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The study of fractals among ecologists

Roger Paulo Mormul[1*] and André Andrian Padial[2]

*[1]Programa de Pós-graduação em Ecologia de Ambientes Aquáticos Continentais, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. [2]Instituto Federal de Educação, Ciência e Tecnologia do Mato Grosso do Sul, Nova Andradina, Mato Grosso do Sul, Brazil. *Author for correspondence. E-mail: roger.mormul@gmail.com*

ABSTRACT. Fractals seemed to have permeated most scientific fields, including ecology. In fact, biodiversity and ecological processes are affected by spatial complexity, and fractals can help understand patterns at multiple scales. In this paper we evaluated the main quantitative trends and the profile of ecology publications using fractals. Publications about fractals in Ecology experienced a high increase in the last two decades, and most articles were published in highly visible ecology journals. However, studies were authored mainly by US scientists, and researchers from developing countries had a minor contribution. In addition, studies were highly biased towards terrestrial environments, and empirical approaches were preferred.

Keywords: fractal geometry, ecology, spatial complexity, scientometrics.

O estudo dos fractais entre os ecólogos

RESUMO. Os fractais pareciam ter permeado a maioria das áreas científicas, incluindo a ecologia. De fato, a biodiversidade e os processos ecológicos são afetados pela complexidade espacial, e os fractais podem ajudar a compreender esses padrões em múltiplas escalas. Neste trabalho avaliaram-se as principais tendências do perfil ecológico, bem como foram quantificadas as publicações utilizando fractais. Publicação sobre fractais em ecologia sofreram grande aumento nas últimas duas décadas e muitos artigos foram publicados em revistas de alta circulação. No entanto, os estudos foram escritos, principalmente, por americanos, e os pesquisadores de países em desenvolvimento tiveram contribuição menor. Além disso, os estudos foram desenvolvidos em sua maioria em ambientes terrestres, e as abordagens empíricas foram preferidas.

Palavras-chave: geometria fractal, ecologia, complexidade espacial, cienciometria.

Introduction

Fractal Geometry, closely related to Chaos theory, arose after criticisms of classical Euclidian Geometry. This new discipline caused a revolution among mathematicians and physicists, mainly because it attempted to understand chaotic and unpredictable processes (MALETSKY et al., 1992). B. B. Mandelbrot, the father of fractals according to Maletsky et al. (1992), defined a fractal as “a rough or fragmented geometric shape that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole” (MANDELBROT, 1983). This remarkable researcher also demonstrated that many natural forms have self-similarity properties between different scales (MANDELBROT, 1983). Studies about fractals seem to have permeated, in addition to areas such as physics, mathematics and even art (e.g. paintings, music), most scientific fields concerned with the morphometry of natural forms (MILOŠEVIĆ; RISTANOVIĆ, 2007), from the micro-level aggregation of water molecules to the macro analysis of the structure of landmasses. For instance, there are recent articles aiming to study fractals in medical sciences (KARPERIEN et al., 2008), chemistry (HILL; NG, 2001), linguistics (MIYAZIMA; YAMAMOTO, 2008) and environmental sciences (McCONNELL; GUPTA, 2008).

Accordingly, fractals can be extremely useful in Ecology, given that biodiversity and ecological processes, such as predator-prey relationships, can be affected by the spatial complexity of physical (e.g. rock beds, mountains) and biological (e.g. plant tissues) structures within habitats (PADIAL et al., 2009). In fact, fractal structures in ecological ecosystems such as coral reefs have been recognized by researchers since the 1980s (BRADBURY; REICHELT, 1983). In freshwater habitats, fractals have also been used to evaluate the effect of spatial complexity of aquatic plants on invertebrate richness and composition (JEFFRIES, 1993; McABENDROTH et al., 2005; THOMAZ et al., 2008). Examples of the use of fractal geometry in terrestrial habitats include the investigations by Dannowski and Block (2005), who related water absorption of shrubs with the structural complexity of their roots, and De Jager and Pastor (2008), who evaluated the population density of moose upon the fractal geometry of plant canopies.

In this paper we evaluated the main quantitative trends and the profile of ecology publications using fractals. To reach this objective, we made a scientometric study with a two-fold goal: (i) to evaluate the main trends of publication, and (ii) to describe the profile of ecological investigations using fractals. For this latter purpose, we asked the following questions: Do ecologists really measure fractals, or just cite word “fractal” in their articles? In which environments (i.e., marine, freshwater or terrestrial) are fractals mostly studied? What is the main approach (i.e., methodological, empirical or theoretical) of ecological studies using fractals?

Material and methods

We downloaded a dataset from the Thompson Institute for Scientific Information (Thomson-ISI: www.isiknowledge.com) in August 2008. We selected articles by searching the following word on the topic field: “fractal*”. Not surprisingly, the main subject areas (categorized by Thompson-ISI data base) of these articles are related to physics and mathematics (Figure 1). However, a total of 291 subject areas were selected by searching the word “fractal*” on the topic field. This highlights that fractals had a profound impact on the scientific community as a whole (MILOŠEVIĆ; RISTANOVIĆ, 2007). “Ecology”, “Limnology” and “Biodiversity and Conservation” were positioned in 25th (424 articles), 61th (161 articles) and 109th (49 articles) places (Figure 1), respectively. To analyze ecology articles of this dataset, we used only the 565 articles belonging to these last three subject areas. Note that there are fewer articles in total (565) than the sum of all subject area (Figure 1), because these subject categories share some articles. After this, we recorded article title, abstract, author addresses, publication years and publication journals. Considering the main quantitative trends of ecology publications using fractals, we evaluated the frequency distribution showing: (i) the temporal distribution of published articles (for that, we took overall growth of scientific publication into account); (ii) the impact of ecology articles (represented by their citation counts) in the scientific community; (iii) the relative contributions of countries to this issue; (iv) the scientific journals that most publish ecology articles using fractals. Finally, information to address our questions considering profile of publication was taken from abstracts and frequency distribution was also used to visualize the main characteristics. When an abstract was not available, we excluded the article from the analyses. We used the software STATISTICA, version 7.1 (STATSOFT, 2005).

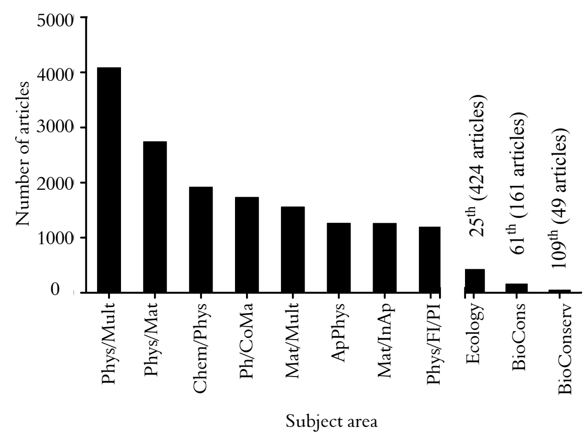

Figure 1. Main subject areas of articles from the Thompson Institute for Scientific Information (Thomson-ISI: www.isiknowledge.com). Phys/Mult = Physics and Multidisciplinary; Phys/Mat = Physics and Mathematics; Chem/Phys = Chemistry and Physics; Ph/CoMa = Physics and Condensed Matter; Mat/Mult = Materials Science and Multidisciplinary; Phys/Ap = Applied Physics; Mat/InAp = Mathematics and Interdisciplinary Applications; Phys/Fl/Pl = Physics, Fluids and Plasmas; MultSci = Multidisciplinary Sciences; Eng/Ele = Engineering, Electrical & Electronic; BioConser = Biodiversity Conservation.

Results and discussion

Main quantitative trends of ecology publication

The number of ecology articles varied from 1 (in 1983, 1984, 1985 and 1989) to 55 (in 2004). It is possible to identify two peaks of publications, one in the mid-1990s and another more recently, in 2003-2004 (Figure 2A). The reasons for these peaks are difficult to explain, but they can indicate that some studies published just before these periods may have had a high influence among ecologists.

In fact, an article published in 1992 (just before the first peak, see Figure 2A) by C.S. Holling (“Cross-Scale Morphology, Geometry, and Dynamics of Ecosystems”) may have attracted attention to ecologists about fractals. This study had a large impact on the scientific community, given that it was the most cited of our dataset (463 times until August 2008 - Figure 2B). Holling (1992) is a review testing the proposition that a small set of plant, animal, and abiotic processes structure ecosystems across scales, suggesting thus the existence of fractals affecting ecosystems. In addition, other articles (e.g., HASTINGS, 1993, 155 citations; FAHRIG, 2001, 192 citations) published before the two peaks could attract attention to fractals, and are among the most cited ones (Figure 2B). Finally, articles with few citations were mostly observed (Figure 2B). This is an expected trend, also found in other scientometric studies (NICOLAISEN; HJØRLAND, 2007). It is important to note that some articles have no citation simply because they were recently published.

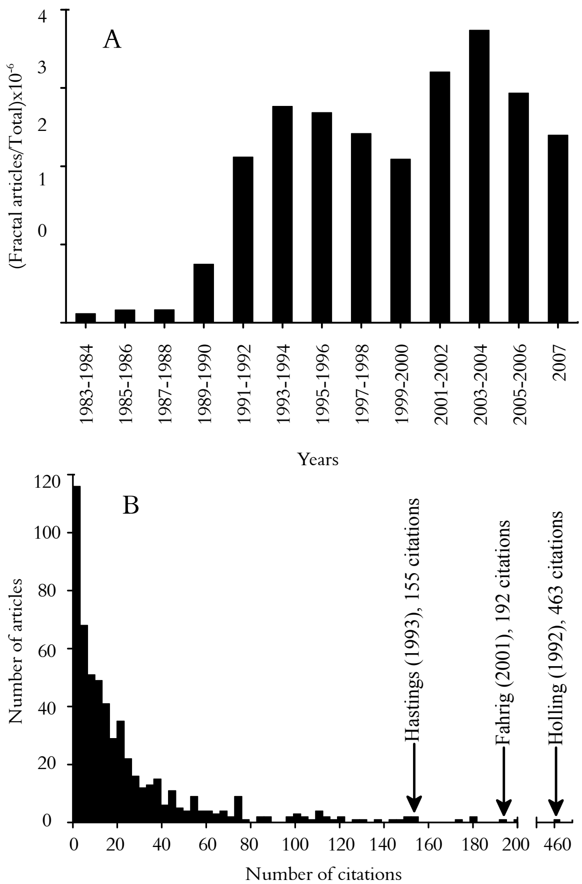

Figure 2. A - Temporal distribution of ecological articles using fractals. Given that overall science also grew along years, we used the number of our selected articles in relation to the total number of articles indexed in Thompson-ISI database (www.isiknowledge.com) per year. B - Distribution of citations of ecological articles selected by searching the word "fractal*" on topic field. Holling (1992): "Cross-Scale Morphology, Geometry, and Dynamics of Ecosystems" received 463 citations. Fahrig (2001): "How much habitat is enough?" received 192 citations. Hastings (1993): "Complex interactions between dispersal and dynamics -lessons from coupled logistic equations" received 155 citations.

Articles published by US scientists were the most frequent (223 out of 565 articles; Figure 3A). The USA has been considered the most important country in overall scientific productivity, both in number of articles, citations, researchers and research centers (KING, 2004; MAY, 1997). Accordingly, developing countries had a minor contribution to articles using fractals in Ecology. The most representative undeveloped countries were China and South Africa, with only 8 articles each (13[th] place). However, when population size or per capita investment in science are taken into account, other countries may arise as scientific powers (MAY, 1997), including in studies about fractals.

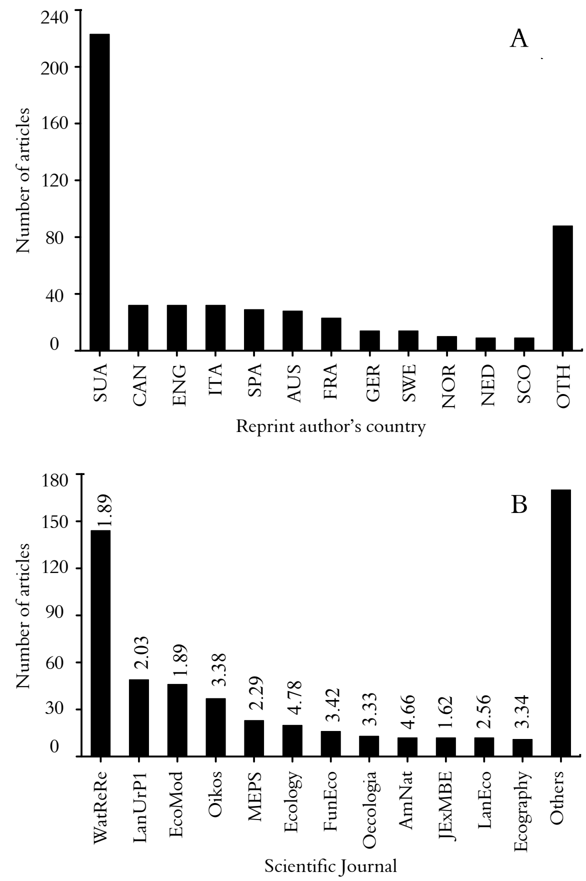

Figure 3. A - Reprint author's country of ecological articles dealing with fractals. USA = United States of America; CAN = Canada; ENG = England; ITA = Italy; SPA = Spain; AUS = Australia; FRA = France; GER = Germany; SWE = Sweden; NOR = Norway; NED = Netherlands; SCO = Scotland; OTH = Others. B - Top 12 journals publishing most ecological articles dealing with fractals. Numbers above bars indicate journal impact factor according to JCR-2006. WatReRe = Water Resources Research; LanUrPl = Landscape and Urban Planning; EcoMod = Ecological Modeling; MEPS = Marine Ecology-Progress Series; FunEco = Functional Ecology; AmNat = American Naturalist; JExMBE = Journal of Experimental Marine Biology and Ecology; LanEco = Landscape Ecology.

The scientific journal that published most ecology articles dealing with fractals was "Water Resource Research", highlighting the usefulness of fractals in explaining patterns in aquatic ecology. In fact, there are studies quantifying the fractal dimension of aquatic environments at different scales, such as: (i) river basins (CAMPOS et al., 2006), (ii) bottom surface (KOSTYLEV et al., 2005), and (iii) aquatic structures, such as macrophytes (McABENDROTH et al., 2005).

It is also interesting to note that the 12 journals that most published ecology articles using fractals had an impact factor (IF) higher than 1.67 (JCR-2006), which is the median of all journals classified into the subject areas “Ecology”, “Limnology” and “Biodiversity and Conservation” in the Thompson-ISI database (www.isiknowledge.com) (Figure 3B). This indicates that fractals have a high visibility among ecologists. In addition, this result can also suggest that ecologists recognize fractals as a relevant issue of research.

Profile of ecology articles

Among the 565 ecology articles selected using the word “fractal*” on topic field, only 306 (54.16%), in fact, analyzed or measured fractals. Despite the recognition of the importance of fractal theory in explaining ecological patterns, there still is a paucity of ecology studies using fractals. This number can be a little higher because 40 (7.08%) articles did not contain abstracts, which did not allow us to analyze them. In spite of that, at least 219 (38.76%) only cited the word “fractal*” in the abstract, title or key words, without directly studying fractal geometry. Articles from this last category may be related to studies of other issues that recognize a potential importance of fractals for future and/or complementary studies.

Among the 306 articles that studied fractals for ecological purposes, the majority (188 articles) was carried out in terrestrial ecosystems (Figure 4A). The second most investigated environment was freshwater (63 articles), followed by marine ecosystems (28 articles). This result is surprising, given that the journal that most published ecology articles had a scope exclusively for aquatic habitats (see Figure 3). Finally, 27 articles did not mention any environment in their abstracts. These discrepant results may indicate that most studies in aquatic ecosystems only cite the word “fractal*” without directly analyzing fractals for ecological purposes. In this sense, despite recognizing their importance, limnologists still need to directly analyze fractals in their studies.

Finally, most of the ecology articles using fractals had an empirical approach (234 out of 306, Figure 4B). This is an expected characteristic, given that empirical studies may indicate those with the most important application of fractals in ecology, i.e., studies identifying fractals in natural habitats and recognizing their importance to explain biodiversity or ecological processes across scales. Fifty-nine articles were methodological and only 13 were theoretical (Figure 4B). This is also not surprising, given that most methodological and theoretical studies may be done by physicists or mathematicians.

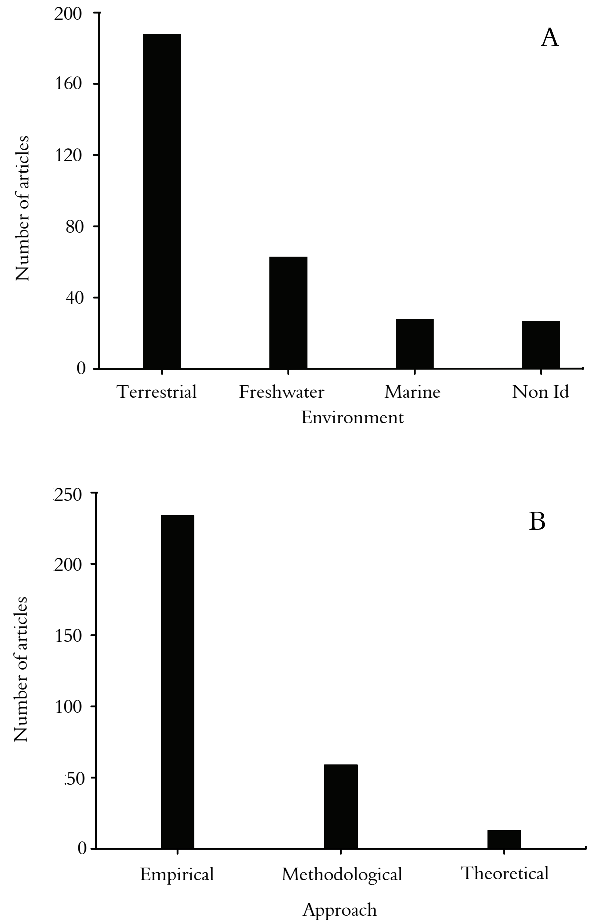

Figure 4. A – Environments in which ecological studies using fractals were carried (Non Id=Non identified in the abstract). B – Main approaches of ecological studies using fractals.

Conclusion

Explaining causes of biodiversity and ecological processes at different spatial scales is one of the main goals of Ecology. In this sense, fractals had (and still has) a profound impact on ecology studies. Therefore, studies using fractals in ecology are experiencing a substantial increase in the last two decades. Moreover, they are published in high impact factor journals, leading to high visibility among the scientific community. However, fractals still need to be popularized, mainly among scientists from developing countries. Furthermore, numerous studies only recognize that fractals are important, without directly studying them. This is especially observed in studies on aquatic environments. Therefore, a direct approach studying fractals in ecology is crucial and, perhaps, the cooperation of physicists can help the improvement of studies. For instance, ecology studies about fractals should focus on experimental or modeling approaches manipulating fractal geometry to explain, for instance, the biological diversity or the abundance of individuals. Indeed, the high number of empirical studies found in our scientometrics suggests that ecologists are mainly trying only to identify fractals in natural structures and recognize their importance for biodiversity or ecological processes. In fact, fractals can be the explanation for some across-scale patterns found in nature, even though it would be difficult to observe self-similarity in all scales on ecological structures.

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