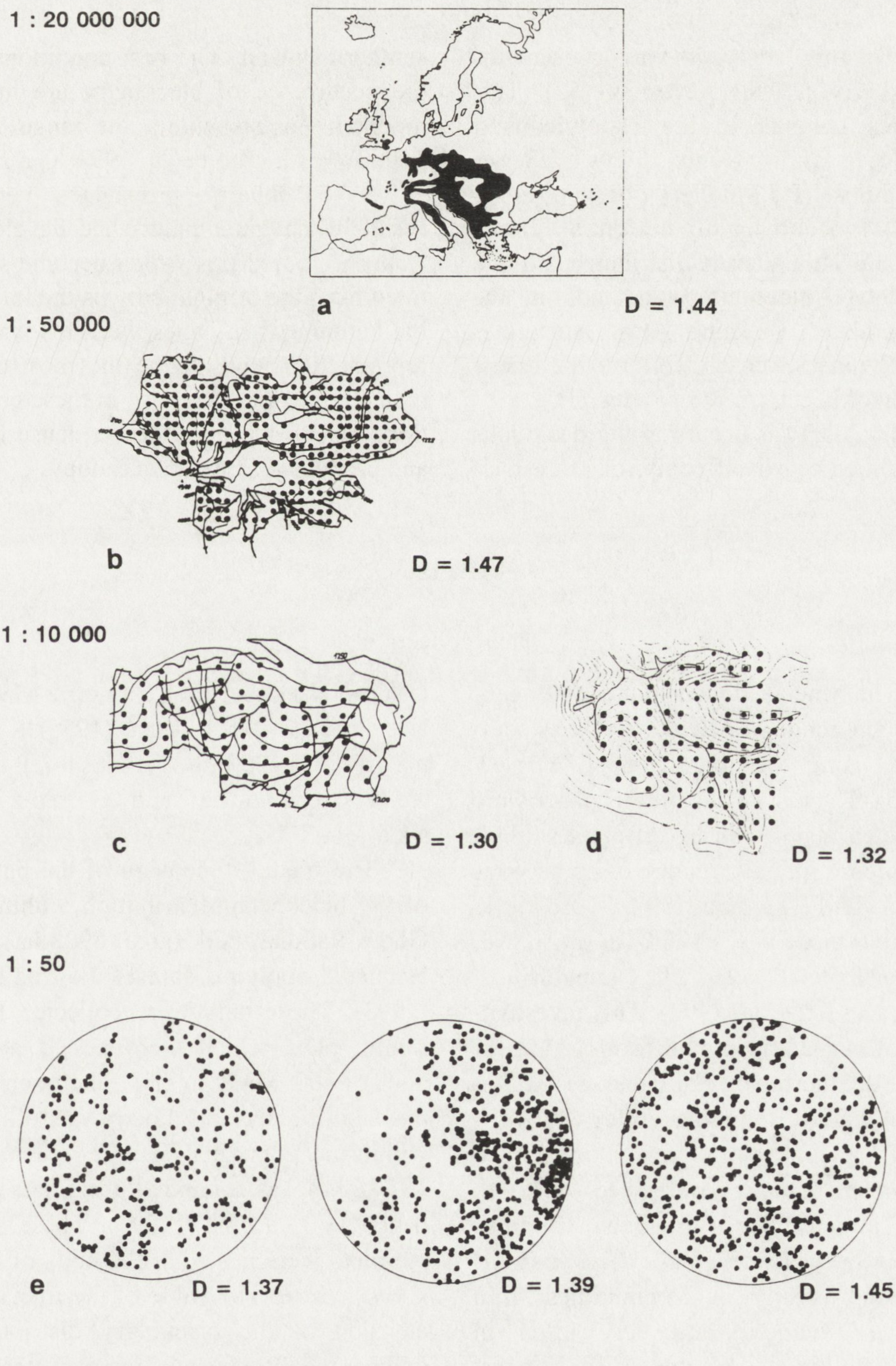

Fig. 1. The multiscale analysis of blackberry (*Rubus hirtus* W. K.)
a) the geographical range;
b) The Gorce National Park (area: 5908 ha);
c) The Reserve Area of Valley Łopuszna (area: 185.86 ha);
d) The Ratanica stream watershed (area: 121.76 ha);
e) the sample plots – the distribution of all crowns which occurred within these plots (area: 28.26 m^2).

2. THE SPECIES STUDIED

To this study it was chosen the blackberry (*Rubus hirtus* W. K.). This species belongs to the Dicotyledones, Rosaceae family, Genus *Rubus* L., Series Glandulosi (P.J.Mueller) (T u t i n *et al.* 1968). It occurs mainly in Central Europe (Fig. 1). This plant is distributed through the lower mountain woodlands in the Carpathians, Balkans, Alps, Apennines and Pyrenees, closely follows the distribution of beech (*Fagus silvatica* L.).

In Poland it occurs in the deciduous and mixed broadleaf-coniferous forests of southern Poland. The best conditions for the occurrence of blackberry are in the mountain forests within the range 900–1100 m a.s.l. (K o t e j a 1991, G a z d a 1992). Blackberry propagates vegetatively by daughter plants had developed from the rooted tips which become separated from the original crowns the following autumn when canes die. This way of reproduction tends to be the most commons in the open forest so in these conditions blackberry may form a dense layer and produce a continuous canopy.

3. METHODS

Data collection

The fractal dimension of the geographical range of *Rubus hirtus* was computed using the map from M e u s e l (1965). The rest of data to this paper were collected mainly during different studies, focused on spatial structure of herbaceous plants at all (G a z d a 1992, J ó z e f i a k 1993, P a n c e r - K o t e j a *et al.* 1998, Pancer-Koteja *et al.* unpublished, R ó ż a ń s k i *et al.* 1993). This investigation of blackberry growth was carried out in the southern part of Poland: in the Reserve Area of Łopuszna Valley (49°34'N, 20°08'E) within the Gorce National Park and in the Ratanica watershed (49°51'N, 20°02'E) (in The Carpathian foothill). Within the Łopuszna Valley *Rubus hirtus* is found mostly in communities from *Fagion silvaticae* and very often in *Abieti-Piceetum montanum* (G a z d a 1992). In Ratanica watershed blackberry occurs mainly in *Pino-Quercetum* (R ó ż a ń s k i *et al.* 1993).

The detailed description of the study areas were given by: A d a m c z y k (1966), H e s s (1965), J a r o s z (1935), M e d w e c k a - K o r n a ś (1955), K o r n a ś (1955, 1957), R ó ż a ń s k i, P a n c e r - K o t e j o w a and G r o d z i ń s k a (1987).

The fractal dimension of the pattern of the blackberry distribution within the Gorce National Park (area: 5908 ha) was estimated applying data of J ó z e f i a k (1993). These data were collected from sample-plots which were nested at the nods of 400 x 400 m grid. The fractal dimension of the blackberry distribution within the Łopuszna Reserve Area (area: 185.86 ha) was computed using data published by G a z d a (1992). These sample-plots were nested at the nods of 150 x 100 m grid. The value of the fractal dimension of the blackberry distribution within the Ratanica stream watershed (area: 121.76 ha) was estimated using data collected by R ó ż a ń s k i *et al.* (1993). These sample-plots were nested at the nods of 100 x 100 m grid. The value of the fractal dimension of both the distribution of blackberry crowns and an "individual"[1] within a plot (radius: 3 m, area: 28.26 m^2) within the Ratanica stream watershed was computed using data collected by Pancer-Koteja (unpublished).

To study changes of the fractal dimension value of the blackberries distribution within the same "space" during a few year there were chosen data which were collected in 1987–1991 and in 1994 within chosen two circle plots. The first one was located in the dense forest in the stable conditions; instead the second one in the forest gap. This gap had been created by the man one year before the beginning of this study.

Moreover it was computed the fractal dimension (D) of the distribution of blackberries crowns originated from the same "mother" crown. There were computed values D of the pattern of the biggest "individuals". These studies had lasted for five years within the same plots.

Methods of analysis

There are many ways of estimating the fractal dimensions of fractal objects (for a summary of methods see Sugihara and May (1990), Hastings and Sugihara (1993), Peitgen and Soupe (1988), Gazda (1996)). I decided to use the grid method to compute the fractal dimension of the spatial patterns of blackberry. The fractal dimension using the grid method is obtained by superimposing a series of squares of side (δ) over an object and then counting the number of grid cells that are occupied by any portion of the object (C(δ)). Next this procedure is repeated for finer δ then log (C(δ)) vs log (δ) is plotted and D is determined.

4. RESULTS

The fractal dimension of the blackberry spatial pattern within its geographical range (Fig. 1) is 1.44 ± 0.02. The fractal dimension of pattern of blackberry distribution within the Gorce National Park is 1.47 ± 0.07, within the Łopuszna Valley Reserve Area is 1.30 ± 0.09 and 1.32 ± 0.06 within the Ratanica stream watershed (Fig. 1). The fractal dimension of pattern of blackberry distribution of five plots located within the Ratanica stream watershed has following values: 1.21 ± 0.09, 1.28 ± 0.05, 1.37 ± 0.09, 1.39 ± 0.08, 1.45 ± 0.06 (Fig. 1).

The fractal dimension of the distribution of blackberry crowns has been changing from year to year for plot located in the forest gap: 1.21 ± 0.16 in 1988, 1.28 ± 0.16 in 1989, 1.39 ± 0.09 in 1990, 1.55 ± 0.06 in 1991, 1.60 ± 0.04 in 1992 (Fig. 2), whereas on the plot located in the dense forest it was unchangeable and reached value 1.28 ± 0.05.

[1] There have been applied only criterium of the origin from one common crown. These data were collected during the study on blackberry which lasted four years. It have not been studied if those area was covered by one individual in genetical meaning, at all.

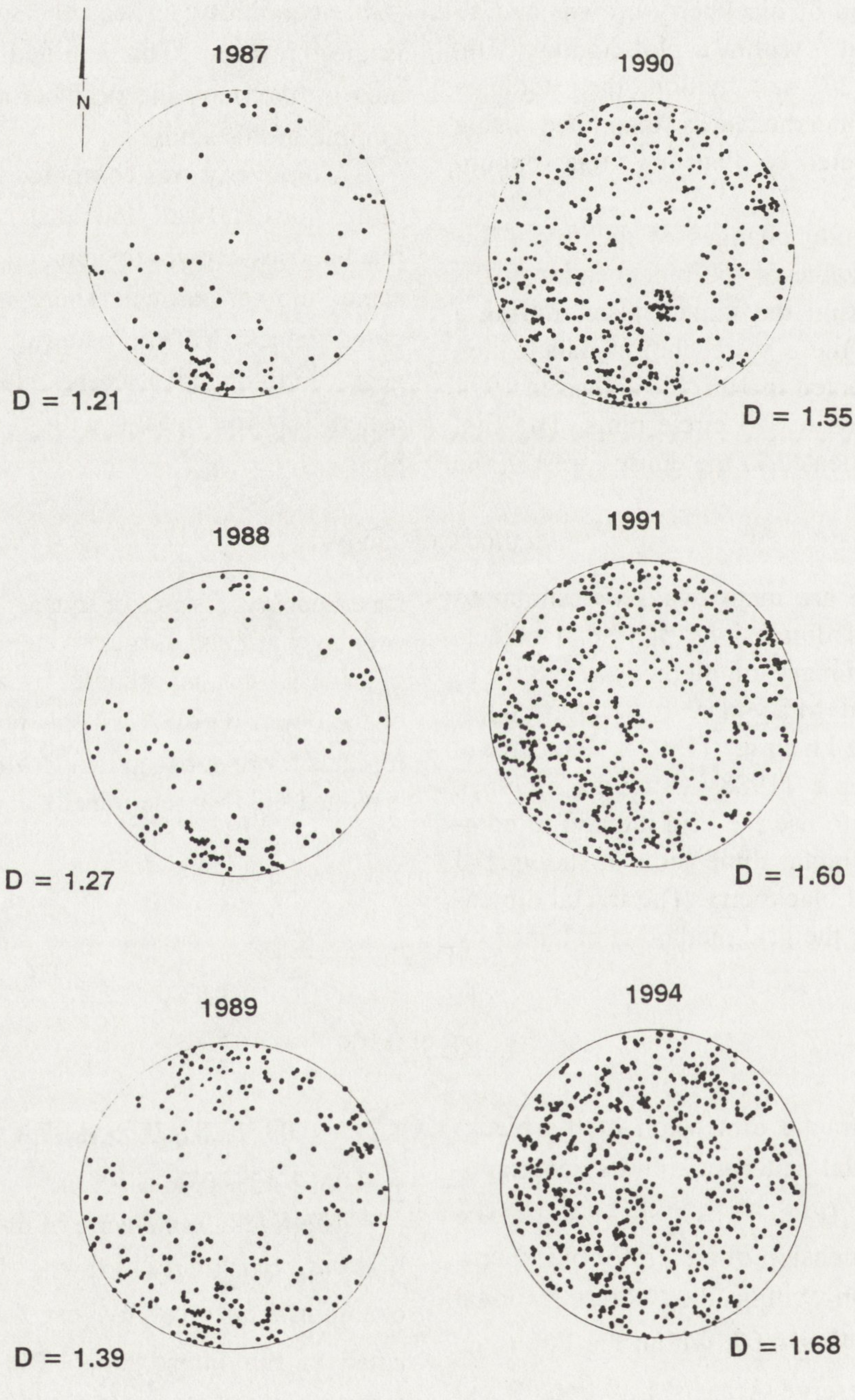

Fig. 2. The changes of blackberries distribution within the gap-plot located within the Ratanica watershed observed during five years

The fractal dimension of the six "individuals" has D values: 1.01 ± 0.06, 1.13 ± 0.16, 1.16 ± 0.10, 1.16 ± 0.18, 1.16 ± 0.14, 1.35 ± 0.06. It was noticed that the fractal dimension of the "giant individual" changed year by year. During first and second years it was impossible to estimate the fractal dimension of this structure because these "individuals" consisted of insufficient number of crowns to compute the fractal dimension. During next years values of D increased. For example the fractal dimension of the biggest "individual" has D values: 1.01 $\pm$ 0.02 in 1990, 1.10 $\pm$ 0.03 in 1991, 1.29 $\pm$ 0.06 in 1992 year (Fig. 3).

5. DISCUSSION

Studies on plant distribution are usually conducted at the level of populations, communities and ecosystems in relation to the different ranges of body size and levels, and are focussed on different questions in different types of environments. The scales chosen for the analysis of spatial pattern are inevitably arbitrary. They tend to reflect the hierarchies in spatial scales from the point of view of the researcher.

This paper is concerned with the study of the pattern of occupancy of blackberry in space. Its purpose is to evaluate the scale dependence (as the degree to which ecological phenomenon varies as a function of different components of the scale) of blackberry in either a temporal scale or a series of a few spatial scales. To compare values of the fractal dimension in different spatial scale see Fig. 4. It is easily noticeable that the fractal dimension tends to decrease (a decreasing value of D is caused by an increasing scale dependency) a little bit as we move from a smaller resolution to a larger one. It reflects the stronger influence on the spatial pattern by the environment (the abiotic components of landscape "composition" also vary with the scale at which the observation is made). It does mean that the data were collected within areas that are situated within the optimum range condition for blackberry. These results estimated using the fractal method are a very similar as

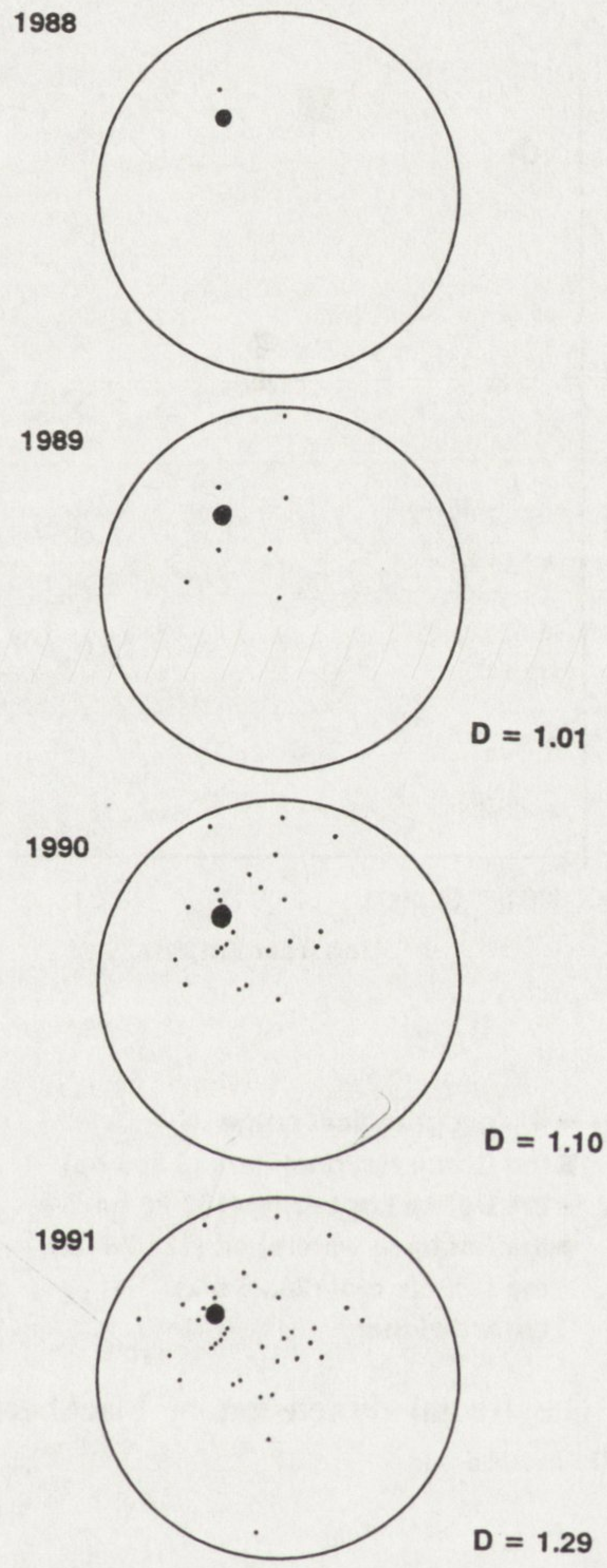

Fig. 3. The spatial structure of ramets (•), within the gap-plot from Ratanica watershade, origined from one common crown (●) and its changes during the time: 1988 – the second year of observation; 1989 – the third year of observation; 1990 – the fourth year of observation; 1991 – the fifth year of observation

Pancer-Koteja *et al.* (unpubl.) obtained using Ripley's K method to analyse the spatial pattern of blackberry crowns distribution within the same plot as described earlier in this paper. They stated that during four years at the beginning of their observation the patterns were clumped at distances of over 0.5 m, later on the patterns were random at all distances. They claimed that the cluster patterns in some blackberry population was caused by microsite mosaic. These two

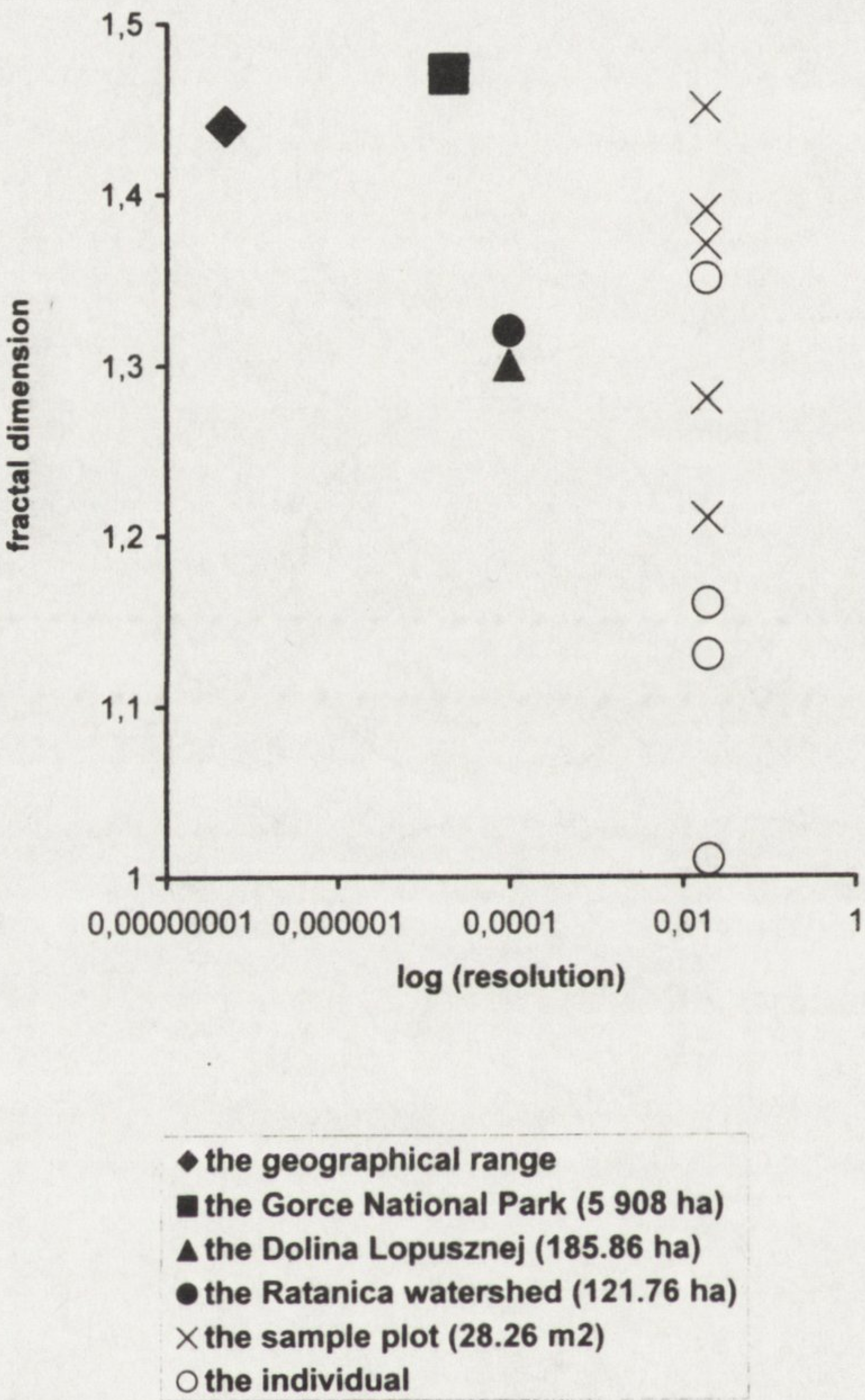

Fig. 4. The fractal dimension of blackberry at different scales

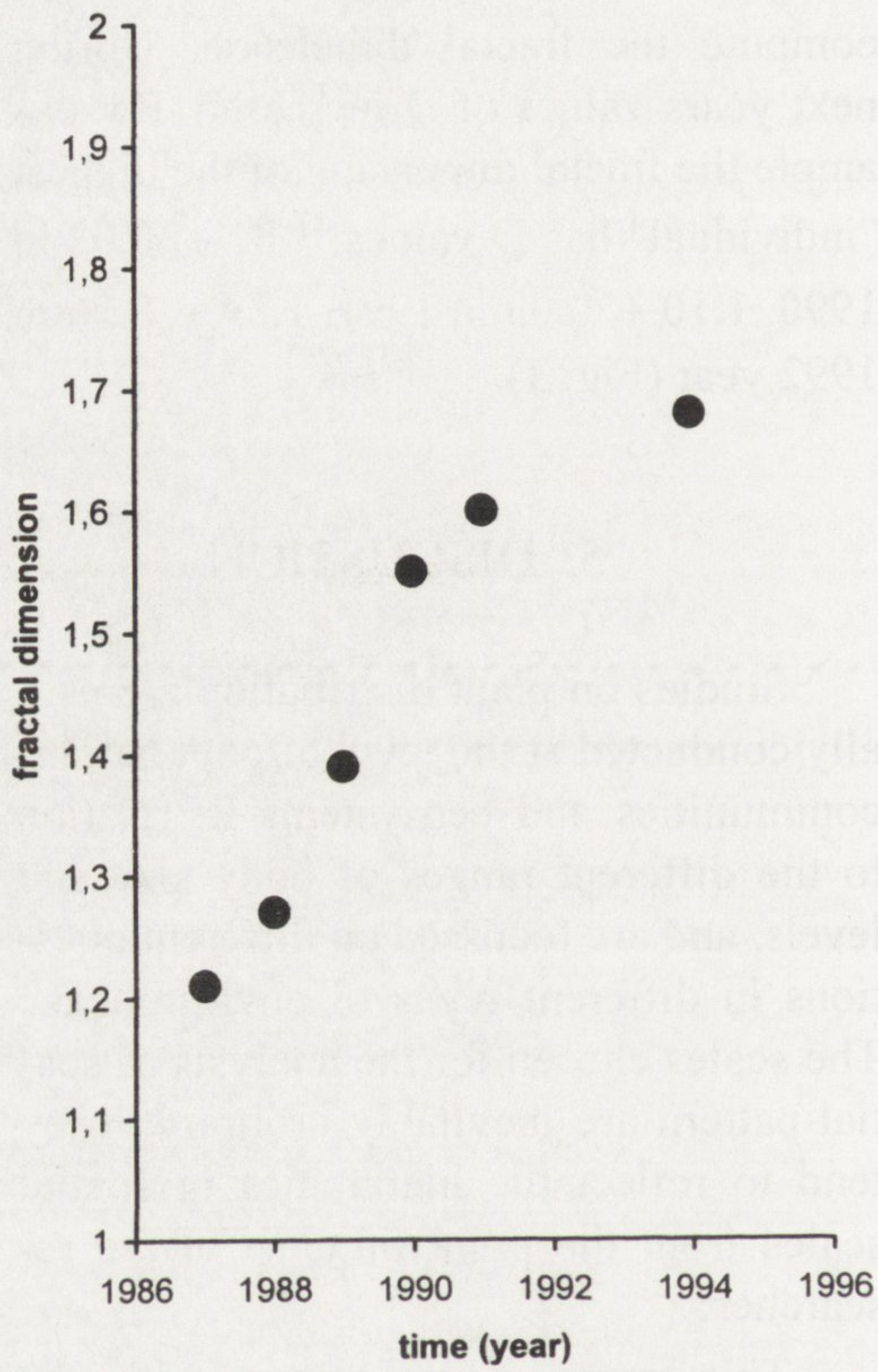

Fig. 5. The changes of the fractal dimension in the temporal scale of blackberry distribution within the sample plot

methods say us about the type of spatial pattern of distribution, both of them give us information about the spatial range of for example some aggregations, whereas the fractal method says us in number about the filling of this aggregate. Applying fractals we are allowed to compare in numbers the speed with which for instance one species of plant is able to fill space in given environmental condition.

There was examined space in terms of occupied and unoccupied patches and offer a qualitative picture of the overall population trends. Usually different processes are expressed by shape, in this example by the pattern of the distribution of this species. This is noticeable that the D value of the distribution of the blackberry crowns have changed from year to year (Fig. 5), within the plot located in the gap. At first the individuals (Rabotnov 1950) were stunned, but after cutting a few trees the light conditions and the fertility were changed. So the changes of D value describe the reaction of blackberry on the condition changes. It is worth to notice that on the control plot the fractal dimension is constant during the interval of this studies.

A very similar results were obtained for the pattern of the "individual" distribution. The value of the fractal dimension of the pattern of distribution of crowns which origined from one common crown has changed from year to year, within the plot situated in the gap. The reason is not only in environmental conditions but in the condition of individual (Rabotnov 1950), and the competition between species within herb layer.

There are no possibilities to detect any breakpoint at scale intervals (to detect changes of hierarchical levels) within the range of spatial scales studied, because the study of pattern was carried out on a noncontinuous scale.

My preliminary analysis of the spatial pattern of blackberry at four scales suggests two fruitful directions for future work. Further development of this research can be seen to lead in two directions: first, to study the spatial pattern of one's species across different scales on continuous scale to detect any breakpoint; the second one, to study and quantify the spatial pattern of another species with different ways of propagation in order to compare in numbers these differences.

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6. SUMMARY

In this paper I attempt to explore and understand the scaling dependency of in an autecological study across a range of scales by applying fractal theory.

The blackberry (*Rubus hirtus* W. K.) was chosen to this study. Blackberry propagates vegetatively by daughter plants had developed from the rooted tips which become separated from the original crowns the following autumn when canes die. This way of reproduction tends to be the most common in the open forest so in this conditions blackberry may form a dense layer and produce a continuous canopy.

The fractal dimension of the geographical range of *Rubus hirtus* was computed using the map from Meusel (1965) (Fig. 1). The fractal dimension of the pattern of blackberry distribution was estimated applying data collected from sample plots located within the Gorce National Park (area: 5908 ha) (Józefiak 1993), the Lopuszna Reserve Area (area: 185.86 ha) (49°34'N, 20°08'E) (Gazda 1992) and the Ratanica stream watershed (49°51'N, 20°02'E) (area: 121.76 ha) (Rózanski *et al*. 1987) (Fig.1). The value of the fractal dimension of both the distribution of blackberry crowns and of an "individual" within a plot (radius: 3 m, area: 28.26 m^2) within the Ratanica stream watershed was computed using data collected by Pancer-Koteja *et al*. (1998 and unpublished) (Fig. 2, 3).

The grid method was used to compute the fractal dimension of the spatial patterns of blackberry. The fractal dimension using the grid method is obtained by superimposing a series of squares of side (δ) over an object and then counting the number of grid cells that are occupied by any portion of the object (C(δ)). Next this procedure is repeated for finer δ then log (C(δ)) vs log (δ) is plotted and D is determined.

This paper is concerned with the study of the pattern of occupancy of blackberry in space. To compare values of the fractal dimension in different spatial scale see Fig. 4. It is easily noticeable that the fractal dimension tends to decrease (a decreasing value of D is caused by an increasing scale dependency) a little bit as we move from a smaller resolution to a larger one. It reflects the stronger influence on the spatial pattern by the environment.

The changes of the value of the fractal dimension of the distribution of the blackberry crowns within the plot located in the gap are illustrated in Fig. 5. At first the individuals (Rabotnov 1950) were stunned, but after cutting a few trees the light conditions and the fertility were changed. So the changes of D value describe the reaction of blackberry on the condition changes.

In this paper there were compared results estimated using the fractal method with results obtained using Ripley's K method by Pancer-Koteja *et al*. (1998 and unpubl.) too.

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