

FRACTAL ANALYSIS OF ENDEMIC PLANTS FROM ROMANIAN CARPATHIANS

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Abstract

Fractals are object with irregular geometric forms, autosimilare, with infinite details, observable at all scales of representation. Measuring the fractal contour irregularity is given by the fractal dimension (Df), and can be calculated by numerical methods and expressed as a specific rational fractional number.

From morphofractal analyses of the endemic species it results that they have similar morphological characteristics, expressed by similar fractal dimensions. Because the analysis is performed on different species it doesn't result similar fractal dimensions. We mention that even in the case of the same species there can appear different results between fractal parameters of the studied species the reason being the zoological criteria.

The research aimed to complete data in order to identify different species of endemic plants in the Romanian Carpathians.

Rezumat

Fractalii sunt cunoscuți ca obiecte cu trăsături geometrice neregulate, autosimilare, cu detalii infinite observabile la orice scară de reprezentare. Măsurarea gradului de neregularitate a conturului fractal este dată de dimensiunea fractală (Df), ce poate fi calculată prin metode numerice specifice și exprimată printr-un număr rațional fracțional.

Din analiza morfofractală a speciilor rezultă că acestea au trăsături morfologice asemănătoare, exprimate prin dimensiuni fractale apropiate. Datorită faptului că sunt analizate specii care aparțin la genuri diferite, acestea nu au dimensiuni fractale identice. Menționăm că și în cazul aceluiași gen apar diferențe între indicii fractali ai speciilor cercetate care pot fi datorate criteriului zoologic.

Cercetarea a avut drept scop completarea diagramelor diferitelor specii de plante endemice din Carpații României.

Keywords: fractal dimensions, fitofractal, box-counting, endemic plants, taxonomy.

Introduction

Endemic is a taxon whose distribution area is limited to a certain region.

The etymology of this concept has its origins in Greek language: “en” – in and “demic” – region, territory. In the same semantic category it is also framing the notion of endemism. The endemism is the appartenance

the phenomenon of certain taxa belonging to a specific geographical area. On the territory of the Romanian Carpathians there are distinguished six specio gene centers: Rodnei Mountains, Bistrița Mountains and Ceahlău Mountains, Bucegi Mountains and Bîrsiei Mountains, Retezat and Godeanu Mountains, Banat and Oltenia Carpathians, Apuseni Mountains.

Different authors, in comparative analysis of the nature of endemic vascular plants in Romania, appreciated that in the flora of our country there are 160 endemic species of which 95 are endemic Carpathian and of these only 61 species are well defined independent taxonomic and 34 are subspecies and varieties.

Superior endemic and subendemic plants of Romanian flora may be classified in three botanical classes: *Pinopsida* (*Coniferopsida*), *Magnoliopsida* (*Dicotyledonatae*) and *Liliopsida* (*Monocotyledonatae*).

So, reporting the number of endemic species to the total number of species, we noticed that they are 4.13%. Of these, only 2.45% are endemic plants in the Romanian Carpathians, and the rest of 1.68% is represented by endemic located outside the Carpathian space.

According to the area that it occupies, endemic grouping allowed the establishment of the following groups:

- endemic taxon whose area does not exceed Romanian space 57.37%;
- subendemic taxon whose area exceeds in a small part Romanian territory 42.63%;

The principles of classification were developed in the same time with the morphological studies, anatomy and embryology of plants, improving gradually, as these sciences have developed through their specific resources, more connections and relationships, proving the existence of new phylogenetic relationships between species.

Fractals are geometric features of known objects with irregular, autosimilare shapes. Technical analysis is an alternative modern fitofractal work leading to the characterization of species and determining their taxonomic position.

Fractal approach appeals to the facilities and resources of numerical processing, provided by modern computing systems.

One of the general characteristics of biological systems is their fractal nature.

Starting from the idea that the fractal theory applies to irregular shapes and the fractal dimension allows the degree of irregularity of an outline, the present paper proposes the utilization of fractal technology in botany systematic and taxonomy.

Materials and methods

In the present study it was used the herbarium collection of the Botanic Garden from Cluj- Napoca. So, there were taken images for each species (taxa) in conditions of high quality and accuracy. Each species photographed from the herbarium, was processed by scanning and analyzed with the “box-counting” algorithm to determine the morfofractal size. In other words, it was calculated the morfofractal code for each taxa in order to obtain the comparative study of endemic species from fractal point.

We mention that all species fractal analysed from the herbarium were in mature stage (flower - fruit) of development which represents the stage required by an international herbarium.

The taxa taken into study were:

I. Ranunculaceae Family: *Aquilegia transsilvanica* Schur; *Aconitum moldavicum* Hacq.; *Hepatica transsilvanica* Fuss ; *Ranunculus carpaticus* Herbich ;

II. Caryophyllaceae Family: *Cerastium transsilvanicum* Schur; *Dianthus callizonus* Schott et Kotschy; *Dianthus spiculifolius* Schur; *Dianthus henteri* Heuffel; *Dianthus tenuifolius* Schur; *Silene nivalis* Rohrb; *Silene dinarica* Sprengel;

III. Plumbaginaceae Family: *Armeria pocutica* Pawl. ;

IV. Saxifragaceae Family: *Saxifraga demissa* Schott et Kotschy; *Chrysosplenium alpinum* Schur;

V. Rosaceae Family: *Sorbus borbasii* Jáv. ; *Sorbus dacica* Borbás;

VI. Fabaceae Family: *Astragalus roemeri* Simonkai; *Oxytropis carpatica* Uechtr.;

VII. Apiaceae Family: *Heracleum carpaticum* Porcius;

VIII. Brassicaceae Family: *Cardaminopsis neglecta* Hayek; *Dentaria glandulosa* Waldst. et Kit.; *Draba dorneri* Heuffel ; *Hesperis nivea* Baumg. ; *Hesperis oblongifolia* Schur ; *Thlaspi dacicum* Heuffel ;

IX. Salicaceae Family: *Salix kitaibeliana* Willd. ;

X. Boraginaceae Family: *Symphytum cordatum* Waldst. et Kit. ;

XI. Lamiaceae Family: *Thymus comosus* Heuffel ex Griseb.; *Thymus bihoriensis* Jalas; *Thymus pulcherrimus* Schur;

XII. Scrophulariaceae Family: *Melampyrum saxosum* Baumg.; *Pedicularis baumgarteni* Simonkai ;

XIII. Campanulaceae Family: *Campanula carpatica* Jacq.; *Phyteuma wagneri* A.Kerner ;

XIV. Rubiaceae Family: *Galium baillonii* Brandza ;

XV. Asteraceae Family: *Achillea schurii* Schultz Bip.; *Centaurea melanocalathia* Borbás; *Centaurea pinnatifida* Schur; *Erigeron nanus* Schur; *Hieracium pojoritense* Woloszczak;

XVI. Poaceae Family: *Festuca carpatica* F.G.Dietr.; *Festuca porcii* Hackel ; *Festuca tatrae* Degen ; *Festuca bucegiensis* Markgraf- Dannenb.; *Festuca pachyphylla* Degen ex E.I.Nyárády ; *Poa rehmannii* Woloszczak ; *Sesleria heuflerana* Schur.

In 1996, the biologist Aristide Lindenmayer, introduced a new instrument of rewrite, based on the notion of L- system applied in biology.

We consider that the strings (words) consist of two letters “a” and “b”, which can occur several times in a string. Each letter is associated with a rewrite rule. Rule “a → ab” means that “a” will be replaced by the “ab” string, and rule “b → a” means that “b” will be replaced by “a”. The rewriting process starts from an initial string called the axiom. We suppose it consists of a single “b”. In the first derivation step (the first step of rewriting) the axiom “b” is replaced by “a” using the production “b → a”. In the second step “a” is replaced by “ab” using production “a → ab”. “Ab” word consists of two letters, both being simultaneously replaced in the next derivation step. So “a” is replaced by “ab”, “b” is replaced by “a”, and results the “aba” string. Similarly, “aba” string is replaced by “abaab” which will be replaced by “abaababa”, then “abaababaabaab”, and so on.

The development is described by the following L – system:

$$\begin{aligned} \omega &: a_r \\ p &: a_r \rightarrow a \ b_r \\ p &: a \rightarrow b \ a_r \\ p &: b_r \rightarrow a_r \\ p &: b \rightarrow a \end{aligned} \quad (1)$$

Starting from a single “a_r” cell (axiom), it is generated the following sequence of letters:

$$\begin{aligned} &a_r \\ &a \ b_r \\ &b \ a_r a_r \\ &a \ a \ b_r a \ b_r \\ &b \ a_r b \ a_r a_r b \ a_r a_r \end{aligned} \quad (2)$$

Around 1914, the German mathematician Felix Hausdorff introduced the coverage dimension as the proportional size with the minimum number of radius sphere necessary to cover the measured object.

So, to cover a curve of length “ l ” are required $N(s)=1/s$ cubes of side “ s ”. To cover a surface of area “ l ” are required $N(s)=1/s^2$ cubes of side “ s ” and finally to cover a cube of volume “ l ” are required $N(s)=1/s^3$ cubes of side “ s ”. The following relationship should be analysed:

$$N(s) \sim (1/s)^D \quad (3)$$

where:

$N(s)$ is the number of necessary cubes;

“ s ” is the side of a cube;

“ D ” is the object size.

Adding logarithm to the expression above we can deduct the approximate account relation for the fractal dimension, “ D ”.

$$D \approx \frac{\log(N(s))}{\log(1/s)} \quad (4)$$

Currently there are several methods for evaluating the fractal dimension. The method applied for the analysis of endemic plants is known as “box-counting” and has two major advantages: it is easy to implement for computer use and can be applied to any complex images.

“Box-counting” fractal dimension derive from the coverage dimension of Hausdorff. By covering the fractal object with cubes of side “ s ”, we are reaching the equation:

$$D \approx \frac{\log(N(s))}{\log(1/s)} \quad (5)$$

It is expected that, for a smaller “ s ”, the above approximation is correct:

$$D = \lim_{s \rightarrow 0} \left(\frac{\log(N(s))}{\log(1/s)} \right) \quad (6)$$

If this limit exists, it is named “box-counting” dimension of the measured object. Because in practice this limit has a slow convergence speed, it is used an approximate estimation.

Whereas the expression:

$$\log(N(s)) = D \log\left(\frac{1}{s}\right) \quad (7)$$

is the equation of a line of slope “ D ”, is drawing the curve “ $\log\text{-}\log$ ”, described by the coordinate points: $(\log(n(S)), \log(1/s))$ and by linear

regression (method of the smallest squares), is determining the slope curve, this being the requested fractal dimension, as follows:

$$Y = aX + b \quad (8)$$

$$a = D_f = \frac{n^2 \sum_{i=1..n} x_i y_i - \sum_{i=1..n} x_i \cdot \sum_{i=1..n} y_i}{n^2 \sum_{i=1..n} x_i^2 - \left(\sum_{i=1..n} x_i \right)^2} \quad (9)$$

$$b = \frac{\sum_{i=1..n} y_i - \sum_{i=1..n} x_i}{n} \quad (10)$$

where $x_i = \log(1/s)$ and $y_i = \log(N(s))$, for different values of scale factor “s”.

The minimum error estimated in this case is given by:

$$R = \frac{1}{n^2} \left[\sum_{i=1..n} y_i^2 + a \left(a \sum_{i=1..n} x_i^2 - 2 \sum_{i=1..n} x_i \cdot y_i + 2 \cdot b \cdot \sum_{i=1..n} x_i \right) + b \left(b \cdot n^2 - 2 \sum_{i=1..n} y_i \right) \right] \quad (11)$$

For more efficient results, for the curve “log-log” it will be calculated the slope from the straightest area. The maximum scale used for choosing the side “s” must be smaller than the object size and the minimum scale should be comparable with the finest detail scale (with minimum resolution) from the image.

Box-counting algorithm involves the fractal dimension, determination depending on the evaluation of the size of the object, relative to the assessment scale factor used. Sequential algorithm implies to cover the image with 4,16,64, etc. of equal squares by sides and counting each time the squares covering the contours of the object, their number being marked with $N(s)$.

Coordinating points ($\log(N(s))$, $\log(1/s)$) (where “s” is the side of the squares coverage and $N(s)$ is the number of coverage squares), will be placed on a curve. If the curve is almost a right, then its slope will be the box-counting fractal dimension.

The algorithm for determining the box-counting dimension for binary image contours is:

- reading the original image and then it will be processed by computer scanning until its binary form;
- extracting the outline by removing the interior points of the object;
- selecting the area of analysis;
- box-counting dimension is calculated, setting the “s” side of the square and counting each time the $N(s)$ squares which contain at least one point of the shape; the obtained values are logarithmic and

represented graphically by a straight line whose slope is the searched box-counting (fractal dimension).

Results and discussion

In this study there were taken 47 endemic taxa from the spontaneous flora of the Romanian Carpathians.

For each taxon it has been calculated the fractal index of the individual as a whole, and of the taxa represented by more individuals, it was determined also the mean fractal value of 11 species for which there were analyzed vegetative organs, determining the leaf's fractal index for 25 individuals. The technique has been applied in histological terms by analyzing different vegetative organs of 11 taxa.

For example we chose *Achillea schurii* Schultz Bip. species that belongs to *Asteraceae* family. After applying the box-counting algorithm for the whole plant it was obtained a fractal index $Df = 1.37$.

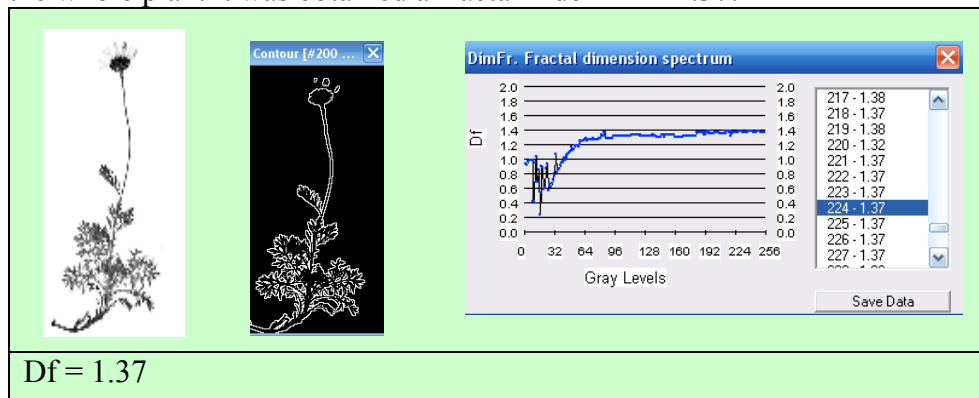


Figure 1

Achillea schurii Schultz Bip. morphofractal size calculation: on the left the general appearance of the plant, in the middle the contour of the plant for the gray threshold 200, on the right the spectrum of the morphofractal dimension, resulting the fractal index $Df = 1.37$.

The analyzed leaves were digitized, without changing the shape or size and they were subjected to the box-counting algorithm.

The scale of gray shades for which it was developed the outline of the leaf took to highlight, less or no ribs, emphasis being on itself contour, because it provides information about the edge of the leaf, and very important criteria in taxonomy and the classification of the species.

Because the fractal parameter of the same species is not identical when it is calculated for several individuals of the same species, we decided to calculate the fractal parameter for each individual and then to make the

average of the obtained parameters. In this way we obtain an average value that features to the respective kind, which we can call the medium fractal parameter.

For example we chosed to illustrate the species *Dianthus spiculifolius* Schur (Figure 2).



Figure 2
Dianthus spiculifolius Schur
Photo from herbarium;
Sheet with six individuals;
Harvested from Piatra Craiului Mountains;

After determining the fractal parameter for each examined individual we obtained a medium fractal parameter $Df = 1.26$, which we can consider as the reference value for the respective species (Table I, figures 3 and 4).

Table I
Calculation of medium fractal parameter for
Dianthus spiculifolius Schur.

No.	Individual Number	Fractal Parameter (Df)
1.	First Plant	1.33
2.	Second Plant	1.55
3.	Third Plant	1.03
4.	Fourth Plant	1.18
5.	Fifth Plant	1.08
6.	Sixth Plant	1.39
7.	Medium Fractal Parameter Df= 1.26	
8.	Standard size of the Plant 10-30 cm	

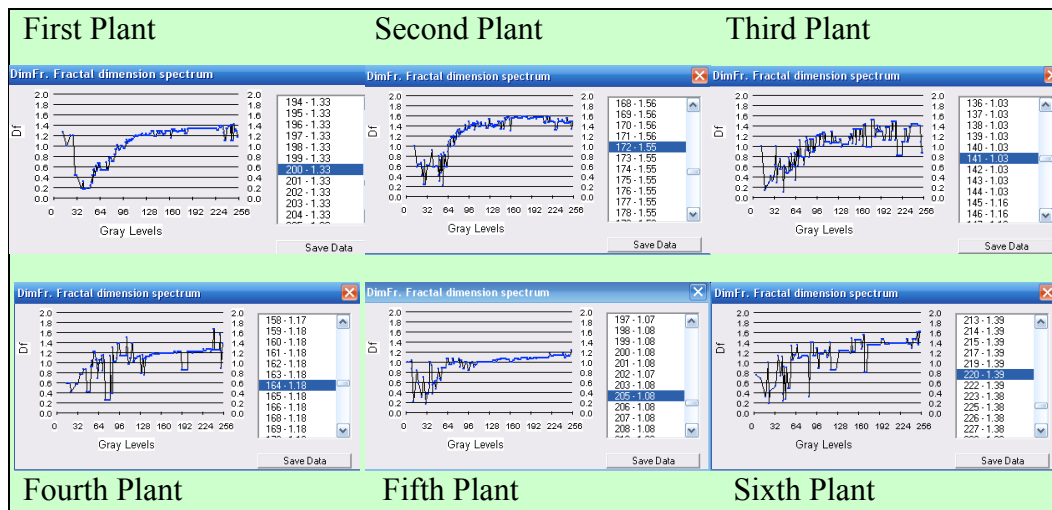
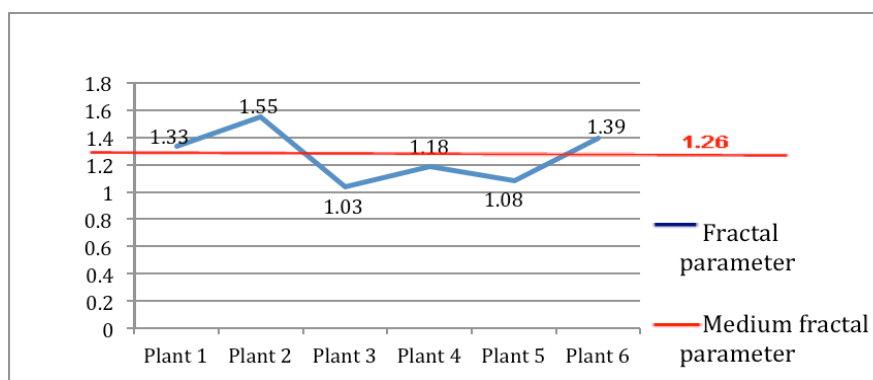


Figure 3
Fractal Parameters of analyzed individuals from
Dianthus spiculifolius Schur species.

**Figure 4**

Distribution of *Dianthus spiculifolius* individuals according to the fractal parameter

Researchers have studied 16 families of plants that have been fitofractal evaluated according to an algorithm for determining the fractal dimension through the contour processing (table II).

Table II

Df value for families that include species of endemic plants from the Romanian Carpathians

No.	Class	Family	Df value of the family
1.	<i>Magnoliopsida</i>	<i>Ranunculaceae</i>	1.36
2.		<i>Caryophyllaceae</i>	1.28
3.		<i>Plumbaginaceae</i>	1.40
4.		<i>Saxifragaceae</i>	1.53
5.		<i>Rosaceae</i>	1.28
6.		<i>Fabaceae</i>	1.56
7.		<i>Apiaceae</i>	1.42
8.		<i>Brassicaceae</i>	1.38
9.		<i>Salicaceae</i>	1.31
10.		<i>Boraginaceae</i>	1.43
11.		<i>Lamiaceae</i>	1.33
12.		<i>Scrophulariaceae</i>	1.39
13.		<i>Campanulaceae</i>	1.34
14.		<i>Rubiaceae</i>	1.39
15.		<i>Asteraceae</i>	1.37
16.	<i>Liliopsida</i>	<i>Poaceae</i>	1.46

It was intended to establish the belonging of species in 16 families studied, according to fractal dimension and the proximity between the genera of the studied families but also to the species having the same gender.

Conclusions

Because the analyzed species belong to different genders, they do not have identical fractal dimensions.

We mention that in the case of the same gender there may appear differences between the fractal indices of the investigated species which may be due zoological criteria.

We consider that the size of individuals of each species fractally studied leads to the identification of a fractal average dimension for the species, much closer to reality than the analysis of a smaller number of individuals.

Leaf's fractal analysis to different endemic species shows that within the same family and the same gender the fractal index has closer and sometimes identical dimensions.

From the leaf's fractal analysis of species belonging to the same family but different genders, the fractal index has approximately the same values.

The method of fractal analysis allows clear evidence of a species, depending on the chosen shade of gray. We can highlight the veins of a leaf, focusing on the area that interests, but first of all provides important facts about the plant as a whole.

After calculating the fractal dimension, it can be obtained the contour of the species or analyzed body, which may be considered a primary criterion for taxonomy.

For the accurate fractal characterization of a species, it is necessary to calculate the fractal dimension of many individuals in the adult life stage of the some species.

The fractal dimension of a species should add the morphoanatomical characters, leading to the characterization of a species in a given stage of life.

After determining the size for different histofractal vegetative organs, we noticed a small change in the values which confirms that in the structures with a low degree of variability technique serves its purpose.

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