Conference Paper

Floristic Phenomena of the Samara Bend: The Fractal Organization of Taxonomic Diversity

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Abstract

Considering the problem of taxonomic diversity as a fractal object is the aim of this article. The prerequisites for such an approach were articles with varying degrees of detail and argumentation that substantiate taxonomic diversity from the standpoint of fractal geometry. Common to these papers is that the authors in their theoretical constructs start from the Willis rule (law) describing the rank distribution of the relationship between the number of taxa and their volume. The flora of the Samara Bend (the bend of the Volga River in its middle reaches) has become an object of the research. The authors distinguish seven basic floristic areas on the Samara Bend, the boundaries of which coincide with the respective landscapes. The authors discuss the efficiency of the Willis rule (law), which approximates the relationship between the number of taxa and their volume by rank distribution. The multifractal spectrum (a generalized geometric image of generic structure) of the taxonomic diversity of vascular plants of the Samara Bend is presented.

Keywords: taxonomic diversity, fractal organization, Samara Bend

1. Introduction

The term 'diversity' has a long history and has firmly established itself in the scientific biological literature in the form of stable word combinations: 'biological diversity', 'species diversity' and, finally, 'taxonomic diversity'. Diversity can also be defined as

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the degree of difference in objects in a studied population. Consequently, the procedure for distinguishing biological objects from dissimilar characters with simultaneous grouping according to the characteristics of similar characters is the essence of a single process of cognition and ordering of the surrounding organic world. So, for example, the term ‘biodiversity’, at present, is widely interpreted. It is understood as a set of specific parameters of communities, flora, fauna, richness of forms and their correlation. In addition, biodiversity is also a synthetic category, corresponding to the tasks of complex studies in ecology, biogeography and evolutionary theory. Thus, the study and quantification of biodiversity parameters is not only of academic interest, but of great practical importance, since it attempts to answer the most important environmental problem – the causes and mechanisms of the stability of communities [1–3]. The aim of the article is to consider the problem of taxonomic diversity as a fractal object, taking into account our experience of the fractal analysis of species diversity [2].

2. Methods

The prerequisites for writing the article were works with varying degrees of detail and reasoning declaring or justifying taxonomic diversity from the point of view of fractal geometry. Common to these works is that the authors in their theoretical constructs start from the Willis rule (law), describing the rank distribution of the relationship between the number of taxa and their volume [4–6, etc.].

The specific structure of biotic communities is a traditional subject of close attention and lively discussion among environmentalists. In the first approximation, it is possible to limit the consideration of the species structure by analyzing the species richness (the number of species) and the relative abundance of the species composing the community, that is, species diversity. Taxonomic diversity, depending on the point of view and ‘taste’ of the researcher, can be represented as the total number of species inhabiting the Earth, simply organisms or as a hierarchy of natural groups recognized as objectively existing taxa of different ranks [7].

As is well known, in the process of knowing the surrounding world, any scientific discipline passes through three main stages: descriptive or inventory, conceptual-theoretical (in which ideas about the structure and functioning of the systems under study are advanced) and the mathematization of these representations (i.e., their formalization in the language of mathematics, currently the most accurate and strict language) [8, 9]. From this point of view, ecology is no exception: an environmentalist wants to know what ecosystems surround it, how many they are, how they function, how the ecosystem is limited in space, what are the ways of constructing artificial ecosystems with specified properties and how to manage the productivity of ecosystems to maximum benefit. Of these three stages in the emergence of ecology as a scientific discipline, we can assume that the first – inventory – in the first approximation is basically completed, the second – the conceptual-theoretical – is in the flowering stage and the third – the formal and theoretical – is only in the process of formation. In this context, theoretical ecology can be defined as a biological discipline (a branch of theoretical biology) that studies the formalization of the patterns of structure and the functioning of ecosystems [9].

3. Results

The Samara Bend is a large hairpin bend of the Volga in the middle reaches of a total area of more than 1.5 thousand km^2. On three sides, it is limited by the water areas of the Saratov (the Volga valley) and Kuibyshev (the Volga valley and its tributary the Usa) reservoirs. The central and southern parts of the peninsula are a flat-sloping plateau with absolute elevations from 150 to 200 asl; the northern part is a mountain range, known as the Zhiguli or the Zhiguli Mountains, where absolute elevations reach 370 m asl.

The flora of the Samara Bend is characterized not only by greater diversity in comparison with the surrounding territories, but also by a significant number of endemic species (in the general list of endemics of different botanical-geographical ranks – 102 species), including a subgroup of narrow-local endemics rare for such flat flora. Special value to the natural complex of the Samara Bend is given by species whose classical places of growth are located there. At present, 21 taxa have been identified and described according to data collection from this territory: 5 in the rank of variations and 16 in the rank of species [10].

Landscape zoning is fundamental to the development of the floristic zoning of the Samara Bend. In the territory of the Samara Bend, seven elementary floristic regions were identified, the boundaries of which coincided with the corresponding landscapes: Zhigulevsky, Vinnovsky, Aleksandrovsky, Perevoloksko–Usinsky, Shelekhmetsky, Volzhsky and Rozhdestvensky (Table 1). The main criterion for isolating elementary floristic regions was the analysis of the species composition of the flora of the Samara Bend and the distribution of some of its elements – endemic, relict, rare and small species [10].

Table 1: The number of genera and species of vascular plants in the elementary floristic regions of the Samara Bend.

Elementary floristic region	**Number of genera (G)**	**Number of species (S)**
Zhigulevsky	366	815
Vinnovsky	375	778
Aleksandrovsky	358	744
Perevolokskо-Usinsky	323	654
Shelekhmetsky	240	460
Rozhdestvensky	355	731
Volga district	276	531
Samara Bend as a whole	505	1302

Source: Authors' own work.

As mentioned earlier, most authors in the analysis of taxonomic diversity rely on Willis' rule (law), which approximates the relationship between the number of taxa and their volume by rank distribution. Recall that rank distribution is a transformed number vector: the most abundant group is assigned the first number, the next largest group – the second, and so on, to the least abundant group, whose number is the same as the total number of groups analyzed.

In the context of taxonomic diversity, the Willis rule relates the number of taxa and their volume: for example, a small number of genera is represented by a large number of species, whereas most genera include one or two species [4–6]. The Willis rule in most cases is valid for such taxonomic categories as species, genera and orders, whereas for classes, types and kingdoms, due to their small number, such dependencies are statistically incorrect. In natural coordinates, the graphical relationship between the number of taxa and their volume is represented by the so-called 'concave curve of taxonomists', that is, the 'Pareto or Zipf distribution', which is synonymous with what Mandelbrot [11] considers 'asymptotically hyperbolic distribution'.

Consider the results of applying the Willis rule to the analysis of the taxonomic diversity of the flora of the Samara Bend, including 1,302 species of vascular plants belonging to 505 genera (Table 1). For the flora of the Samara Bend, the relationship between the number of taxa and their volume is satisfactorily described by a power function whose graph has the form of a 'concave curve of taxonomists' in ordinary ($N_G = 5{,}6 * N_S{}^{-1{,}77}$) and bilogarithmic coordinates, confirming the validity of the Willis rule [1]. At the same time, the rank distributions and 'concave curves of taxonomists' fix only the 'static taxonomic portrait' of the community and do not answer the question: how will the number of genera change as new species appear in the community? Recall that within the extensional character of the taxon (the relation [similarity] is primary, the attribute is secondary [7]), its volume is, in fact, limited only to those species that are really known to the taxonomist. At the same time, the elucidation of the regularity of the growth of the number of genera is subject to an increase in the number of species: this 'dynamic taxonomic portrait' may prove useful in analyzing the structural and functional organization of the community, including in the prognostic plan.

4. Conclusion

When dealing with fractals, the main thing is the form-building idea of self-similarity, the essence of which is to replicate the fragment of the structure into its whole while reproducing the properties of the whole in each fragment. Earlier, we developed the methodological foundations of a fractal theory of the species structure of a community [2], which allowed us to adapt the existing mathematical apparatus and the logic of the justifications to the analysis of the fractal structure of taxonomic diversity.

In the application of multifractal formalism to the analysis of taxonomic diversity at the level of genera ('generic diversity'), the totality of the taxa of generic rank is considered as a set consisting of separate fractal subsets that can be interpreted as aggregates of genera of a certain volume. For such subsets, one can calculate the fractal dimension which will characterize the generic variety. This is precisely the meaning of the ordinate of points on a graph of the multifractal spectrum (Figure). The abscissa of the points characterizes the relative volume of the genus of a particular subset. If the presence on the graph of the spectrum of points lying along axis 'a' ('singularity index') is close to zero, this means the presence of dominants (taxa of generic rank with the highest species representation) in the studied taxonomic set: the lower the abscissa of the points, the stronger the dominance. If the presence of points lying on the 'a' axis is close to one, this means the presence in the studied taxonomic set of genera with a small species representation (by analogy with rare species). The area under the curve of the spectrum can be interpreted as an indicator inversely proportional to the leveling of genera over a relative volume: the larger it is, the less the alignment, and vice versa.

The figure shows the multifractal spectrum of the taxonomic diversity of the vascular plants of the Samara Bend. Spectrum '1' is a multifractal spectrum of the generic structure of the plant community of the Samara Bend. The community is characterized by a high proportion of one- and two-species genera (238 and 100, respectively). Spectrum '2' is a theoretical spectrum with an increase in the general community

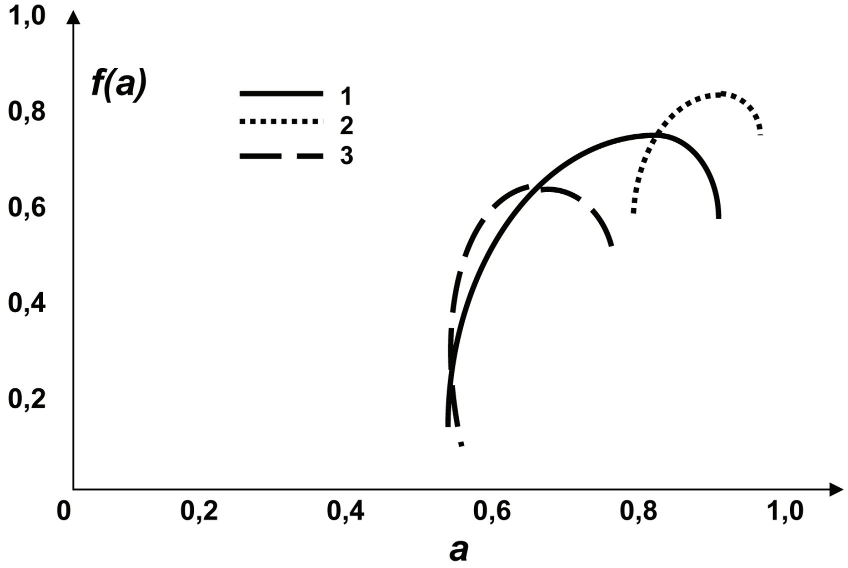

Figure 1: Multifractal spectrum of taxonomic diversity of the vascular plants of the Samara Bend; a – is the 'singularity index'; f(a) – is the function of the multifractal spectrum or the 'singularity spectrum' [1, 2].

equalization and the 'disappearance' of genera with a much larger number of species than the main mass. Spectrum '3' is also a theoretical spectrum with an 'increase' of diversity in the community partly due to 'getting rid' of one- and two-species genera. This allows us to conclude that the patterns we identified earlier for the multifractal spectrum of the species structure of the community [1] to a certain extent persist for the spectrum of the generic structure.

We recall that within the framework of fractal methodology we were interested in the question of how the structure of taxonomic diversity (in this case the generic structure) is invariant with respect to the transformation of its scale, expressed through the growth of the number of species. Without going into the details of the discussion on the issue that 'the increase in the number of species as a result of speciation does not yet mean the appearance of a new genus', we note that, regardless of how the process of formation of new genera in time functions (on an evolutionary scale), any taxonomic diversity should have a self-similar, or fractal, character.

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References

[1] Gelashvili, D. B., Iudin, D. I., Rozenberg, G. S., et al. (2013). *Fractals and Multifractals in Bioecology*. Nizhnii Novgorod: Publishing House of Nizhny Novgorod State University.

[2] Gelashvili, D. B., Saksonov, S. V., Rozenberg, G. S., et al. (2011). Floristic phenomenon of the Samara bend: Fractal structure of taxonomic diversity. *Samarskaya Luka: Problems of Regional and Global Ecology*, vol. 20, no. 2(36), pp. 80–104.

[3] Chernov, Yu. I. (1991). Biological diversity: Essence and problems. *Advances in Modern Biology*, vol. 111, no. 4, pp. 499–507.

[4] Pozdnyakov, A. A. (2005). The value of the rule of Willis for taxonomy. *Journal of General Biology*, vol. 66, no. 4, pp. 326–335.

[5] Chislenko, L. L. (1977). On the structure of taxa and taxonomic diversity. *Journal of General Biology*, vol. 38, no. 3, pp. 348–358.

[6] Willis, J. C. (1940). The course of evolution by differentiation or divergent mutation rather than by selection. L.: Cambridge University Press.

[7] Pavlinov, I. Ya. (2001). Concepts of systematics and biodiversity concept: Interaction problem. *Journal of General Biology*, vol. 62, no. 4, pp. 362–366.

[8] Rozenberg, G. S. (2005). On the ways of constructing theoretical ecology. *Advances in Modern Biology*, vol. 125, no. 1, pp. 14–27.

[9] Rozenberg, G. S. (2013). *Introduction to Theoretical Ecology. In 2 volumes* (second edition). Togliatti: Kassandra.

[10] Saksonov, S. V. (2006). *The Samara Bend Floristic Phenomenon*. Moscow: Nauka.

[11] Mandelbrot, B. (2002). *Fractal Geometry of Nature*. Moscow: Institute of Computer Studies.