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ASSESSMENT OF THE LEVEL OF STRESS ON PLANTS OF WESTERN SIBERIAN RAISED BOGS BY THE METHOD OF FRACTAL ANALYSIS

V.B. Ivanov, A.V. Scherbakov

Sufficient evidence has been collected that alternative biological and ecological processes may occur in individual plant specimens that dwell in environmentally equivalent habitats. Environmental stress triggers individual, specimen-specific adaptive response. The paper shows how fractal analysis can be used to study the degree of stress that plants in different habitats and environmental factor combinations are exposed to.

Keywords: *fractal analysis; habitat; stress; morphological and physiological parameters*

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ОЦЕНКА УРОВНЯ СТРЕССОВОЙ НАГРУЗКИ НА РАСТЕНИЯ ВЕРХОВЫХ БОЛОТ ЗАПАДНОЙ СИБИРИ МЕТОДОМ ФРАКТАЛЬНОГО АНАЛИЗА

В.Б. Иванов, А.В. Щербаков

В настоящее время накопилось достаточно сведений, что в экологически эквивалентных условиях среды обитания могут реализоваться альтернативные биологические и экологические процессы у индивидуальных образцов растений. Давление окружающей среды на растения, способствует запуску индивидуальных, отличных от других растений данного сообщества, ответных адаптивных механизмов. В статье показана возможность применения фрактального анализа для изучения степени стрессовой нагрузки у растений в различных местообитаниях и комбинациях факторов внешней среды.

Ключевые слова: *фрактальный анализ; условия обитания; стресс; морфофизиологические параметры*

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Introduction

Individual environmental factors vary substantially, which is typical of natural plant habitats [1, 2, 12, 8]. Another important factor of such natural habitats is that they are dynamic, which causes the ubiquitous presence of various stressors [20, 21]. Lack of mineral nutrients, suboptimal water access and temperatures, and fierce competition are but a few of the many common natural stressors [3, 6, 15, 22]. Under such conditions, plants develop an extremely complex and plastic pattern of adaptive responses; these processes in individual plant specimens can be tracked by a broad spectrum of direct and recalculated morphological and physiological indicators [9, 28, 36].

Several papers have shown that in order to adapt to such unpredictable habitats, plants apply a multiplicity of adaptive responses, which makes them radically different from animals [5, 13, 14, 16, 17, 18, 38]. The principle is essential as follows: when exposed to this or that stress, a plant will trigger as many protective mechanisms as their resources allow [23, 19]. The intensity ratio of these mechanisms in individual plant specimens may vary on a daily basis whether in a laboratory setting or in field. In terms of the quantity and quality of its physiological mechanisms, a single plant may differ not only from its neighbors, but also from its former self from a day or a few days ago [11, 37, 39].

This is why the specimen-specific indicators and the general pattern of correlations in the environmental parameters vary so greatly. Correlations between plant indicators show a high degree of plasticity, which makes it difficult to estimate the influence of individual factors and the general stress that plants in this or that habitat are exposed to. Apparently, more intense stress is associated with lower resources available to plant defenses, which means plants need to use less defenses. This fully applies to plants in the harsh wilds of Western Siberia [4, 24, 25, 26, 28, 29, 31, 32, 33].

Therefore, plants may be expected to have more similar behavior when under severe stress, which can be shown by a variety of mathematical methods. This is the idea behind this research. To date, science lacks a simple and versatile stress assessment method applicable to plants in natural habitats.

Materials and Methods

The fractal analysis finds ever greater use in biology and ecology. The general principles and applicability of fractal analysis to the ecological physiology of plants consist in the following. A multi-level object that features self-similarity across its levels, or a process that has self-similarity across its timespan, can be considered of fractal nature [7, 27, 31].

The fractal analysis classifies any multi-component system into one of the three categories:

– regular objects;

– fractal objects;

– predominantly chaotic objects.

Fractal analysis methods described in the literature and adapted herein apply to any array of specimen-specific data. This applies to both plants and to soil sampled in plant habitats. The fractal analysis procedure is outlined in Table 1.

Table 1.

Steps of fractal analysis

Step	Actions	Criteria and results
Sampling	This step produces a matrix sized 10*10 as a minimum; the matrix contains the inputs (specimen-specific indicators). Columns are for the indicators, and lines are for their values. After lines with specimen-specific values, there go lines that sum these values and scale them by an increasing value (by 2, 3, 4, and 5). The lowest value is for the totals of individual cells.	There must be at least 10 indicators. The number of objects for analysis must be composite (10, 12, 15, 16, etc.)
Determine N (the scale)	The scale varies from 1 (singular specimens) to a maximum equal to the total number of tested specimens, N.	N is essentially the maximum total number of tested individual specimens.
Find n_i, the contribution of each value to the total of each parameter.	This is a conventional ranking by variables. For each parameter, divide the value of each cell by the total in the bottom line. This will produce relative values for each parameter.	Cells should therefore total 1 in the bottom line. Other cells must be less than 1 and increase proportionally as more and more cells are summed up until the value reaches 1
Find q (the scaling range)	A fractal object must feature self-similarity across a wide range of scales. The range is set by the values of q.	In practice, a q range from -5 to 5 with increments of 0.1 to 0.5 is sufficient. The increment can be reduced for a greater resolution.

End of a Table 1.

Calculate the value of distribution moments Mq	1. For each q, raise the values of the matrix to the power of q. 2. In each of the matrices, find the totals of each horizontal row in each line.	The result is the scaling of distribution moments Mq
Scaling of the distribution moments Mq	Fundamental for fractal analysis is the fact that Mq is a power function of N. This can be proven by calculating the coefficients of correlation between the logarithms of these parameters for the given q.	logMq is in a significant correlation with logN; this is the **fundamental sign** of self-similarity in the tested object, therefore of its potential fractal nature.

Self-similarity is considered proven if logMq is in significant correlation with logN across the q range. This is the primary condition of being in line with the principles of fractal formalism.

The practice of fractal analysis of plant and soil parameters has shown that the coefficient of significant ($p \leq 0.05$) correlation between logMq and logN may vary in a range that depends on the object under analysis. A coefficient equal to 1 in absolute value means that the input array contains indicators of identical elements and represents a regular object. If the coefficient deviates from -1 to 1 whilst still being significant, it signifies a greater diversity in specimen-specific indicators.

Results and Discussions

Studies carried out by the authors hereof show that indeed, habitat and in particular the mineral nutrition it provides is of utmost importance for diversifying the indicators. Stress that *Oxycoccus palustris* Pers., *Chamaedaphne calyculáta* (L.) Moench., *Andromeda polifolia* L. was exposed to was measured by fractal analysis of plant and soil parameters in a control field and an experimental field. The control field was the tested plants' natural habitat. The experimental field was natural habitat with a single application of Nitroammophosca, see Table 2.

Table 2.

Fractal analysis of the indicators of *Oxycoccus palustris* Pers., *Chamaedaphne calyculáta* (L.) Moench., *Andromeda polifolia* L. and soil in Western Siberia

No.	Object, year, site	Parameters used in fractal analysis	Average absolute value of the logMq-logN correlation coefficient
1	Cranberry, 2014, control	Morphological and weight parameters, total flavonoid content	0.922
2	Cranberry, 2014, fertilized	Morphological and weight parameters, total flavonoid content	0.915
3	Myrtle, 2014, control	Morphological and weight parameters, total flavonoid content	0.922

End of a Table 2.

4	Myrtle, 2014, fertilized	Morphological and weight parameters, total flavonoid content	0.995
5	Bog rosemary, 2014, control	Morphological and weight parameters, total flavonoid content	0.922
6	Bog rosemary, 2014, fertilized	Morphological and weight parameters, total flavonoid content	0.920
	Soil, 2014, control	Concentrations of P, N, Cd, Pb, Cu, Zn, Fe, Mn	0.88
	Soil, 2014, fertilized	Concentrations of P, N, Cd, Pb, Cu, Zn, Fe, Mn	0.922

Notes:

1. Nitroammophosca, an N/P/K fertilizer, was applied once early in summer vegetation at a dose of 16 kg/ha.
2. All the correlation coefficients shown in the table are significant at $p \leq 0.05$
3. A total of 27 plant indicators and 10 soil indicators were tested by fractal analysis.

As shown in Table 2, two of the three tested species (*Oxycoccus palustris* Pers., *Andromeda polifolia* L.) had a slight reduction in their logMq-logN correlation coefficient as a result of applying the fertilizer in early vegetation; thus, the difference between the specimen-specific morphological and physiological indicators increased. The authors hereof believe this could indicate a slight improvement in their habitats.

Therefore, it might be safe to say that the logMq-logN correlation coefficient for different species in their natural habitats can be used as a universal stress indicator.

This study produced a general algorithm of how to use fractal analysis to assess the condition of plants exposed to a varying degree of stress. Fractal analysis-based testing for stress involves these steps:

1. Collect specimen-specific indicator values.
2. Add the input to the unified matrix.
3. Find (if necessary, adjust) the scaling range q.
4. Run the fractal analysis.
5. Find the logMq-logN correlation coefficients.
6. Compare the coefficients against the reference, i.e., against the values typical of regular objects (-1 for negative q, 1 for positive q).
7. Find the deviation of the correlation coefficient from the reference for each q.
8. Assess the stress.

Conclusions

The proposed plant stress assessment technique can use any data specific to a single plant specimen, whether it is growth or morphological indicators, the concentrations of individual metabolites including the secondary ones, or local readings of the habitats, be it soil, atmospheric, or hydrological readings. The key requirement is to avoid zeroes in data as much as possible, as such data might skew the calculations and result in misevaluation of stress. The method requires a minimum data array of 10*10 (10 plant specimens and 10 indicators). Stress calculations involve Excel and Statistica.

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ДАННЫЕ ОБ АВТОРАХ

Иванов Вячеслав Борисович, кандидат педагогических наук, доцент

ФГБОУ ВО «Нижневартовский государственный университет»
ул. Ленина, 56, г. Нижневартовск, Ханты-Мансийский автономный округ, 628605, Российская Федерация
karatazh@mail.ru

Щербаков Аркадий Владимирович, кандидат биологических наук, доцент
ООО «Институт тканевой и генетической инженерии»
ул. Менделеева, 9, г. Уфа, 450047, Российская Федерация

DATA ABOUT THE AUTHORS

Vyacheslav B. Ivanov, Candidate of Pedagogical Sciences**,** Associate Professor
Nizhnevartovsk State University
56, Lenin Str., Nizhnevartovsk, Khanty-Mansiysk Autonomous Area-Yugra, 628605, Russian Federation
karatazh@mail.ru
ORCID: 0000-0001-6617-4634
Scopus Author ID: 56282339200
ResearcherID: ААУ-5511-2020

Arkady V. Shcherbakov, Candidate of Biological Sciences, Associate Professor
Institute of Genetic and Tissue Engineering
9, Mendeleev Str., Ufa, 450047, Russian Federation
humanist314@rambler.ru
ORCID: 0000-0002-7089-6100