DARWINIAN POND SYSTEM AS A MODEL FOR THE ESTABLISHMENT OF LIFE ON THE ARCHAIAN EARTH

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The main doubt that exists about the appearance and subsequent development of life on earth, regardless of whether its origin is due to panspermia or abiogenesis processes, is related to the necessary conditions so that, once implanted or synthesized, life can be established and prosper. Following the idea proposed by Darwin in 1873 that the origin of life took place in "warm shallow pools" located on newly emerged land, a mathematical model of a Darwinian Pond System is proposed, taking into consideration that, within the classification of fractional Brownian fractals, Mandelbrot addresses the study of the areas of islands, lakes and ponds, which in the present study will be called pond system, which will be understood as a set made up of a finite hyperbolic structure and connected to shallow hollows filled with warm seawater to the edge, which, upon receiving a small volume of additional water, will drain into other hollows, following a continuous downward path towards the sea. These geometric considerations turn out to be decisive for the establishment and subsequent development of emerging life forms on the archaic earth, whose predator-prey type dynamics are associated with a system of medium-sized ponds. The present study supports the theory that life on Earth first developed in small bodies of saline water located on dry land, and emerged through extensive geological processes 4 billion years ago, from where it subsequently flowed to the sea.

Key words: Darwinian ponds; Brownian fractals, Origin of life; Networks.

Introduction

The application of network science to biology has improved the understanding of the metabolism of individuals, organisms, and the organization of ecosystems, but it has hardly been applied to life on a planetary scale and even less to the study of the establishment and development of life on earth. There is growing interest in whether biology is governed by general principles, not tied to its specific chemical instantiation or contingent on its evolutionary history (Sterenly 1997). Such principles would be strong candidates for being universal to all of life (Gisiger, 2001; Goldenfeld et al. 2017). Universal biology, if it exists, would have important implications for our search for life beyond Earth (Davis & Walker, 2016; Walker et al., 2017), for designing synthetic life in the laboratory (Purnik et al., 2009; Bashor et al., 2010), and for solving the origin of life (Scharf et.al., 2015; Cronin & Walker,2016).

The main doubt that exists about the appearance and subsequent development of life on earth, regardless of whether its origin is due to panspermia or abiogenesis processes, is related to the necessary conditions so that, once implanted or synthesized, life can be established and prosper. Various types of primeval habitats have been proposed as cradles of life, of which the most accepted are the hydrothermal vents of the archaic seas and the hollows or shallow ponds on portions of land that emerged from the ancient seas (Cantine & Fournier, 2017; Clark & Kolb, 2020). Concerning hydrothermal vents, various authors maintain, based on their current knowledge of them, that they are habitats that are not very conducive to the development of living organisms because they eliminate too much heat, which would make the establishment of living organisms very difficult. for long periods.

On the other hand, in the case of hollows or shallow ponds, these could maintain more stable physicochemical conditions, which would allow the establishment of living beings and, more importantly, the development of new populations, however, they require the presence of land. firm to be able to act as "warm shallow pools". This idea was proposed by Darwin in 1873; For this reason, this second type of primitive habitat was not considered the strongest option for biogenic development on Earth. In fact, until 2021, there was no scientific evidence to maintain the idea of the existence of dry land areas. very possibly islands, in the archaic era (4000 million years ago), when new evidence obtained from computer simulation models, established the possibility of the emergence of seamounts above sea level, forming islands or island systems, over which hollows could develop, which, under the effect of solar energy, constitute stable habitats for life to establish, survive and prosper (Rosas & Korenaga, 2021).

Mathematical Model

Darwinian Pond System

It is important to note that scientific evidence indicates that the establishment and development of living organisms is a population-type phenomenon that requires an active interaction between individuals belonging to different genomic variants, quasispecies or species (Biebricher & Eigen, 2005), giving rise to the dynamics of competition for common resources, transmission of strong indirect population effects through trophic cascades, emergence of key species, migration, differentiation in terms of population density and body sizes (Goldenfeld & Woese, 2010; Carroll, 2018). These mechanisms of how life works were established as soon as the Darwinian limit was surpassed, the one that separates prebiotic forms from living forms themselves (Woese & Fox, 1977; Woese, 2002; Jeancolas et al. 2020). Since this work focuses on the role of ponds and more specifically pond systems, in this process they are called the "Darwinian Pond System".

To study the action of the population phenomena explained above, the model of the Darwinian Pond System, whose chemical and physical characteristics are related to the nature of its origin: geosphere, hydrosphere, atmosphere, and astronoosphere (**Table 1**), considers that, if Although the combination of these characteristics could have given rise to a large number of different types of ponds, in the present study it is assumed that, (i) the ponds were located on dry land, due to the geological phenomena predominant in the archaic era. (ii) the physical-chemical characteristics were generally quite homogeneous. (iii) the geometric structure and arrangement of the ponds played an essential role in the establishment and subsequent exponential spread of life.

It is precisely from this third point that the mathematical model of the Darwinian Pond System is developed, taking into consideration that, within the classification of fractional Brownian fractals, Mandelbrot (1977) addresses the study of the areas of islands, lakes, and "ponds", which in the present study will be called pond systems, which will be understood as a set made up of a finite and connected hyperbolic structure of shallow holes filled with warm seawater up to the edge, which, upon receiving a small additional volume of water will drain into other hollows, following a continuous downward path towards the sea (**Figure 1a**), because the contour curves on which the holes are located follow a topographic pattern equivalent to the well-known "devil's stairs." (**Figure 1b**).

Given the conditions described, the following Mandelbrot conjecture, rewritten in terms of the present study, is expressed as follows: "In the archaic emergent land landscape, the holes that constituted the pond systems were always arbitrarily close to each other", which guarantees the connectivity between the constituent elements of the pond systems, enabling the development of population dynamics necessary for the successful development of life on earth 4000 million years ago.

Population dynamics

Once the environment in which the interaction between populations of primordial living beings takes place has been defined, a dynamic simulation (SD) model is proposed based on the following premises.

Premise 0. The minimum set of differentiated common ancestors

X= {P, C}

Premise 0 is based on the fact, well documented in studies of microbial populations, that when a single species is found in an environment, although it grows exponentially at first, it then moves to a plateau phase from which it decreases. , once it consumes the available resources, which is associated with the high vulnerability that comes from genetic homogeneity and/or occurrence of extreme events, increases the probability of disappearance of the species.

Premise 1. Once species C appears, it interacts with *P*, generating a parameter *Q*, defined as follows,

*Q=P*C*

Q affects the mortality rate of *P* and the birth rate of *C*. This premise is taken from the "law" of population dynamics according to which, in the interaction between species, one will act as a transmitter of strong effects on the other through the primordial trophic cascade.

Premise 2. The carrying capacity *K* depends on the size of the hollows that make up the pond system. For the simplicity of the model, it is assumed that these have a cylindrical shape, so the number of primordial cells expressed in thousands of individuals, whether of *P* or *C*, is given by the relationship to the volume of the pond,

$$V = \frac{\pi}{4} \propto D^3$$

And

$$\alpha = d/D$$

D is the diameter of the exposed surface of the pond and *d* is its maximum depth, both expressed in meters. From the formulations proposed for premise 2, the set of values of K for a given α is obtained. Based on the established premises, the Stock-Flow (SF) diagram is constructed (**Figure 2)** in which the dynamic simulation model for the proposed primary populations is presented. **Table 3** specifies the components of the SF diagram.

Results

The analysis of the dynamic simulation model (SD) suggests the appearance of certain dynamic patterns of behavior of the primitive populations of species *P* and *C*, as observed in **Figure 3**. First of all (**Figure 3a**), it can be seen that with load capacity K=1, the system presents asymptotically stable solutions, of increasing order for *C* and decreasing order for *P*, but no interaction is established between them. Secondly, when K=2 (**Figure 3b**), oscillatory periodic solutions are observed for both populations. Initially, we start from a state in which the populations of *P* and *C* are relatively low, subsequently, the population of the species that act as prey increases, in this case, *C*, while the density of *P* decreases, which leads to the decrease in *C*, repeating the oscillatory pattern, typical of predator-prey dynamics, which is maintained until resource exhaustion.

By increasing the carrying capacity to K=3, K=4, and K=5 (**Figure 3c, 3d, 3e**), the oscillatory pattern is maintained for a longer time, which implies greater interaction between species, enabling the establishment of both populations. for longer periods or cycles, which is essential to maintain species in developing ecosystems and to colonize new habitats. Finally, when $K>6$ and up to K=20 (**Figure 3f**), cyclic solutions are presented for both species whose occurrences are increasingly separated in time, which ends, when $K>20$ (**Figure 3g**), in the disappearance of both species.

The numerical solutions of the dynamic simulation model suggest that ponds with a carrying capacity of $2 \leq K \leq 5$ promoted interaction between individuals of species *P* and *C*, following predator-prey type behavior, which increases the chances of permanence. and, therefore, the evolution of both species. Since it is postulated that the Darwinian pond system followed a hyperbolic pattern of size distribution, that is, within each system the small ponds with $1.5 \leq \alpha \leq 2.5$ were more numerous than the large and deep ponds, the above implies that in the emerging archaic land there were possibly millions of habitats where productive interactions between primitive living species took place, and the connectivity within the pond system generated processes equivalent to the migration of organisms, which made it possible to increase the number of individuals of competing species and the subsequent development of new genomic variants and new species.

About the connectivity of the Darwinian pond system and the "diabolical" topography of the dry land, it is possible to suggest an underlying tree structure within the system, configuring a digraph, whose nodes were the ponds and the arcs were the positive flows. between ponds (**Figure 1a**). From this perspective, the results indicate that ponds with $2 \leq K \leq 5$ were central nodes in terms of their role in the dynamics of competition between species *P* and *C*, forming neighborhoods of ponds suitable for increasing biodiversity, whose source F was located in the highest sectors of the emerging portion of land and its sink *S*, with $F \neq S$, was the sea, which, having a much larger size than any of the ponds, would not, at least initially, be a favorable habitat. for the establishment and development of the first living organisms.

Conclusions and discussion

In the model of Darwinian Pond System, the geometric aspects associated with both the local structure of the ponds, when taking into account their carrying capacity, and the global structure, when describing the system of ponds within the category of Mandelbrot hyperbolic Brownian fractals. These geometric considerations turn out to be decisive for the establishment and subsequent development of emerging life forms on the archaic earth, whose predator-prey type dynamics are associated with ponds whose carrying capacity fluctuates between 2 and 5. Of course, we start from a set of simplifying premises, which when expanded in subsequent studies can lead to more detailed results than those presented in the present study.

The present study supports the theory that life on Earth first developed in small bodies of saline water located on dry land, and emerged through extensive geological processes 4 billion years ago, from where it subsequently flowed to the sea. On the other hand, within the pond system and due to its overall geometric structure, various types of dynamic patterns could be experienced at the same time among the species considered, which, linked to the flows between connected neighborhoods of ponds, could increase the possibilities of growth and diversification of archaic living populations, explaining the overwhelming success of life on the planet once established in the appropriate environments.

The use of biological principles in cosmology has proven to be a profitable scientific strategy, with the anthropic principle perhaps being the best-known case (Penrose, 2007), but it is worth mentioning other interesting results such as the self-propagating stochastic model of galaxy creation. (Gerala et.al., 1980), the Sorkin model of causal ensemble growth dynamics (Rideaout & Sorkin, 1999), the dispersion of complex organic molecules within star clusters (Burgos-Salcedo & Sierra, 2021), and Smolin's striking theoretical proposal of life and evolution of the universe (Smolin L, 1997). Studies such as the previous ones have led to proposing the idea of the universality of biology, which states that biological norms or laws, of a qualitative nature, but with long-range quantitative effects on the processes of formation of the universe and life in the universe.

Finally, and taking into consideration the fact, well known in cosmology, by the theory of relativity, of the fundamental role that the geometry of space plays in the dynamics of the events that occur within it, a geometric model of space systems is proposed. related ponds as a weighty element for the establishment and subsequent development of life on earth since the archaic era.

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Figure 1. Darwinian Pond System

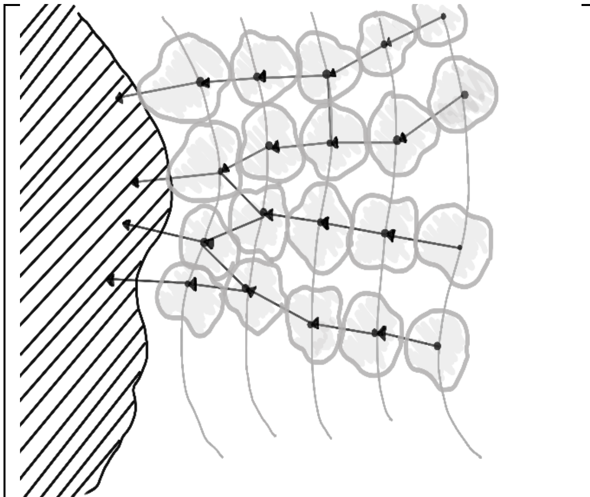


Figure 1a. Darwinian pond system

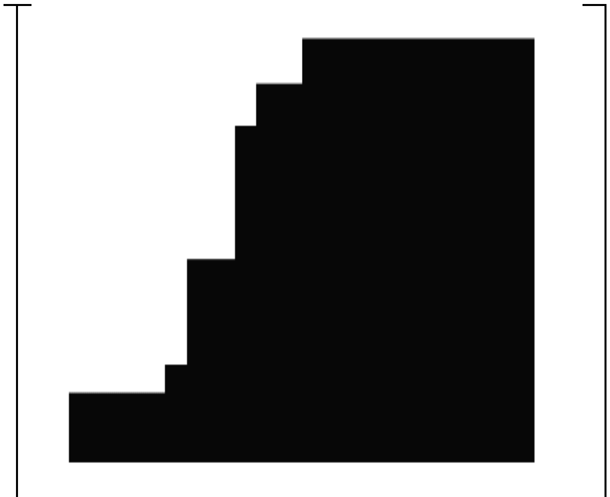
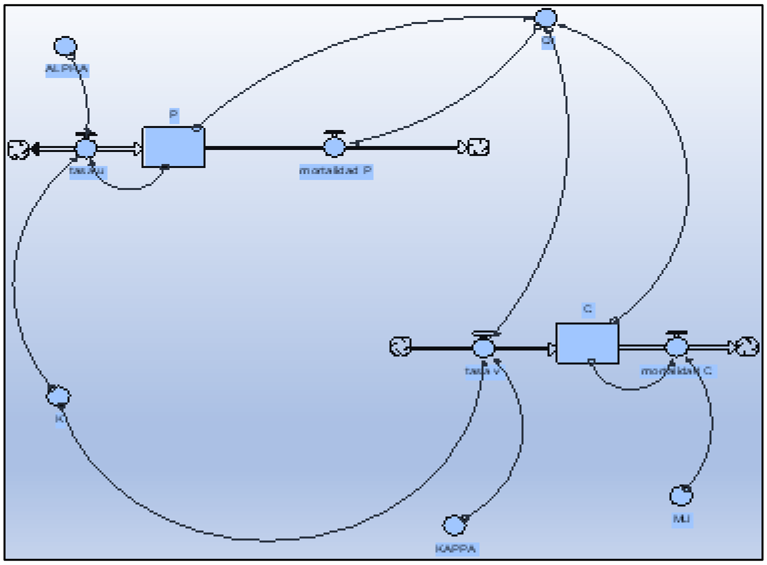


Figure 1b. Devil´s staircase

Legend Figure 1a. The geometric model consists of a set of connected ponds or hollows whose sizes are distributed in a hyperbolic manner. The connection between the ponds generates a flow between them, which is represented by a directed graph, whose sink is the sea.

Figure 1b. It is a cross section that represents the terrain on which the Darwinian pond system is based following the Mandelbrot conjecture, which guarantees the generation of flow from the pond system to the sea.

Figure 2. SF diagram for the interaction between primordial species



Legend Figure 2. The interaction pattern between the two species *P* and *C* corresponds to a predator-prey system. Note that the model establishes that both species share the same pond, defined by their carrying capacity *K*. The fact is emphasized that the mortality rates of species *P* and the birth rates of species *C* are controlled by their interaction represented by the *Q* parameter.

Figure 3. Dynamic simulation of the interaction between species under different values of carrying capacity for the primordial ponds.

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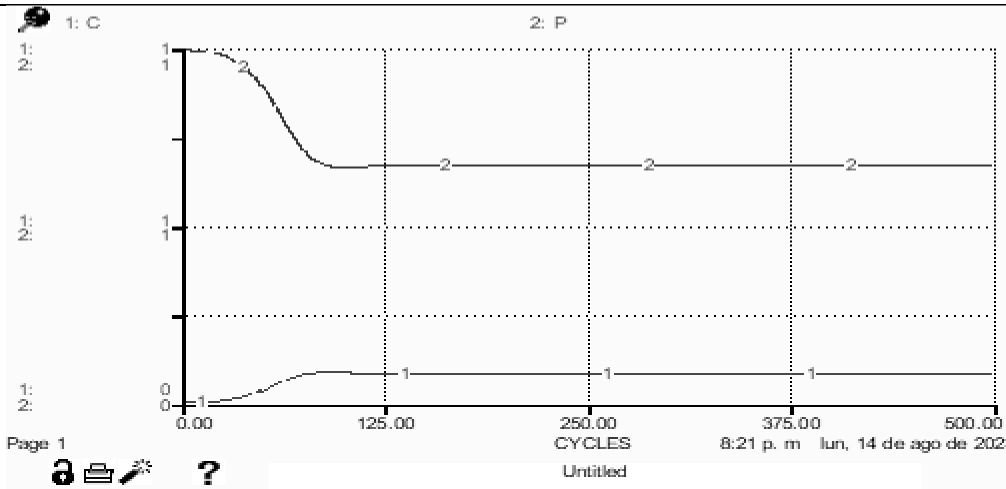
<tr><td>1</td><td>
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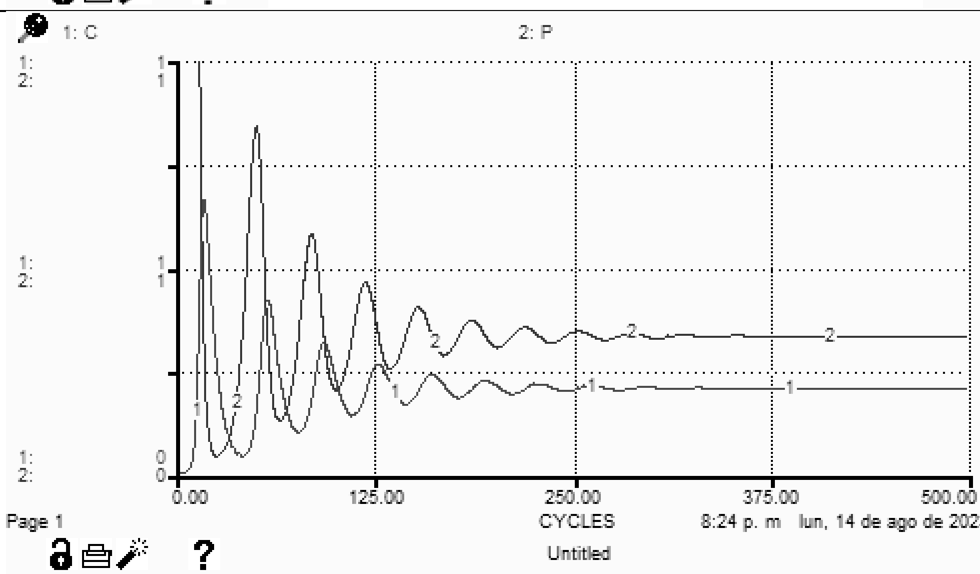
<tr><td>2</td><td>
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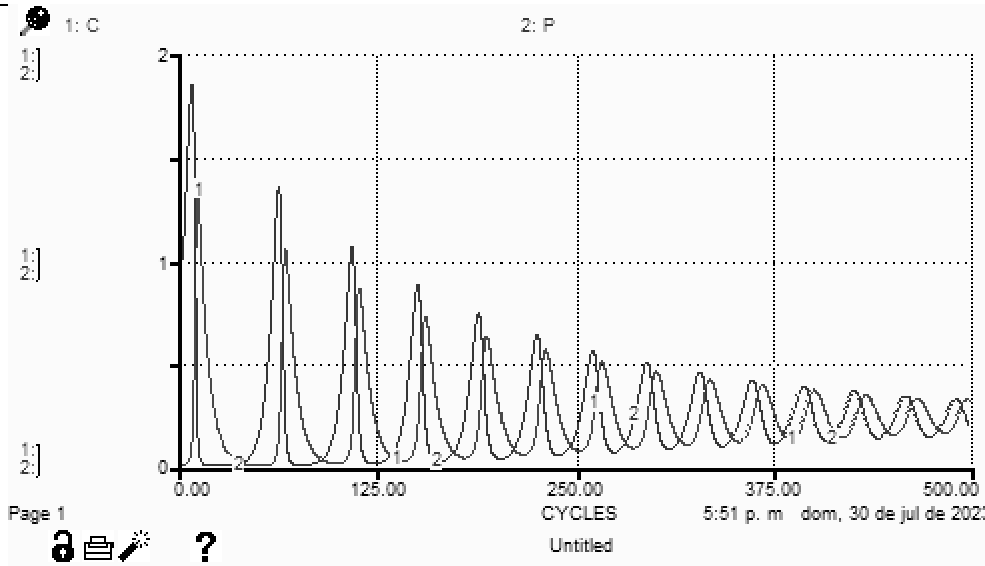
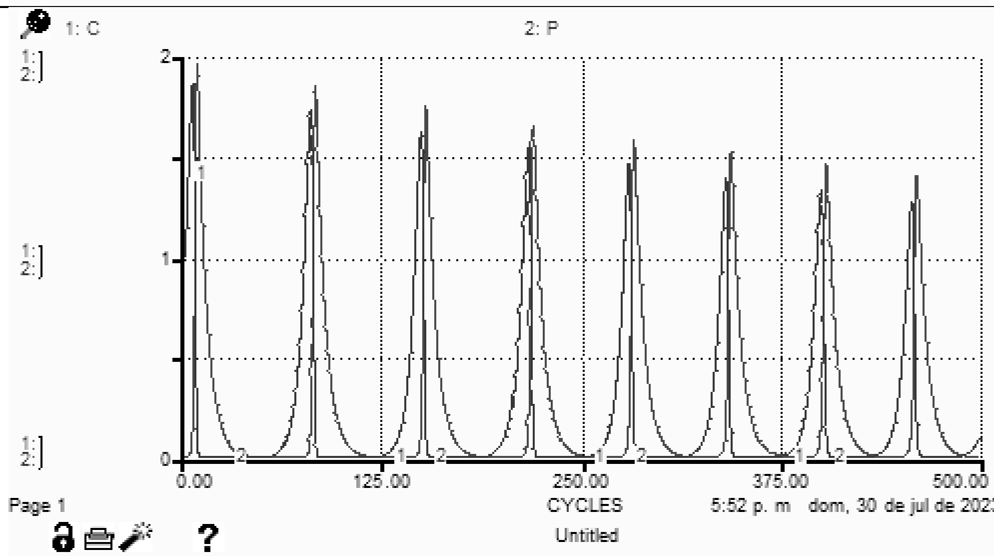
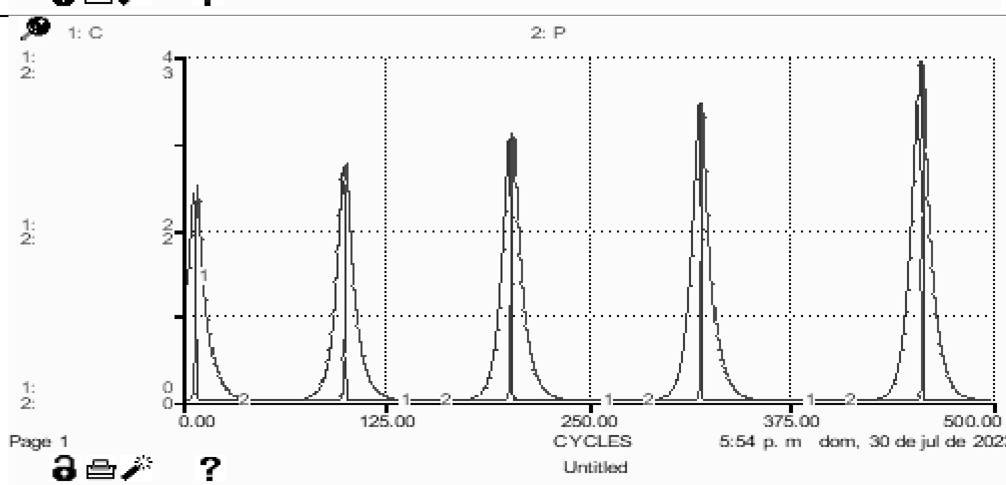
3	
4	
5	

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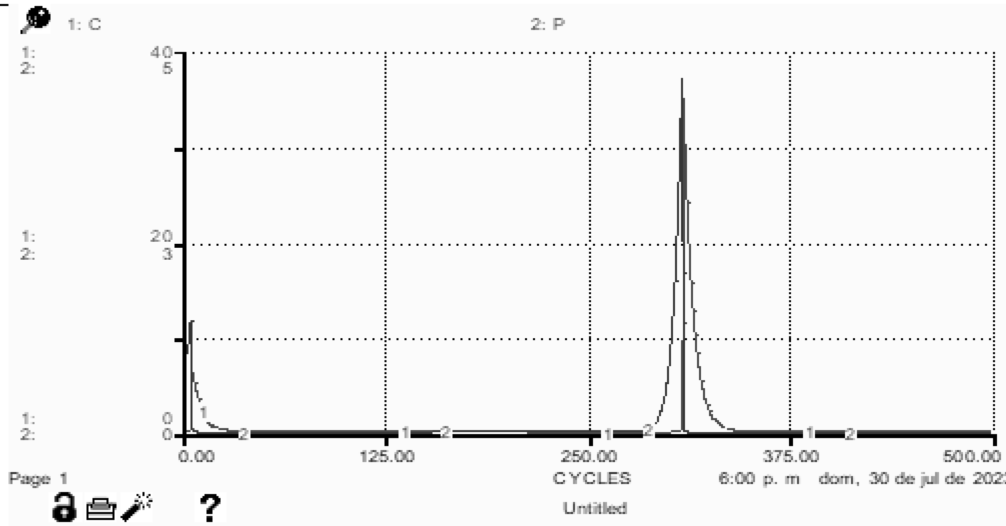
<tr><td>6 a 20</td><td>
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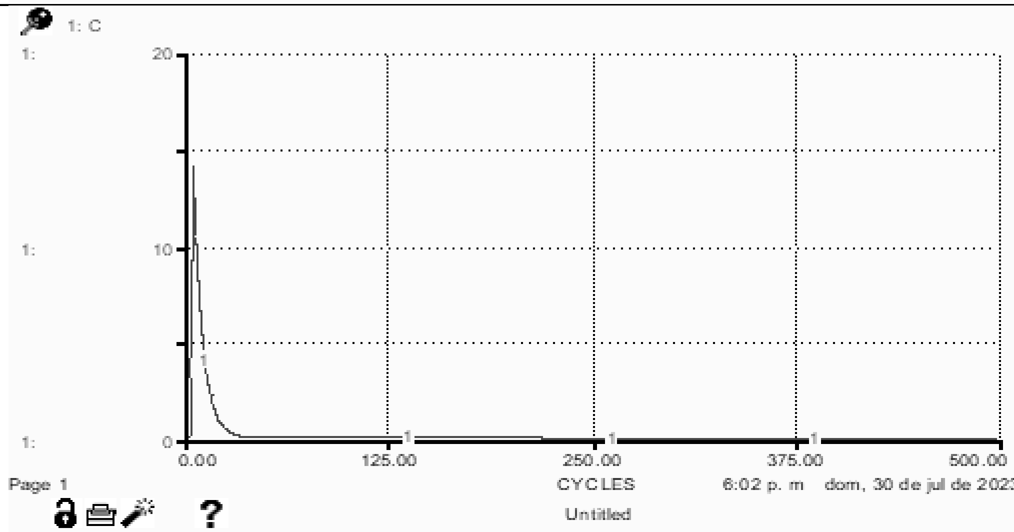
<tr><td>Mas de 20</td><td>
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Table 1. Origin and characteristics of primitive ponds

Origin	Chemical characteristics	Physical characteristics
Geosphere	Fundamental elements: C, N, P, O, S	Gravitational field, vulcanism
	Other elements: Mg, Ca, Fe, Mn, Co, Mo, Zn	Size, shape, depth
	Minerals: carbonates, ashes, clay	
Hydrosphere	Water, ions, pH, soluble gases	Ionic capacity, thermal conductivity, specific heat, viscosity, conductivity, surface tension
Atmosphere	Volatiles: CO_4, CH_4, H_2O, HCN, N_2, H_2, NH_3, SO_2	Climate: temperature, rainfall, cloudiness, wind, vortices, Greenhouse gases
Astro noosphere	Carbonaceous chondrites, trace elements, biogenic organic compounds	Daily transactions, Milankovitch cycles, ionizing radiation, gamma rays, geomagnetic field

Legend Table 1. General characteristics of primitive ponds are based on the macrobiont´s theory of Clark Y Kolb (2021). Even though the combination of these characteristics can give rise to a large number of possible primordial conditions, it is assumed in the present study that once established they remain constant to facilitate the establishment and interaction of living organisms that arrive at the pond system.

Table 2. Carrying capacity of primordial ponds

$\alpha = d/D$	K
1	1
1.5	2
2	3
2.5	5
3	7
4	13
5	20

Legend Table 2. The carrying capacity K is defined as the number of individuals per unit of volume that the pond can maintain. In the present case, K depends on the parameter α, which is dimensionless, and which expresses the relationship between depth (d) and diameter (D).

Tabla 3. SF Model

COMPONENT	SYMBOL	VALUE/FORMULA
Stocks		
Progenotes	*P*	0.999
Colonizer	*C*	0.001
Parameters		
Birth rate of *P*	ALPHA	0.25
Birth rate of *C*	KAPPA	0.25
Carrying capacity	*K*	Table 2
Interaction between *P* and *C*	*Q*	P*C
Mortality rate of C	*MU*	0.167
Flows		
Reproduction of *P*	Function	Depends on *P, K* y *ALPHA*
Reproduction of *C*	Function	Depends on *K, Q, KAPPA*
Mortality of *P*	Function	Depends on *Q*
Mortality of *C*	Function	Depends on *C* y *MU*

Legend Table 3. Stocks P and C correspond to thousands of individuals per cubic milliliter. The birth and death rates of each species are established in individuals per unit time cycle. The values are adjusted from the dynamic simulation.