Title: **Biodiversity is a cauliflower under the sunlight**

Authors: Roberto Cazzolla Gatti*

Affiliations:

*DIBAF, University of Tuscia, Strada San Camillo de Lellis, snc, Viterbo, Italy. e-mail: robertocazzolla@unitus.it

Abstract: For long time ecologists questioned on the variations of biodiversity across the latitudinal gradient. Recently emerged that the changes in β-diversity is caused simply by changes in the sizes of species pools. I combined the species pool size and the fractal nature of ecosystems to clarify some general patterns of this gradient. Considering temperature, humidity and NPP as the main variables of an ecosystem niche and as the axis of the polygon in the Cartesian plane, it is possible to build fractal hypervolumes, whose the fractal dimension rise up to three moving towards the equator. It follows that the best figure that graphically synthesize the evolutionary forces that fit this ecosystem hypervolume is the fractal cauliflower.

One Sentence Summary: Latitudinal gradient of biodiversity can be explained as differences in fractal dimension of ecosystem niches.

Main Text: One of the most interesting question in ecology is why tropics are so diverse or, in other words, why there are variations of biodiversity across the latitudinal gradient. Since the extent of tropical diversity respect to temperate areas became evident during the XIX century, a large number of different factors have been suggested as possible explanations (for a summary see ref. 1). Recently it has been evidenced that the changes in β-diversity is caused simply by changes in the sizes of species pools. In fact, after correcting for variation in pooled species richness (γ-diversity) the differences in β-diversity disappear. Thus, differences in local assembly processes are not the causes of latitudinal and altitudinal patterns of biodiversity, where the variation in biogeographic processes that sets the size of the species pool is a more plausible explanation (2). One of the most corroborate ecological and evolutionary hypothesis is that climate (C) influences Net Primary Production (NPP) in such a way that, rising/lowering available biomass (B) and so increasing/decreasing the number of individuals (I), it "controls" the number of species (S). So far the Climate→NPP→I→S correlation has not been clearly demonstrated, because it seems to be not mediated directly by biomass. I will show that it is not I or B that influence S, further the extent of climatic and NPP on niche variables .

It is possible to extend the ecological niche concept to an ecosystem dimension to better define the size of species pool invoked by (2) . This "ecosystem niche", therefore, can be imagined as the sum of the niches of each species included in the pool. In an Hutchinsonian view an ecosystem niche is an n-dimensional hypervolume, where the dimensions are environmental conditions (C) and the resources (NPP) that define the requirements of all the species in an ecosystem to reproduce themselves.

Furthermore, examples of the fractal nature of nature have been argued continuatively during the last years (3). Different elements of the natural world have been associated to or defined as fractals but only considering them separately and not in an holistic perspective. That ecosystems are structured in a fractal way, made by relationships that are self-similar over a wide range of spatial or temporal scales as well as the single elements whose they are composed, is becoming an intriguing idea in ecology. I combined this two apparently distinct concepts, the ecosystem niche and the fractal nature of them, in an attempt to clarify some general patterns of biological diversity.

Here I show that latitudinal gradient of biodiversity can be explained as differences in fractal dimension of ecosystem niches (Fig. 1a). Let's reduce the C variables can shape the ecological niche to the fundamental ones. Temperature (T) is surely one of these (4). Different authors suggested that the richness of species which cannot regulate their internal temperature (ectothermic) can be predicted from environmental temperature (5,6). The second fundamental variable of an ecosystem hypervolume is humidity (H), which shows different values in terrestrial regions but it is constant in marine environment, where temperature and photic zone depth are the main factors. The latitudinal variation of both these variables is shown in Fig. 1b. Merging temperature and humidity from pole to pole it is possible to estimate the curve of Net Primary Production (NPP). This latter shows a triple-humped-shape, with one big hump within about 20°N and S from the Equator and two moderate over the temperate areas. The lower values of NPP are in polar and tropical (deserts) latitudes where T and/or H are low. Simple models of spatial dynamics (7) accurately predicts the increase in species richness with increasing environmental productivity (i.e. "energy richness hypothesis"). It seems reasonable that autotrophic organisms diversity may principally be driven by humidity (or light in marine environment), that of ectotherms by temperature, whereas resource availability (NPP) is the fundamental variable that allow differentiation of endothermic species. Thus, both T and H are constituent and co-variables of NPP in the ecosystem niches. Therefore, considering this niche as a polygon in the Cartesian plane where the x, y and z axis are T, H and NPP (Fig. 1c) I demonstrate that where these values, and in particular the NPP are close to zero such as in polar or deserts areas, the fractal dimension (D, Fig. 1d where L is the linear scaling and S is the result of size increasing) of this polygon is lower than two (~1.5). This means that there is further a hypersurface available for species than a hypervolume. Moving along latitude and following the NPP curve the fractal dimension pass through the value 2.5 reaching the value three (a 3-D shape) at the equator (Fig. 1a and b). Explicitly, here I consider the D value of the ecosystem hypervolume as a proxy of the available space for species pool. Evidently, the greater are T and H, and so the NPP, the higher is D and the bigger is the ecosystem niche amplitude (Vn, Fig. 1b and c). This seems to solve "niche conservatism" (8) and "energy richness" hypothesis problems (such as the misunderstanding influence of B or the weaker correlation between NPP and I than between NPP and S). Defined the ecological causes of "biodiversity dimension", it is then fundamental to focus on evolutionary processes that can fill the niche space available. The best figure that graphically synthesize the evolutionary forces that fit the ecosystem hypervolume is the fractal cauliflower. In fact, for each iteration, that can be assumed as the addiction/speciation of a new species (s), the niche volume can be filled up to reaching a value close to 3 D (such as 2.7-2.9 of the equations in Fig. 1d). The simple system in Fig. 1d accomplishes in the most efficient way the filling of an available functional space, where n_s is the ecosystem niche occupied by species ecological niches and a, b and c the portion of the three fundamental variables (T, H and NPP) utilized by each species. The branches of the fractal cauliflower are created step by step (Fig. 1e) by the addition/speciation of new species towards the maximum amplitude (Vn) allowed by NPP and consequently by D. Each segment constitutes a new available ecological niche within the ecosystem hypervolume which other species can occupy, as suggested by the hypothesis of the diversity that begets diversity (9, 10)

The patterns described above, synthesisable as the “cauliflower hypothesis of biological diversity”, although could appear oversimplified, can be also extended to altitudinal gradients and shed more light on ecological and evolutionary processes which shape biodiversity on Earth.

References and Notes:

1. E.R. Pianka, Latitudinal gradients in species diversity: a review of concepts. *American Naturalist* **100**, 33-46 (1966).

2. J. B. Nathan Kraft, et al., Disentangling the Drivers of b Diversity Along Latitudinal and Elevational Gradients. *Science* **333**, 1755 (2011)

3. James H. Brown et al., The fractal nature of nature: power laws, ecological complexity and biodiversity. *Phil. Trans. R. Soc. Lond.* B **357**, 619–626 (2002)

4. R.H. McArthur, Geographical Ecology, *Princeton University Press* (1972)

5. T.M. Blackburn and K.J. Gaston, A sideways look at patterns in species richness, or why there are so few species outside the tropics. *Biodiversity Letters* **3,** 44-53 (1996)

6. D.H. Janzen and C.M. Pond, A comparison, by sweep sampling, of the arthropod fauna of secondary vegetation in Michigan, England and Costa Rica. *Transactions of the Royal Entomological Society of London* **127,** 33-50 (1975)

7. R.F. Kay et al., Primate species richness is determined by plant productivity: implications for conservation. *Proceeding of the National Academy of Science* USA **94**, 13023-13027 (1997)

8. J.J. Wiens and C.H. Graham, Niche Conservatism: integrating evolution, ecology and conservation biology. *Annual Review of Ecology, Evolution and Systematics* **36**, 519-539 (2005)

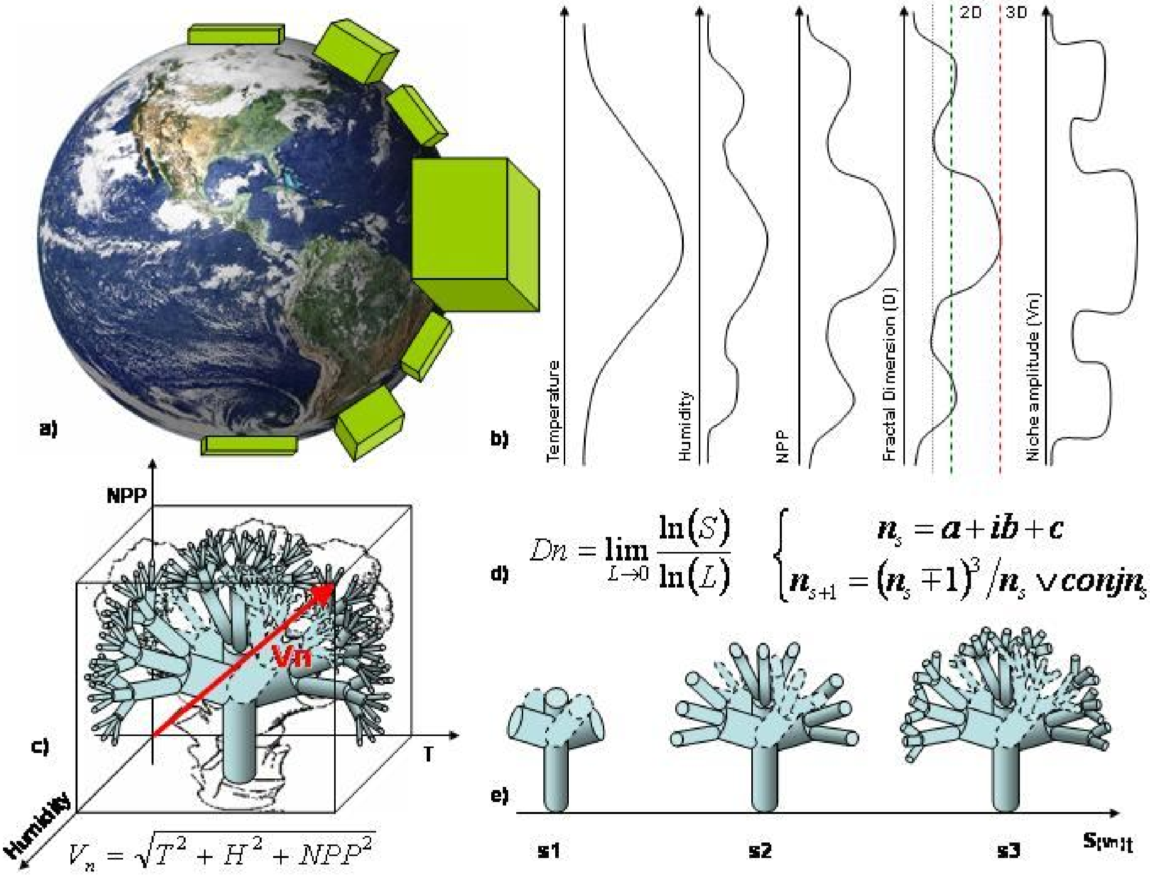
9. D.J. Currie et al., Predictions and tests of climate-based hypotheses of broad scale variation in taxonomic richness. *Ecology Letters* **7,** 1121-1134 (2004)

10. R. Cazzolla Gatti, Evolution is a Cooperative Process: The Biodiversity-related Niches Differentiation Theory (BNDT) Can Explain Why. *Theoretical Biology Forum*, **104**-1 35-44 (2011)

Figure Captions

Fig. 1. The latitudinal gradient of biodiversity can be explained as differences in ecosystem niche amplitude (*a*) and fractal dimension derived by the combination of T, H and PPN (*b*). These three variables are the axis of the fractal hypervolume (*c* and green polygons in *a*). The fractal 3-D cauliflower (*d*) is the best fitting mathematical object (*e*) that takes into account the addiction of new species within the fractal ecosystem niche (*c*). The number of species present in each region are thus dependent on the number of possible iterations of the fractal function (*e*) which is constrained by the ecosystem niche amplitude (Vn).

Figure 1


a)
b)
Temperature
Humidity
NPP
Fractal Dimension (D)
2D
3D
Niche amplitude (Vn)
c)
NPP
T
Humidity
Vn
$V_n = \sqrt{T^2 + H^2 + NPP^2}$
d)
$Dn = \lim_{L \to 0} \frac{\ln(S)}{\ln(L)}$
$\begin{cases} n_s = a + ib + c \\ n_{s+1} = (n_s \mp 1)^3 / n_s \vee conjn_s \end{cases}$
e)
s1
s2
s3
$S_{(Vn)t}$