



## Distribution of species diversity values: A link between classical and quantum mechanics in ecology



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### ABSTRACT

Despite the well-known thermodynamic traits of ecosystem functioning, their description by means of conventional physics should be regarded as incomplete, even if we take into account the most recent advancements in this field. The analytical difficulties in this field have been especially complex to get a reliable modeling of species diversity per plot ( $H_p$ ) by endowing this indicator with a fully clear theoretical meaning. This article contributes to resolve such difficulties starting from (a) the previous proposal of an ecological state equation, and (b) the preceding empirical finding of an ecological equivalent of Planck's constant at the evolutionary scale. So, in the first instance, this article proposes an equation for density distributions of  $H_p$  values ( $ED_H$ ) based on a simple transformation of the Maxwell–Boltzmann distribution for molecular velocity values ( $M-BD_v$ ). Our results indicate that the above-mentioned equation allows an appropriate fit between expected and observed distributions. Besides, the transformation from  $M-BD_v$  to  $ED_H$  establishes connections between species diversity and other indicators that are consistent with well-known ecological principles. This article, in the second instance, uses  $ED_H$ s from a wide spectrum of surveys as an analytical framework to explore the nature and meaning of stationary trophic information waves (STIW)s whose stationary nature depends on the biomass-dispersal trade-off in function of  $H_p$  values ( $B-D_{TO-H}$ ) that characterizes the most of the explored surveys.  $B-D_{TO-H}$  makes these surveys behave as ecological cavity resonators (ECR) by trapping functional oscillations that bounce back and forth between the two opposite edges of the ECR: from  $r$ -strategy (at low biomass and diversity, and high dispersal) to  $K$ -strategy, and vice versa. STIW)s were obtained by using the spline-adjusted values from the arithmetical difference between standardized values of species richness ( $S$ ) and evenness ( $J'$ ) in function of  $H_p$  values (i.e., a 2D scalar space  $H_p, S-J'$ ). Twice the distance on the abscissas ( $2\Delta H_p$ ) between successive extreme values on the ordinates (whatever a maximum or a minimum) along the above-mentioned spline adjustment was taken as the value of ecological wavelength ( $\lambda_e$ ).  $\lambda_e$  was assessed in order to obtain the value of the ecological equivalent of Planck's constant ( $h_e^{ec}$ ) at the intra-survey scale that was calculated as:  $h_e^{ec} = \lambda_e \times m_e \times I_e$ ; where  $m_e$ : individual biomass, and  $I_e$ : an ad-hoc indicator of dispersal activity. Our main result is that the observed value of  $h_e^{ec}$ 's mantissa is statistically equivalent to the mantissa of the physical Planck's constant ( $h = 6.62606957E - 34 Js$ ) in all of the discontinuous (i.e., with interspersed categories in which  $n = 0$ ) statistical density distributions of  $H_p$  values per survey.

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This means that  $h_e^{ec} = 6.62606957E\varphi J_e$  nat/individual, where  $\varphi = -x_1, \dots, -3, -2, -1, 0, +1, +2, +3, \dots, +x_i$  depending on the type of taxocenosis explored. That is to say,  $h_e^{ec}$  indicates the minimum amount of energy exchange allowed between two individuals. The exploration of the analytical meaning of this result in the final sections of the article explains why quantum mechanics (QM) is a useful tool in order to explain several key questions in evolutionary biology and ecology, as for example: the physical limit of adaptive radiation; the balance between competitive exclusion and functional redundancy to promote species coexistence by avoiding the negative effects of competitive exclusion; the apparent holes in the fossil record; the progression of body size along a wide spectrum of taxa as a general evolutionary trend; the non-continuous nature of net energy flow at the ecosystem level; the way in which the energy level is stabilized under stationary ecological conditions; the reasons of the higher sensitivity of high diversity ecosystems under environmental impact despite their higher stability under natural conditions; the tangible expression of complex concept as ecological inertia and elasticity; as well as the increased risk from pushing the biosphere until a rupture limit because of the potential discrete behavior of ecological resilience in the large scale due to the quantum nature of ecosystem functioning.

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## 1. Introduction

Species diversity is one of the most widespread and interesting ecological concepts. Ecologists have considered, for several decades, that species diversity has multiple and remarkable interactions with other concepts as stability (e.g., McNaughton, 1978; Zaret, 1982; Kimmerer, 1984; Tilman et al., 1998; Li and Charnov, 2001; Pfisterer and Schmid, 2002; Ptacnik et al., 2008), habitat perturbation (e.g., Mackey and Currie, 2001; Solé et al., 2004) and trophic energy or “production” (e.g., Tilman et al., 1997, 2001; Evans et al., 2005; Huston and Wolverton, 2009; Witman et al., 2008; Rodríguez et al., 2013a,b, 2015a,b).

The concept of species diversity was theoretically analyzed in a rigorous manner first, by Hurlbert (1971). He pointed out, among other problems, toward the weak theoretical support for correlations between species diversity and other indicators. There are not particularly strong reasons to consider that this situation has radically changed nowadays (see Rossberg, 2008, p. 21). It is very probable that this situation is rooted in the fact that the most frequently used measure of species diversity (Eq. (1)) was borrowed from a foundational external source (Shannon, 1948). This source includes certain degree of relativism in regard to: (1) the name assigned to this concept itself (see Tribus and McIrvine, 1971), and (2) the subject taken as a reference point to describe the transmission of signals. That is to say, a net input of information ( $H$ ) means a reduction of uncertainty that, simultaneously, is equivalent to a local net output of entropy (Tribus and McIrvine, 1971; Ayres and Nair, 1984; Ayres, 1994, p. 36).

$$H = - \sum_{i=1}^S \left[ \left( \frac{n_i}{N} \right) \left( \ln \frac{n_i}{N} \right) \right] \quad (1)$$

where  $S$ : species number,  $n_i$ : number of individuals of species  $i$ ,  $N = \sum n_i$ ,  $H$  is conventionally expressed in nat/individual when natural logarithms are used.

Several of the current theoretical trends about biodiversity could be seen as attempts to answer those doubts stated by Hurlbert forty-four years ago. Thus, we continue looking for a solid theoretical meaning (Spellerberg and Fedor, 2003) for a concept whose main commitment is to reflect a tacit empirical truth: that the undeniable successional increase of species diversity is a sort of “central dogma” in ecology (e.g., Margalef, 1963; Odum, 1969).

Nevertheless, is it right to grant so much importance to species diversity? What is the “normally” expected statistical behavior of diversity under a given set of ecological conditions? Is there any general way to model diversity starting from other significant ecological indicators? Could be used this way to model diversity as an analytical framework to expand our understanding of the

ecosystem functioning? What is the role of other disciplines to assign a solid theoretical meaning to species diversity?

According to recent findings,  $H$  can be successfully used as the main state variable to obtain: (1) an ecological state equation (ESE; Rodríguez et al., 2012; see Eq. (6)) that is universally valid providing that the system analyzed is under stationary or quasi-stationary ecological conditions (SEC, hereafter); (2) a consistent explanation for the relationship between production and species diversity (Rodríguez et al., 2013a,b); (3) a potential solution to the debate between competitive exclusion principle (CEP, one species  $\leftrightarrow$  one niche; Hardin, 1960; Darlington, 1972; Gordon, 2000; Wang et al., 2005) and functional redundancy (FR, several species  $\leftrightarrow$  one niche; Walker, 1992; Lawton and Brown, 1994; Wohl et al., 2004; Petchey and Gaston, 2006; Mayfield and Levine, 2010) through a stationary waves model for species coexistence (WMSC) based on the concurrency between transient equilibrium nodes of CEP, and wide antinodes of limited FR; in a similar way to the standing waves on a string (see Rodríguez et al., 2013b).

The attempts to describe the ecosystem via statistical mechanics are abundant (e.g., Messer, 1992; Schneider and Kay, 1994; Svirezhev, 2000; Zhang and Wu, 2002; Jørgensen and Svirezhev, 2004; Jørgensen and Fath, 2004; Maurer, 2005; Shipley et al., 2006; Dewar and Porté, 2008; Capitán et al., 2009; Banavar et al., 2010; Kelly et al., 2011), and they are based, in general, on the concept of species diversity. Thus, the approach reflected in the items of the previous paragraph appears to be usual but, in the second instance, it is quite unusual precisely because of its full equivalence to the standard physical algorithm, in comparison with the proposals mentioned in this paragraph.

In addition, Rodríguez et al. (2015b) showed, at the inter-survey level, that a robust straight line adjustment between  $E_e$  and the ecological equivalent ( $k_e$ , see additional explanations in Eq. (6)) of the Boltzmann constant ( $k_B$ ) has a regression constant whose mantissa ( $h_e^{ev} = 6.6260727E - 01 J_e \cdot \nabla k_e$ ; where  $\nabla k_e = 1 J_e$  nat/individual;  $ev$ : inter-taxocenosis or evolutionary scale;  $J_e$ : ecoJoule, an *ad hoc* ecological measurement unit, see additional explanations in Appendix A, Section 2) coincides with the respective value of physical Planck's constant ( $h = 6.6260727E - 34 J_s$ ; see e.g., Halliday et al., 1999; Tipler and Mosca, 2010<sup>1</sup>). The above-mentioned paper concludes that the evolutionary process can be understood as an initial “micro-plot of life” that has been “ecologically driven” across a step by step evolutionary gradient ( $\nabla k_e$ ) of exchange of information by eco-kinetic energy at a constant eco-kinetic energy increment rate of  $h_e^{ev}$  per each unit of  $\nabla k_e = 1 J_e$  nat/individual.

<sup>1</sup> All the following comments about conventional physical principles without citing a particular source are supported by principles, methods and concepts exposed in any of these two books.

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