



## HOW MANY SPECIES OF LIVING BEINGS FIT INTO THE UNIVERSE?

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Corresponding author email: edgardoga2@hotmail.com**ABSTRACT**

Extraterrestrial life is to be discovered soon so we aim to contribute to Astrobiology to go beyond by asking the same as Ecology: how many species the universe hosts and how such a number changes in space and time. Based on data from Amazonian and other tropical forests, it could be said that the universal number of species may tend to infinite because of the huge availability of space and ecological niches. However, living beings are particles of which species are groups so the just mentioned hypothesis is not viable. By falsifying that, we show how the number of species oscillates at different moments of universal history depending on the rates of speciation and extinction, each of them multiplied by a species accumulation factor to be calculated based on the age of the first planet producing life. We use the instant of the Big Bang as the time of origin for all formulations. We feature Big-Bang-time standardized formulae to estimate the number of species for each planet so the average among planets can be a proxy for the universal number of species to be updated as Astrobiology continues its progress. Effects of migration, habitat constraints, and related Natural Selection are absorbed by our equations. Our formulae are compatible with Fisher's biodiversity index. Once humankind will discover living and fossil life outside Earth, a major step to be made will be the discovery of the planet where life was born at first.

**KEY WORDS:** Amazon, Big Bang, Fisher's , Speciation-Extinction, Species accumulation factor.**INTRODUCTION**

Humankind have always asked whether we are alone in the Cosmos. Conservatively assuming that the chemistry of life is similar on other planets respect to ours (Huang 1959), astrobiologists have discovered hundreds of potentially inhabited planets (Adibekyan *et al.*, 2016; Armstrong *et al.*, 2016; Kopparapu, 2013; Lineweaver and Chopra, 2012). Chances to find life outside Earth become larger when considering that life on other planets may not necessarily be based on the same chemical substances than here. Astrobiology is putting on the table a cosmic-level expansion of two fundamental questions of Ecology: how many life forms are there –in the universe and why they are present on some places (planets) but not on others. Ecologists address aforementioned questions by surveying biodiversity while recording its distribution. Indeed, we begin this essay by exposing how biodiversity surveys are

made and the way they lead to ask *how many species of living beings fit into the universe?* We illustrate how terrestrial field data from the Amazon and the definition of ecological niche suggest the universal number of species may tend to infinity. We then use the latter as a working hypothesis (H-1) and proceed to falsify it while developing another. In concrete, we feature hypothesis H-2a indicating that the number of species held by the universe at any time of its history depends on: speciation, extinction, rise, and annihilation of life on celestial objects (hereafter *planets*). We introduce a similar model to be applied to any planet (hypothesis H-2b). Towards the end of this article, we show that our models are compatible to Fisher's biodiversity index (Fisher's- ). Table 1 summarizes all equations discussed in this paper. Used symbols are explained throughout the text and summarized in appendix 1.

**TABLE 1.** Formulae for addressing how many species of living beings fit into the universe and its components. Speciation, extinction, and rises of life are considered to determine the number of species. See symbols throughout text or in appendix 1.

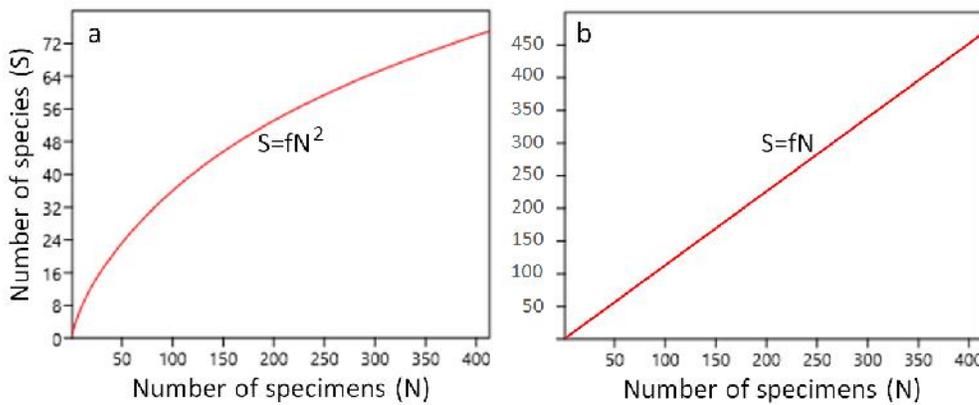
| Equation | Formula                               | Explanation  | Application levels (examples)                  |
|----------|---------------------------------------|--|--|
| 1        | $\lim_{S \rightarrow \infty} S = fN$  | limit of the number of species when each species has one individual      |  |
| 2        | $\lim_{S \rightarrow \infty} S = N^+$ | maximum number of species hypothetically (H-1) fitting into the universe | universe                                       |
| 3        | $E = S_n / t$                         | universal speciation rate  | universe                                       |
| 4        | $e = s_n / t$                         | speciation speed on any celestial object                                 | planet, satellite                              |
| 5        | $e_{prom} = e_i / i$                  | average speciation rate  | universe, galaxy, solar system, habitable zone |

|    |                       |  |  |
|----|-----------------------|--|--|
| 6  | $g = tv - t_{form}$   | interval between the formation of a celestial object and the rise of life there  | planet, satellite                                |
| 7  | $m = 1 - [g/tv]$      | species-accumulation factor of a celestial object  | planet, satellite                                |
| 8  | $m_{prom} = mi/i$     | average species-accumulation factor (m) among celestial objects  | universe, galaxy, solar system, habitable zone   |
| 9  | $G = tvD - t_{form}D$ | time spent by the universe to generate life by the first time after forming the planet where life rose   | universe   |
| 10 | $M = 1 - [G/tvD]$     | universal species-accumulation factor  | universe   |
| 11 | $P = Sp/ t$           | universal speed of extinction  | universe   |
| 12 | $p = sn/ t$           | extinction speed on a celestial object   | planet, satellite                                |
| 13 | $S = [ME - MP] / t$   | <b>Hypothesis H-2a:</b> universal biodiversity equation. The universal number of species for any moment of the history of the universe. Correction of hypothesis H1 (see equation 2) | universe   |
| 14 | $s = [me - mp] / t$   | <b>Hypothesis H-2b:</b> number of species on a celestial object for any moment of its history  | planet, satellite                                |
| 15 | $s_{prom} = ( si)/i$  | average number of species among celestial objects  | universe, galaxy, solar system, habitable zones. |

**SURVEYING BIODIVERSITY: AN AMAZONIAN EXAMPLE**

Ecologists make surveys to assess biodiversity. For instance, in order to determine how many tree species coexist in a hectare of Amazonian forest, field biologists delimit the hectare, then walk among trees, and register the species of each tree. Individuals are marked with unique numbers so no specimen is registered twice. In this way, identity numbers and species are registered for individuals 1, 2, 3, and so forth. We made this for some fragments of Amazonian secondary forests. The forest of one of those fragments was just 35 years old and we only surveyed all trees 10 cm diameter (Garrido-Pérez *et al.*,

in prep.). Our data enabled us to make the graph shown in figure 1a where the first tree in the survey belonged to species 1, the second to species 2, the third to species 3, and so on. The curve remained fairly straight for the first ~10 individuals (fig.1a). But as the survey progressed, some individuals started to belong to previously registered species. The same occurs to very exhaustive surveys of insects, birds, and other living beings because some species are represented by two, three, or even tens of individuals. Therefore, resulting line is curve and described by a second-degree function (fig. 1a) instead of straight and described by a first-degree function (fig.1b).



**FIGURE 1.** Rarefaction curves showing the accumulated number of species in response to the cumulative number of individuals. (a) Actual curve got because of species having more than one individual. (b) Curve to be obtained if all species had one individual. Graphs were made after surveying all trees 10 cm diameter inside a 1ha plot in a secondary forest in the Ecuadorian Amazon (Garrido-Pérez *et al.*, in prep.). S=number of species, N=number of individuals, f= function."

Notice that the curve of figure 1a asymptotically tends to an upper limit. If we had surveyed all trees of the world – rather than only 10cm diameter-trees inside 1ha, we had reached a fairly acceptable empirical value for the mentioned limit on our planet. For 10cm diameter trees, multi-country surveys suggest there are >40 000 (and perhaps >50 000) species all over the tropics (Silk *et al.*, 2015). Determining how many species our planet hosts is a first step for sampling biodiversity across the universe.

**FROM ONE HECTARE TO THE UNIVERSE: HOW MANY SPECIES ARE THERE?**

Let us focus on one hectare, then move to universal dimensions. By looking into the axes of figure 1a we realize our 1ha plot had about 415 individuals belonging to some 72 species. Since our curve started to reach a plateau, we can declare our 1ha-plot fairly represented tree species living on the site. However, we cannot argue the same for the overall biodiversity because we excluded small trees and shrubs, herbaceous plants, bryophytes, vertebrates, invertebrates, fungi, and microorganisms.

Including all these may have put out a much larger number of species. Moreover, resulting curve would have become much similar to figure 1b where the line tends to infinity, rather than asymptotically approaching a limit.

Living beings are particles ranging from giants (like trees and dinosaurs) to microorganisms (like protozoans and bacteria). Small particles have higher likelihoods of occupying at least one place in space compared to larger particles. For instance, the chances of bacteria to find a place inside one hectare is much higher compared to the chance for an elephant. Conversely, large spaces have higher chances of hosting at least one life form, compared to smaller spaces: the number of living beings able to fit into one hectare is smaller than in two hectares, in three hectares, and so on.

Moreover, living beings survive on a place by exploiting its resources –like nutrients and tolerating conditions like temperature, moisture, acidity, and so on. According to the concept of niche and niche-partitioning theories as well, different species tend to specialize in using different amounts of all these resources and tolerating different ranges of the conditions (e.g. Cardinale, 2011; Silvertown, 2004). Small spaces offer less ecological niches while larger spaces offer more ecological niches. For surveying biodiversity, the lower sample unit can be a grain of dust while the largest sample unit can be the universe. The universe has so much space offering so many niches that we may wonder that the cosmos is not full of life. In fact, it has been proposed that nearly 100% of all stars can be surrounded by at least one Earth-like planet potentially hosting life (Lineweaver and Chopra, 2012).

However, every particle has a limited size so all particles fitting into a given space can eventually saturate it. If particles are classified into species, then the number of species fitting into the space should be possible to get determined by means of calculus, or at least estimated using statistics.

**BIODIVERSITY AND LIMITS**

In order to guide the search of how many species fit into the universe, we first establish a maximum hypothetical range where such a number should appear (hypothesis H-1). Then, while criticizing the limits of such a range, we will propose an alternative hypothesis (H-2): a formula to determine the number of species the universe can host at any time of its history. The lowest possible number of species is zero (total absence of life). Let us assume that, on the other extreme, the theoretically most extreme possibility is each species to be represented by one individual so the total number of species (S) corresponds to the total number of individuals (N). In such a case, resulting species-cumulative curve would be similar to figure 1b with function fN and limit:

$$\lim_{S \rightarrow N} S = fN. \text{ (equation 1)}$$

But we already know smaller individuals have higher likelihood of finding any space. Thus, when the size of any living being asymptotically tends to zero, space available for the individual asymptotically tends to plus infinity (+ ∞). Therefore, the maximum number of individual’s theoretically fitting into (an infinite) universe may tend to plus infinity (N → + ∞). Assuming this as true,

and if  $\lim_{S \rightarrow N} S = fN$ , then we can hypothesize (H-1) the maximum number of species able to fit into the universe tends to + ∞ too:

$$\text{if: } \lim_{S \rightarrow N} S = fN. \text{ (equation 1),}$$

and, if:  $N \rightarrow + \infty$ ,

$$\text{then: } \lim_{S \rightarrow N} S = fN = f(+ \infty),$$

and therefore:

$$\lim_{S \rightarrow N} S = + \infty \text{ (equation 2; hypothesis H-1).}$$

In a nutshell, the “virtually infinite” available space and ecological niches supplied by the universe contribute to explain why efforts to find extraterrestrial life are highly expected to find it (see also Heller and Armstrong, 2014; Lineweaver and Chopra, 2012). Nevertheless, species concepts as well as speciation, extinction, rise, and annihilation of life avoid the universal number of species to tend to infinity. Let us expose all these in order to be able to combine the mentioned processes in a general formula to calculate how many species the universe may host at a given time of its history.

**SPECIES CONCEPTS AS LIMIT TO THE UNIVERSAL NUMBER OF SPECIES**

Classically (Futuyma, 2013a; Mayr, 1963), a biological species is a group of organisms actually or potentially able to interbreed and produce fertile offspring. Other definitions discussed by the same authors consider species as groups too. For instance, a morphological species is a group of individuals sharing the same phenotypic characteristics. If species are groups, then species have >1 individual, making impossible the number of species to be always the same as the number of individuals anywhere. This avoidance to the fulfillment of  $S = N$  makes  $S \rightarrow + \infty$  impossible as well. Therefore, even if the universe had  $N = + \infty$ , the total number of species must be  $S < + \infty$ .

**LIMITED SPECIATION RATES**

Speciation is the production of new species from pre-existing ones (Futuyma, 2013b). Speciations occur in space, generating species that may occupy ecological niches. Individuals of the resulting species also occupy fragments of the universal space. Also, speciations take time so speciation rate is the increment of the number of new species (Sn) appearing during a given time span (t). We can calculate a universal speciation rate E for a given time span of universal history as follows:

$$E = Sn / t \text{ (equation 3),}$$

where t can be calculated for any instant after the Big Bang considering the latter as “time zero” or time of origin (O). In other words, t = t-O. Slower speciations take longer to fill spaces and ecological niches made available by the universe compared to faster speciations. On Earth, speciation rates and the speed of other aspects of evolution change (see Fitch and Ayala (1994), and references therein). Also, speciation in some planets may be faster compared to other planets (Lineweaver and Chopra, 2012) so we need to adapt equation 3 to calculate speciation rates for particular planets, and for comparing among planets. We make it by staying using O for calculating t thereby using the Big Bang as a universal standard to calculate any time span. For a given planet we have:

$$e = sn / t \text{ (equation 4)}$$

Where  $e$  is the speciation rate for the planet, and  $sn$  is the change in the number of new species there.

While an empirical value of  $E$  is very difficult to achieve because of the large size of the universe, field data to be got in a relatively nearer future will enable scientists to average  $e$  among planets. Let us call  $e_{\text{prom}}$  to such an average. This  $e_{\text{prom}}$  and its confidence intervals will expectably allow to start estimating universal speciation rates  $E$ . The  $e_{\text{prom}}$  is to be got as follows:

subindex:  $e_{\text{prom}} = e_i/i$  (equation 5),

where  $i$  is the total number of planets in the sample (e.g. the universe). Notice that  $e_{\text{prom}}$  can be obtained for systems of planets, galaxies, and other groups of planets; then compared among groups in order to check whether speciation rates are faster in some zones of the universe compared to others for a given period of universal history.

### LIMITED NUMBER OF PLANETS PRODUCING LIFE

We propose life started to exist so late after time  $O$  that speciations had no time to fill all universal space and ecological niches (see also Lineweaver and Chopra, 2012). Life is made out of molecules and feasibly rose on Earth as a result of autochthonous molecular processes. That is why astrochemists (e.g. Shematovich, 2012) look for complex molecules in the cosmos when searching for life. This suggests the moment where celestial objects produce molecules ( $t_{\text{form}}$ ) is crucial for further rise of life (see also Shematovich, 2012). The process culminates at a moment  $t_v$  where the first life form appears on the planet. Once again, all  $t$ -values like  $t_{\text{form}}$  and  $t_v$  are standardized respect to the Big Bang (time  $O$ ) in order to assess the uneven production of life among all planets of the universe. That makes  $t_{\text{form}}$  and  $t_v$  to respectively represent the age of the universe when: (1) a given life-hosting planet started to have molecules, and (2) when life started to exist in such a planet. By resting  $t_v - t_{\text{form}}$  we calculate the time span  $g$  spent by the planet to generate life:

$g = t_v - t_{\text{form}}$  (equation 6).

Planets spending longer to produce life will have smaller  $g$ -values compared to other planets. Let us illustrate that by assuming two planets hosting life today and that both planets are the same age after time  $O$ . From these two planets, the one where life rose latter will have lower  $g$ -value so the planet had less time for accumulating species compared to the other planet. This illustration makes clear the following: because not all planets have the same age, and because life may have arose latter in some planets respect to others, we need to calculate a species-accumulation factor ( $m$ ) for each planet in order to this number to correct the speciation rate of the planet ( $e$ ), otherwise our  $e$ -values will not suffice to kinetically describe universal biodiversity. For calculating  $m$ , we standardize the  $g$  of a given planet per the time spent by life to rise in such a planet ( $t_v$ ) as follows:

$m = 1 - [g/t_v]$  (equation 7)

or in other terms:

$m = 1 - [(t_v - t_{\text{form}})/t_v]$ .

Thus,  $m$  changes inside a continuum ranging from 0 to 1 where smaller values correspond to planets having longer time to accumulate species by means of speciations (since life rose earlier after the Big Bang on such planets). On the contrary, planets with larger  $m$ -values will be the ones where life spent longer to arise so they have had less time to accumulate species. As well as for  $e$  and other values featured here, an average  $m_{\text{prom}}$  (and its confidence interval) can be got by taking into account the  $m_i$  ( $m$ -values for all  $i$ -planets) as follows:

$m_{\text{prom}} = m_i/i$  (equation 8)

It is also possible to obtain an  $m$ -value for the whole universe, then use it as a factor to adjust the universal speciation rate ( $E$ ) at a given time span –shown in equation 3. The Big Bang and its closest periods are not to be considered as the instant starting the process of rise of universal first-born life because no molecule existed then. Instead, the production of life should have started at the  $t_{\text{form}}$  of the planet that produced first-born life in the universe. Let us call  $D$  to such a planet,  $t_{\text{form}}D$  to the instant of the first formation of molecules there after time  $O$ , and  $t_vD$  to the instant where life rose there after time  $O$ . All these enables us to modify equations 6 and 7 in order to calculate: how much time was needed for the universe to generate first-born life ( $G$ ), and a universal species accumulation factor ( $M$ ) useful to correct universal speciation rates ( $E$ ) at any period of universal history. Let us proceed:

$G = t_vD - t_{\text{form}}D$  (equation 9)

and

$M = 1 - [G/t_vD]$  (equation 10),

or in other terms:

$M = 1 - [(t_vD - t_{\text{form}}D)/t_vD]$ .

Thus, the universal species-accumulation factor is an index of how long the universe has taken to produce life. If  $M$  is to be calculated now, its value should be very unprecise because we know only one planet (Earth) hosting life. Evidence that Mars hosted life (McKay *et al.*, 1996) is still under criticism and investigation (e.g. Tosca *et al.*, 2008) and can point to former, not current life there (Squyres and Knoll, 2005). If confirmed, that suggests Mars may have experienced both extinction and annihilation of life (see also Lineweaver and Chopra, 2012) –which are processes making the universal number of species  $< +$ .

### EXTINCTIONS, ADAPTIVE RADIATIONS, AND ANNIHILATION

While speciations tend to fill the universe with species, extinctions tend to make the universe empty of species. So, a modified version of equation 3 replacing speciation rate ( $E$ ) by extinction rate ( $P$ ) denotes how fast species are lost at any period of universal history:

$P = S_p / t$  (equation 11),

where  $S_p$  is the number of species the universe losses by extinction at the time span  $t$ . Also, extinctions can be calculated for planets and other spatial scales smaller than the universe. Planets where extinction rate is faster are the ones more vigorously re-opening ecological niches in the universe. All these lead us to modify equation 4 in order to

get a formula for the extinction rate ( $p$ ) of any planet as follows:

$$p = s_p / t \text{ (equation 12),}$$

where  $s_p$  is the number of species the planet loses for the studied time span  $t$ . Where extinction is not total, remaining species experience adaptive radiations so the planet accumulates new species again. Classic paleontological studies have documented cycles of mass extinction-and-further-radiation taking place every ~26 million years on Earth (Raup and Sepkoski, 1986). Thus, Earth sometimes adds- and sometimes reduces the overall species pool of the universe. There is no reason to deny other life-hosting planets to do the same.

Life annihilation is an extreme case of extinction reducing the number of species to zero, and being thereby the opposite of the rise of life on any planet. Planets with higher  $g$ -values (and smaller  $m$ -values) generated life earlier after the Big Bang so annihilation there had longer time for occurring. Therefore, the same species-accumulation factor ( $m$ ) for a given planet is needed to modify the extinction rate ( $p$ ) when kinetically describing extinction there. Keeping the same logic, the  $M$ -value is useful to describe extinction kinetics for the whole universe. Thus, factors  $m$  and  $M$  help to correct the rates of increase and decrease of the number of species at both planetary and universal levels –as well as their intermediate levels (e.g. galaxies).

### COMBINING EQUATIONS

The number of species hold by the universe at any time of its history is the balance between processes enhancing- and reducing life's production and diversification. Therefore, we now can combine all already discussed equations into single formulas to assess how many species the universe (and its planets) holds at a given moment. summing equations 3, 10, and 11 we have:

$$S = [ME - MP] / t \text{ (equation 13) (universal biodiversity equation).}$$

In words: the total possible number of species in the universe ( $S$ ) at a given time after the Big Bang is: the product of the species-accumulation factor ( $M$ ) multiplied by the universal speciation rate ( $E$ ) at the given time, minus the product of the species-accumulation factor ( $M$ ) multiplied by the universal extinction rate ( $P$ ) at the given time, then divided per the age of the universe has for the studied period ( $t$ ) respect to the Big Bang. Thus, equation 13 corrects hypothesis H-1: the number of species in the universe is a reachable value; it does not tend to infinity. Notice that  $S$ -values may oscillate around a time-series trend line throughout the history of the universe.

For now, the large size of the universe makes difficult to empirically get values of  $S$ . But our theory supplies a theoretical framework for interpreting the increasing evidence provided by Astrobiology. Humans will enhance the precision of values of the number of species ( $s$ ) for different planets over the centuries. The average of these  $s$ -values ( $s_{prom}$ ) will become a proxy of  $S$ . In other words,  $S_{prom}$  and its surrounding confidence intervals estimate (give probable values) of  $S$ , while  $S$  itself and its oscillations throughout cosmic time remain as the possible numbers of species in the universe. The  $s$ -value for any

planet can be calculated by combining equations 4, 7, and 12 as follows:

$$s = [m_e - m_p] / t \text{ (equation 14) (number of species on a celestial object),}$$

and the average of such numbers of species ( $s_{prom}$ ) can be got as follows:

$$s_{prom} = (\sum s_i) / i \text{ (equation 15)}$$

where  $s_i$  is the number of species on the  $i$ th planet, and  $i$  is the number of planets. So,  $s_{prom}$  is to be calculated like this:

$$s_{prom} = (s_1 + s_2 + s_3 \dots s_i) / i$$

Also,  $s_{prom}$  can be obtained for groups of planets like systems, galaxies, and so on making possible to compare species richness among groups of planets.

### FISHER'S- AND UNIVERSAL BIODIVERSITY

Interestingly, our equations to determine  $S$  and  $s$  are related to the already classic (Fisher *et al.*, 1943) and widely used (e.g. Silk *et al.*, 2015) Fisher's- biodiversity index. Alpha is taken from the log-series equation  $S = \ln(1 + N/\alpha)$  where  $S$  is the number of species in a sample, and  $N$  is the number of individuals; these are the same variables we used as a start point for all our reasoning. According to Fisher's- ,  $S$  only changes as a function of  $N$ . When sampling more than 1000 individuals, the effect of the variation of the sampling effort on  $S$  is virtually negligible (Magurran, 2004). Technical contingencies like large distances among planets and risks of spacecraft's damage may make the (palaeo)biota of some planets to be better sampled than the one of others. Biodiversity indexes other than Fisher's (e.g. Shannon's) use the number of individuals and species, but also the number of individuals per species. Therefore, such indexes are less parsimonious- and more sensitive to sample size compared to Fisher's- . For all these, Fisher's log-series should continue being useful to assess biodiversity beyond Earth while complementing information to be got using our equations.

### MIGRATIONS, HABITAT CONSTRAINTS, AND NATURAL SELECTION

Interplanetary migrations may: (1) alter the number of species on the host planet, making "repeated species" to appear on different planets, but not changing the total number of species in the universe for the studied time span. (2) Migrations can start allopatric speciation as explained by Mayr (1963): migrants on an isolated place mate among themselves, then can evolve there eventually producing new species. In such a way, migrations can enhance the universal number of species. On counterpoise, migrating species can enhance extinction by competitively excluding some local species (Pérez *et al.* 2012).

For just explained processes to occur, migrating species need to survive and reproduce on its newly-reached planet, despite the filtering effect of the biotic and non-biotic constraints there (Pérez *et al.* 2012). All these processes are related to Natural Selection and are to be considered mechanisms underlying  $E$ ,  $P$ , and  $m$ -values, yet the roles of those processes are comprehended in our equations 4 and 6 and thereby throughout all our formulae.

## CONCLUSIONS

Living beings only use an extremely small fraction of the space and ecological niches existing in the universe. The slow pace of the processes of rising and diversification of life, together with extinction and annihilation, avoid the Cosmos to be totally occupied by living beings. The universal number of species is neither infinite nor fixed: its value may change throughout time in response to: speciation- and extinction rates, time span after the Big Bang, and the universal species accumulation factor related to the rise of life. For establishing how many species may fit into the universe, it is crucial to discover the planet where life appeared at first; that will be an exciting, major challenge for Astrobiology.

Modern biodiversity research started in 1735 when Carolus Linnaeus sampled and sorted living beings into his *Systema Naturae*. Almost 300 years later, classic Biology still has “a universe” of data to collect for understanding biodiversity. The job is hard but affordable: any total number of species in the universe is finite, and consequently prone to be discovered, or –at least estimated.

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**Appendix 1. Symbols and abbreviations used in this paper.**


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|                   |   |                    |   |
|-------------------|---|--------------------|---|
|                   | greater or equal than                                 | $g$                | interval between the formation of a celestial object and the rise of life there       |
| $\sim$            | approximately   | $m$                | species-accumulation factor of a celestial object                                     |
| $=$               | equal   |                    | summation   |
| $S$               | total number of species. Also for the universe        | $m_{\text{prom}}$  | average species-accumulation factor among celestial objects                           |
| $N$               | total number of individuals                           | $D$                | the first celestial object where life rose in the universe                            |
| $f$               | function of   | $t_{\text{form}D}$ | time spent for the formation of the celestial object $D$                              |
|                   | infinity  | $tvD$              | time spent for the rise of life on the celestial object $D$                           |
| $\lim$            | limit   | $G$                | interval between the formation of the celestial object $D$ and the rise of life there |
|                   | tends to  | $M$                | universal species-accumulation factor   |
| $<$               | less than   | $P$                | universal speed of extinction   |
| $E$               | universal speed of speciation                         | $Sp$               | number of extinct species in the universe from its origins (from the Big Bang)        |
|                   | change, difference                                    | $p$                | extinction speed on a celestial object  |
| $S_n$             | universal number of new species                       | $s$                | number of species on a celestial object   |
| $O$               | time of origin, instant of the Big Bang               | $sp$               | number of extinct species on a celestial object from its                              |
|                   |   | $t_{\text{form}}$  | time spent for the formation of a celestial object                                    |
| $t$               | time respect to the Big Bang                          | $s_{\text{prom}}$  | average number of species among celestial objects                                     |
| $sn$              | number of species on a celestial object               |                    |   |
| $e$               | speciation speed on a celestial object                |                    |   |
| $e_{\text{prom}}$ | average speciation rate among celestial objects       |                    |   |
| $i$               | $i$ -th   |                    |   |
| $t_{\text{form}}$ | time spent for the formation of a celestial object    |                    |   |
| $tv$              | time spent for the rise of life on a celestial object |                    |   |

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