Simulating the Population Dynamics of Lizards in the Sand Dunes of the São Francisco River: A Simulator for the Calangos Game

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Abstract

Calangos is an under development educational game based on the fauna and flora of the desert-like field of the sand dunes in the middle São Francisco River, located within the Caatinga biome in Brazil. One of the player's goals is to manage the behavior of species of lizards that inhabit this biome, with consequences to their ecology and evolution. For the development of the game, a *prototype*, or *simulator*, is proposed. This prototype will be used to simulate the natural predator-prey dynamics based on the Evolutionary Biology and Ecology literature. The objective of this paper is to introduce the simulator and present some key experimental results obtained with the simulations performed with it. The results clearly show that in a balanced environment without predators it is possible to observe a dynamic equilibrium of populations in accordance with a typical Lotka-Volterra model of population dynamics. In turn, it is also observed that in the most hostile environments containing large numbers of predators, the capability of evolution allows the lizard species to survive in the environment, which does not occur if the lizards' evolution is disabled during the simulations. In the context of the Calangos game, the results presented here serve as the initial proof of concept necessary for the modeling of the lizards to be incorporated in the game.

Keywords: educational games, videogames, evolutionary computing, ecology, evolution.

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1. Introduction

The development of the Calangos game involves researchers and developers from three Brazilian universities: UPM, UEFS, and UFBA. The game will be playable on three different platforms: Web Player (playable directly from a web browser), PC and Android (mobile phones and tablets), and it is based on the modeling of a real ecological case about lizards that inhabit a desert-like field of sand dunes in the region of the São Francisco River, located in the Caatinga biome (at the state of Bahia, Brazil). The main objective of the project is to develop and test in classroom a game which aids in the teaching and learning of core concepts of biology related to ecology, population biology, and evolution. More specifically, the game should work as a tool to support the teaching and learning of ecology and evolution at the high school level, not by direct exposure of contents to be learned by the player, but by learning from the experience of trying to solve problems within the game.

When fully developed, the Calangos game is going to have four distinct levels.

- Level 1: the player controls a single lizard, choosing one out of three species; the main objectives are the survival and reproduction of the lizard.
- Level 2: the player is able to create a lizard from an interactive editor, choosing traits related to morphology, physiology and behavior, which will influence the success or failure in its survival and reproduction. This level emphasizes the relationship between the traits of the animal and its likelihood of successfully surviving and reproducing.
- Level 3: the game changes from the individual organism level to the level of populations, putting the player in the condition of managing an entire population of lizards. Population ecology will then come to the fore as a subject to be learnt.
- Level 4: this moves from the ecological to the evolutionary time. The player will be given the challenge of maintaining a population of lizards, but also of dealing with its evolution over the generations.

The first scientific challenge of the project, in addition to the technological challenge of developing the game itself, is related to the modeling of the population dynamics and evolutionary biology in the context of Calangos. To investigate these aspects independently of the game, this paper proposes a simulator for Calangos, as well as a genetic-evolutionary model for the lizards. Furthermore, it performs a set of experiments that examine the ecology and evolution of the lizards in the proposed simulated environment. More specifically, four experimental scenarios and three difficulty levels for each scenario are proposed to analyze the dynamics of populations and the influence of the evolution on the fertility and longevity of lizards' populations located within the simulated environment.

2. A Simulator for the Calangos Game

The Calangos project started in the year 2007, when the first level of the game was developed. This included the three-dimensional modeling of the characters and scenery, climate and environmental modeling and the development of the graphical interface [Loula et al. 2009; Oliveira et al. 2009; Oliveira et al. 2010].

To develop the game, it was necessary to implement the NPCs (non-playable characters) based on existing animals from the Caatinga. The behavior of these animals was also modeled, but in a simplified way, for instance, termites and ants grouping, hunting strategies of predators (eight types of predators - birds, snakes, mammals and other lizards - were modeled). In addition to insects and spiders, lizards may also feed on a wide variety of fruits and flowers found in the environment. Each type of food provides a different amount of energy and hydration.

Two major challenges in developing Calangos are the simulation of the populations' biology and the evolution of species within the game. To overcome these challenges it was developed a Java *simulator* for the game, in which concepts related to these topics could be simulated, studied and prototyped by the developers and biologists of the project prior to the implementation in the game itself. This section describes the main concepts and components of the simulator.

3.1 Agents Behavior

The agents in the simulations are the lizards, their predators and preys. To simulate the interaction between lizards and the environment, the scenario is abstracted as a two-dimensional grid. Each cell of the grid can be occupied by a single element at each instant of time. This element can be a lizard, a predator or a food resource.

The simulation consists of a sequence of iterations. At each iteration, all the existing agents in the simulation perform their specific tasks, such as walking, eating, reproducing and consuming energy.

There are male and female lizards that reproduce or not depending on a certain probability. Lizards live for a determined number of iterations, and have three life stages: *infant*, *adult* and *senior*. Infant and senior lizards cannot reproduce, whilst adult lizards may do so. Lizards are controlled by finite state machines, and have four possible actions, *looking for food*, *looking for reproductive partners*, *resting* and *fleeing* from predators. The lizard's energy and hydration are decreased over the iterations with a rate proportional to their size, speed and state. They feed on vegetables and insects randomly dispersed over the grid and replenished at a given rate. Lizards die when their energy or hydration drops to zero, or if they are predated.

Vegetables supply lizards with a large amount of hydration and a small amount of energy, and insects provide low hydration and high energy. There are different types and sizes of vegetables and insects in the environment, thus providing different amounts of energy and hydration.

There is a single type of predator in the simulation, based on a model of the *seriema*, which is a terrestrial bird. The predators feed on lizards only, and they gain energy proportionally to the size of the lizard they consume. The energy of the predators is decreased every iteration, and if it reaches zero the predator dies. Predators reproduce asexually at a rate proportional to their energy level: the more energy they have, the greater their reproduction probability. There is also a small probability of a new predator being added to the simulation at every interaction, simulating a migrating animal. Predators have only two states: looking for preys and hunting.

3.2 Population Dynamics

To simulate the population dynamics within the game, it is necessary to understand the underlying natural phenomena.

The density of populations in nature is dependent upon two primary factors: 1) birth rates, which depend on environmental changes, such as temperature, humidity, lack of food and/or water shortages; and 2) the size of the population itself. In nature, when a certain population becomes very large compared to the availability of resources, a drastic decrease in the number of individuals commonly happen due to lack of resources. Some biological systems are inherently unstable and tend to develop oscillations [Ricklefs 2010].

If one performs a similar analysis for the fluctuation in the availability of resources in the environment of a population, it is noticeable that these resources also fluctuate cyclically. That is, when the population is small, there is abundant food and they have time and resources to grow, but when the population is large, food becomes scarce promoting the death by starvation. This is a typical example of a predator-prey ecological relationship [Berryman 1992]. Predator-prey relationship systems like the model of Lotka-Volterra [Volterra 1928; Lotka 1925] are widely studied in biology.

In Calangos there is this type of relationship between lizards and food (insects and plants), and between lizards and predators (seriemas). Such interaction generates a cyclic behavior in which there is an increased prey population, followed by an increase in predation, leading to an increase in the predator populations [Ricklefs 2010]. The result is a cyclic oscillation between the numbers of prey and predators, as illustrated in Figure 1.

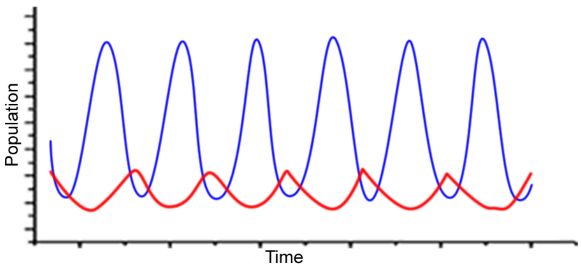

Figure 1: Cyclical behavior of the predator-prey relationship according to the Lotka-Volterra model. Prey population is shown in the top curve and predator population in the bottom curve. Adapted from [Ricklefs 2010].

To simulate the population dynamics in the simulator, it was necessary to test and adjust the parameters of the initial configuration simulation, like the initial number of predators and prey and initial amount of food, until a model similar to the ones studied in biology was achieved.

3.3 The Proposed Genetic-Evolutionary Model

Population dynamics is also affected by natural evolution. This can be seen when the system is observed for a longer period of time.

Evolution is a process of genetic and phenotypic change that occurs in populations of organisms in response to several factors, such as natural selection on selective regimes in which certain population variants tend to be more successful than others. Besides the change in populations, evolution also includes the generation of new species from the interruption or substantial reduction of gene flow between populations and evolution by reproductive isolation between its members [Linden 2012]. Unlike the learning process, which happens to an individual during its lifetime, evolution occurs on a much larger time scale (evolutionary time), involving generations of individuals. It is a process that does not occur locally in an individual and is not perceived by it, but affects the whole population. It is a process that may allow the organisms of a species to increase their level of adaptability to the environment over the generations [Stearns and Hoekstra 2000].

An essential component in the evolutionary process is the genetic material, organized in *chromosomes*. Chromosomes are formed by proteins and DNA, and this latter molecule carries the genetic memory, in the form of nucleotide sequences of genes that encode aminoacid sequences, and, thus, the primary structure of proteins. This contributes (alongside with codifying for RNAs) to the appearance of traits observed in an organism [Charles et al. 2008].

The complete set of genes of an organism is called *genotype*. The genotype plays an important role in the growth and development of multicellular organisms. It directly influences the *phenotype*, which includes all the observable physical and biochemical features of the organism (such as height, eye color, skin tone, etc.), and is constructed by a complex process including genetic, epigenetic, and environmental influences in a complex relationship [Waddington 1962; Van Speybroeck 2002; Hall 2003; Arthur 2011].

According to the theory of evolution by *natural selection*, individuals compete for limited resources, such as food and water, and vary in their successes for survival and reproduction depending on their phenotypes. Individuals that are less successful in this competition tend to have less or no offspring, reducing the likelihood that copies of their genetic material (and, also, of other epigenetic components) are passed onto the next generations.

To model natural selection in the simulator, a solution based on *evolutionary algorithms*, EAs [Holland 1975, Holland 1992, Goldberg 1989] is proposed. EAs are inspired by Darwin's theory of evolution by natural selection [Darwin 1859] and are widely used as search and optimization algorithms for solving complex problems.

It is typical in evolutionary algorithms to use populations of candidate solutions formed by sets of binary digits or real-valued vectors, representing the genotypes of individuals. A numerical function (also known as *fitness function*) is defined to evaluate each phenotype according to their success in solving a given problem. This is associated with that individual's level of adaptability to the environment: more adapted organisms have higher survival and reproduction probabilities [Sims 1994] provided that the environment does not change in a manner that past adaptations lose current adaptability (a limiting premise of the model). The general operation of an evolutionary algorithm is described in Figure 2.

```
BEGIN
    INITIALIZE a population of candidate solutions;
    EVALUATE each candidate;
    REPEAT UNITL stop condition;
        SELECT parents;
        CROSS pairs of parents to generate new individuals;
        MUTATE new individuals;
        EVALUATE new population;
    END
END
```

Figure 2: General scheme of an evolutionary algorithm in pseudocode. Adapted from [Eiben and Smith 2003].

A population of random individuals is initially generated. The evaluation of each individual results in a fitness value being attributed to it. Individuals with greatest fitness are more likely to be selected for reproduction. Reproduction is performed by means of a *crossover* between pairs of individuals, given a certain crossover probability. When two individuals are crossed they generate two new individuals from the combination of their genes, so that the offspring will be mixtures of both parents, as illustrated in **Erro! Fonte de referência não encontrada.**.

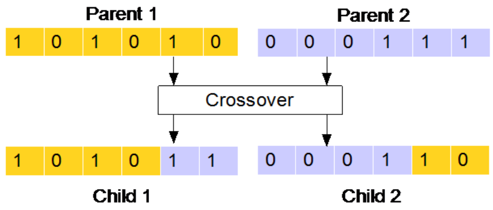

Figure 3: Example of a standard crossover in an evolutionary algorithm for individuals with genotypes represented as binary arrays.

Mutation is another important process in an evolutionary algorithm because it introduces genetic variability in the population. Mutation takes place with a given probability, usually small. When it happens, an individual newly generated by crossover undergoes a change in some of its genes. Selection, crossover and mutation are repeated for a number of generations or until an expected stopping criterion is met.

The evolution process in the simulator is different from classical evolutionary algorithms. In the simulator, the initial population is generated randomly, but there is no direct calculation of the fitness of the individuals. Instead, natural selection is imposed by the digital environment, i.e. those lizards that are better prepared to obtain resources from the environment and escape predators will have better chances to survive and reproduce, spreading their genetic material.

The genotype of the lizards is represented by an array of traits. Each feature of a lizard is generated from the genes in the chromosome. Therefore, in the simulator introduced here, a mixed encoding scheme is proposed. **Erro! Autoreferência de indicador não válida.** summarizes these features and the domain of each feature.

Table 1: Genetic modeling of the lizards in Calangos (data based on Rocha & Rodrigues (2005) and on assumptions made by a researcher of the Calangos team with large experience in the field of herpetology, who conducted extensive research on the lizards of the dunes of the São Francisco River [Rocha et al. 2005]).

Feature	Range
Gender	{female (0), male (1)}
Body size (Bs)	[10.0, 40.0]
Head width	[Bs/5–Bs/10, Bs/5+Bs/10]
Speed	[1, 5]
Preference for insects	[0.0, 1.0]
Preference for vegetables	[0.0, 1.0]
Energy satisfaction threshold	[60%, 90%]
Hydration satisfaction threshold	[60%, 90%]
Minimum hydration threshold	[20%, 50%]
Minimum energy threshold	[20%, 50%]

The genetic features defined for the lizards in Calangos are:

- **Gender**: male or female.
- **Body size**: the larger the body of a lizard, the greater its speed, ability to inhibit attack by predators, and its demand for food and water.
- **Head width**: lizards with heads of different widths have different restrictions on the types of food they can consume. Larger heads imply larger mouths, which can catch larger objects, but have more difficulty in handling small objects.
- **Preference for insects (PI)**: represented by an integer value between 0 and 10 corresponding to the lizard's preference for insects.
- **Preference for vegetables (PV)**: also represented by an integer value between 0 and 10 corresponding to the preference for vegetables. It is calculated as follows: PV = 10 − PI.
- **Speed**: the rate of energy consumption is influenced by the speed of a lizard and its basal energy expenditure (resting). The higher the speed, the greater its ability to escape predators and energy consumption.
- **Satisfaction thresholds**: ranging from 60% to 90% of the total energy of the lizard. Define the threshold of energy and hydration when the lizards stop searching for food and begin searching for sexual partners or rest.
- **Minimum energy and hydration thresholds**: ranging from 20% to 50% of the total energy of the lizards. It sets limits that represent the percentage of energy and hydration in which a lizard starts feeling hungry. When the energy or hydration of a lizard becomes lower than their respective thresholds, the lizard begins searching for food, until its food satisfaction threshold is reached.

In the proposed model, crossover occurs between males and females of the same species when both are close to one another and able to reproduce. One reproduction event may generate from one to four offspring. There is also competition between males for mating with a female and, usually, the strongest male will overcome the weaker. Thus, there is a higher probability that the genes of the fittest lizard pass onto the next generations.

3. Simulating Population Dynamics with the Calangos Simulator

Simulations that aim at showing the impact of different types of environmental conditions in the ecological and evolutionary dynamics of the lizards were designed and assessed. Three types of environment, with different levels of difficulty, were proposed: 1) a *favorable environment* with abundant food and low reproduction rate of predators; 2) a *hostile environment* with a small amount of food and high reproduction rate of predators, and 3) a *balanced environment* with balanced amounts of food and predators. The specific parameters for each type of environment are shown in Table 2.

Table 2: Types of environment and their parameters.

Environment	Parameter	Value
Favorable	Reproduction rate of predators	1%
	Rate of addition of insects	10%
	Rate of addition of vegetables	10%
Balanced	Reproduction rate of predators	5%
	Rate of addition of insects	5%
	Rate of addition of vegetables	5%
Hostile	Reproduction rate of predators	10%
	Rate of addition of insects	1%
	Rate of addition of vegetables	1%

Four sets of simulations (scenarios) were performed for each of the three types of environment, resulting in twelve sets of experiments, as follows (Table 3): 1) For Scenario 1, the evolution of lizards was disabled and predators were not present in the simulations. This is a control scenario, where we seek to build an environment with a dynamic equilibrium between lizards and food sources; 2) Scenario 2 also had no predators, but the evolution of lizards was enabled. This scenario aims at showing the convergent evolution of lizards in an environment without predators; 3) Scenario 3 did not enable evolution, but added predators. This scenario aims to assess the impact of predation on the ecosystem's dynamic equilibrium; and 4) Scenario 4 is the most similar scenario to Calangos' Level 4, in which it is tested the evolutionary behavior of the lizards in an environment with predators.

Table 3: Scenarios for simulations with and without evolution, and with and without the presence of predators.

Scenario	Evolution	Predators
1	No	No
2	Yes	No
3	No	Yes
4	Yes	Yes

In the simulations without evolution lizards are all identical, varying only in gender. Their genetic information is the mean of the domain of each gene. For instance, for a gene that ranges from 1 to 10, it receives the value 5. The running parameters of the simulations are shown in Table 4. The parameters for the genetic operators were based on the results of simulations and presented in [Almeida et al. 2012], where different crossover operators, crossover and mutation rates were evaluated.

Table 4: Simulation parameters.

Parameter	Value
Maximum age	3,000 iterations
Adult age	1,000 iterations
Seniority	2,500 iterations
Mating probability	30%
Initial population of lizards	100
Maximum number of lizards	500
Predator speed	3
Initial population of predators	1
Initial number of insects	100
Initial number of vegetable	100
Maximum amount of food	1,000
Min and max food sizes	[1. 10]
Number of simulations per environment	10
Number of iterations per simulation	100,000
Grid size	1,000 × 1,000
Crossover probability	10%
Mutation probability	1%
Mutation operator	Random resetting
Crossover operator	N-Point crossover

4. Results and Discussions

To demonstrate the fluctuations in a population of lizards in the simulations, Figure 4 shows an average of ten simulations of a balanced environment with evolution disabled over 50,000 iterations. It can be noted that the fluctuations obtained resemble the ones observed in real biological systems.

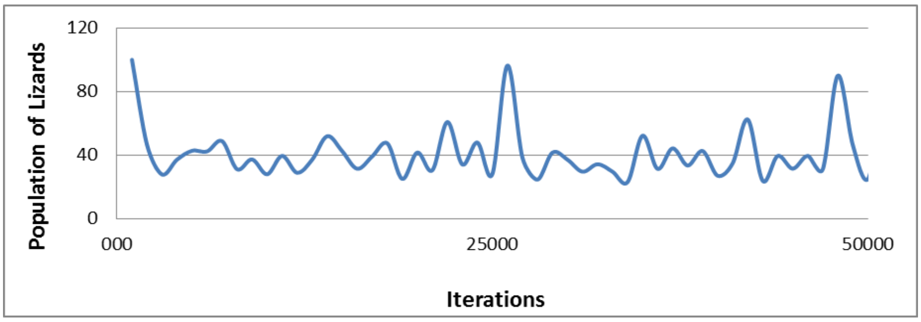

Figure 4: Fluctuations in the lizard's population in an average of ten simulations of a balanced environment with evolution disabled in the simulator.

Ten simulations were performed for each of the four scenarios and three environments. The tables in this section present the results of the mean and standard deviation of the simulations. Figure 5 to 6 show the balance between the average amount of food in the environment and the population of lizards in the four scenarios. The performance differences between the populations of lizards in scenarios with and without evolution become evident, especially with regards to the comparison between Scenarios 3 and 4, in which both have the presence of predators. Despite that, an extinction of the population is seen in Scenario 3 in the balanced and hostile environments, but not in Scenario 4. This suggests that evolution was vital for the surviv-al of the lizards in this environment

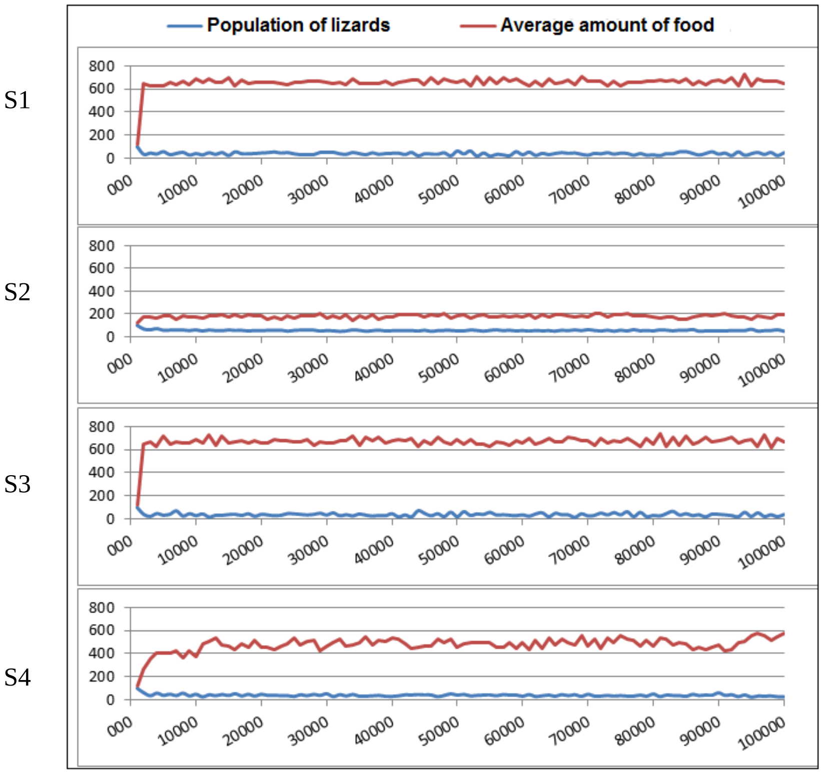

Figure 5: Comparison between the amount of food in the environment (top curve) and the population of lizards (bottom curve) over the iterations in the simulations of the favorable environment for the four scenarios.

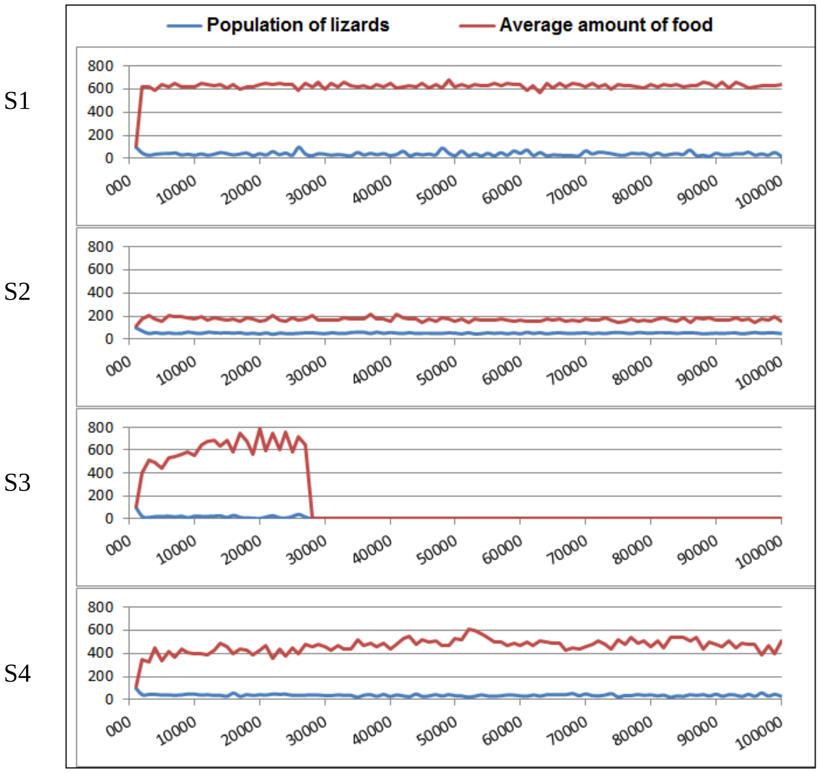

Figure 6: Comparison between the amount of food in the environment (top curve) and the population of lizards (bottom curve) over the iterations in the simulations of the balanced environment for the four scenarios.

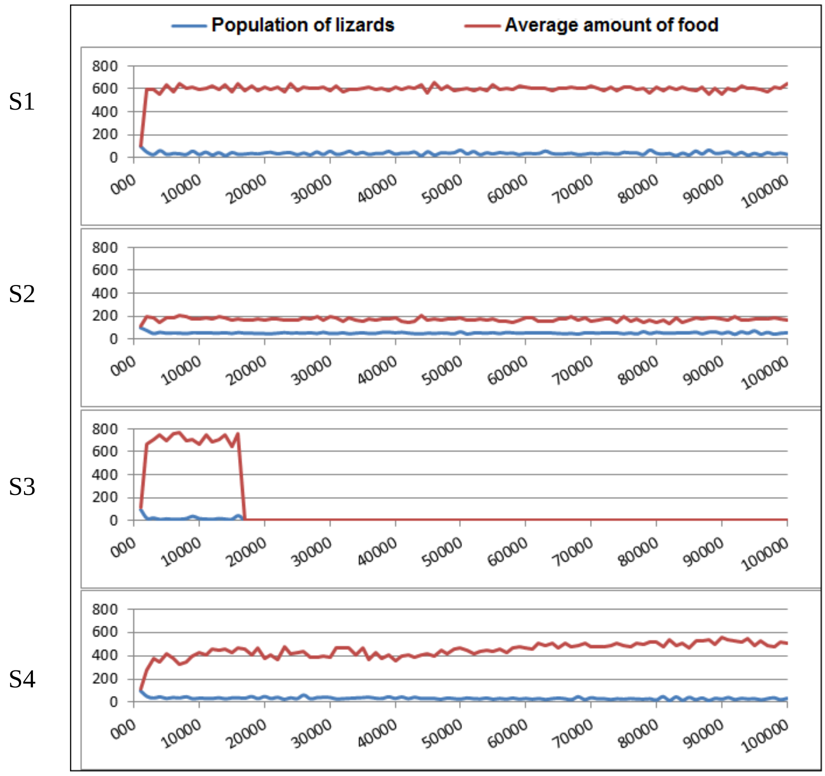

Figure 7: Comparison between the amount of food in the environment (top curve) and the population of lizards (bottom curve) over the iterations in the simulations of the hostile environment for the four scenarios.

Table 5: Comparison between the average values of all features in the favorable environment in the four scenarios.

Favorable Environment	C1	C2	C3	C4
Number of lizards	41.17±(12.52)	54.26±(4.46)	37.59±(17.31)	38.2±(9.25)
Number of predators	--	--	1.55±(0.52)	1.95±(0.52)
Longevity	823.35±(132.26)	969.8±(64.65)	814.17±(197.11)	909.3±(141.23)
Number of offspring per generation	9.48±(2.52)	20.43±(2.41)	9.71±(5.34)	15.34±(4.48)
Speed	3±(0)	5.53±(0.1)	3±(0)	5.24±(0.21)
Body size	20±(0)	19.5±(0.48)	20±(0)	19.58±(1.26)
Head width	5±(0)	4.78±(0.1)	5±(0)	4.58±(0.25)
Size of insects	4.31±(0.04)	3.52±(0.21)	4.33±(0.07)	4.36±(0.21)
Size of plant	4.31±(0.04)	3.72±(0.25)	4.32±(0.06)	4.39±(0.2)
Number of insects	659.4±(27.83)	184.78±(17.23)	670.06±(39.76)	513.74±(58.9)
Number of plants	659.47±(27.82)	176.62±(17.6)	669.84±(39.89)	515.39±(63.42)
Preference for insects	5±(0)	5.21±(0.22)	5±(0)	5.14±(0.46)
Preference for vegetables	5±(0)	4.79±(0.22)	5±(0)	4.86±(0.46)
Energy threshold	25±(0)	25.49±(1.64)	25±(0)	28.52±(1.6)
Hydration threshold	25±(0)	26.82±(1.62)	25±(0)	24.05±(4.76)
Deaths by poor nutrition	5.41±(4.73)	1.6±(0.5)	4.71±(4.54)	1.75±(1.08)
Deaths by dehydration	5.42±(4.75)	1.79±(0.62)	4.72±(4.53)	1.91±(1.27)
Deaths by age	0±(0)	0±(0)	0±(0)	0±(0)
Deaths by predation	--	--	2.03±(1.4)	1.32±(0.59)

Table 6: Comparison between the average values of the features in the balanced environment in the four scenarios.

Balanced Environment	C1	C2	C3	C4
Number of lizards	38.91±(13.04)	53.75±(4.43)	20.26±(15.63)	37.15±(8.53)
Number of predators	--	--	5.97±(1.99)	1.89±(0.48)
Longevity	825.8±(140.23)	967.23±(65.29)	770.38±(253.34)	916.14±(128.45)
Number of offspring per generation	9.32±(2.57)	19.69±(2.3)	12.64±(9.72)	15.74±(4.36)
Speed	3±(0)	5.52±(0.11)	3±(0)	5.29±(0.2)
Body size	20±(0)	19.27±(0.46)	20±(0)	17.8±(0.87)
Head width	5±(0)	4.79±(0.1)	5±(0)	4.31±(0.2)
Size of insects	4.32±(0.04)	3.72±(0.25)	4.4±(0.07)	4.54±(0.2)
Size of plant	4.31±(0.04)	3.88±(0.25)	4.4±(0.07)	4.58±(0.19)
Number of insects	627.49±(27.51)	167.72±(17.92)	694.36±(93.05)	490.78±(54.5)
Number of plants	627.03±(27.48)	160.22±(17.38)	692.9±(92.74)	492.14±(57.95)
Preference for insects	5±(0)	5.16±(0.21)	5±(0)	5.02±(0.34)
Preference for vegetables	5±(0)	4.84±(0.21)	5±(0)	4.99±(0.34)
Energy threshold	25±(0)	29.8±(0.68)	25±(0)	24.49±(1.92)
Hydration threshold	25±(0)	25.88±(1.6)	25±(0)	27.36±(1.6)
Deaths by poor nutrition	5.15±(4.62)	1.6±(0.5)	2.83±(2.58)	0.97±(100.68)
Deaths by dehydration	5.17±(4.63)	1.78±(0.61)	2.83±(2.56)	1.05±(109.1)
Deaths by age	0±(0)	0±(0)	0±(0)	0±(0)
Deaths by predation	--	--	2.24±(1.61)	0.67±(50.6)

The results obtained allow us to draw several important conclusions about the ecology and evolution of the lizards in different settings and with varying levels of environmental challenges. Tables 5 to 7 show comparisons between the average and standard deviations of the results of all iterations in the four scenarios.

Scenario 1 shows the smallest number of offspring per iteration in all environments, with the highest number of deaths from malnutrition and dehydration. This can be explained by the fact that lizards in this scenario have a static head size, not being able to consume most of the resources within the environment, which are not compatible to them.

In all environments the greater the longevity of the lizards, the largest the growth in population size, and the largest the number of offspring per iteration seen in Scenario 2. This is the scenario that has the lowest number of deaths from malnutrition and dehydration.

Table 7: Comparison between the mean values of the factors in the hostile environment in the four scenarios.

Hostile Environment	C1	C2	C3	C4
Number of lizards	37.07±(11.97)	52.4±(4.41)	19.5±(14.8)	31.96±(14.46)
Number of predators	--	--	5.39±(1.76)	1.79±(0.71)
Longevity	834.48±(140.06)	969.71±(66.31)	802.41±(262.55)	919.82±(229.68)
Number of offspring per generation	9.81±(2.67)	20.06±(2.43)	10.59±(5.64)	16.18±(6.85)
Speed	3±(0)	5.53±(0.11)	3±(0)	5.31±(0.34)
Body size	20±(0)	19.8±(0.46)	20±(0)	19.21±(2.8)
Head width	5±(0)	4.79±(0.1)	5±(0)	4.23±(0.5)
Size of insects	4.32±(0.04)	3.52±(0.23)	4.35±(0.1)	4.58±(0.31)
Size of plant	4.31±(0.04)	3.68±(0.24)	4.38±(0.09)	4.6±(0.29)
Number of insects	605.18±(25.73)	178.37±(17.27)	591.3±(132.57)	455.71±(88.95)
Number of plants	604.91±(25.4)	171.48±(17.81)	604.28±(115.29)	465.75±(91.45)
Preference for insects	5±(0)	5.18±(0.22)	5±(0)	5.09±(0.55)
Preference for vegetables	5±(0)	4.82±(0.22)	5±(0)	4.91±(0.55)
Energy threshold	25±(0)	29.05±(0.62)	25±(0)	32.66±(1.38)
Hydration threshold	25±(0)	28.22±(0.93)	25±(0)	24.85±(5.58)
Deaths by poor nutrition	5.08±(4.41)	1.62±(0.52)	0.7±(21.33)	1.67±(1.02)
Deaths by dehydration	5.1±(4.41)	1.81±(0.65)	0.69±(21.32)	1.82±(1.25)
Deaths by age	0±(0)	0±(0)	0±(0)	0±(0)
Deaths by predation	--	--	1.3±(14.35)	1.29±(0.57)

In Scenario 3 it is observed the largest number of deaths due to predation, the smallest populations of lizards and shortest longevity considering all types of environments. This can be understood as the most challenging scenario, in which the lizards do not evolve and predators are present (lizards are unable to adapt and immersed in a hostile environment).

Scenario 4, although still challenging for the lizards, was the most balanced of all. The evolution in this scenario allowed the survival of the lizards even in the presence of predators.

By analyzing the results of this study it is noted that the genetic-evolutionary model proposed for the simulator allows the adaptation of the lizards to the environment and its variations, such as food shortages and the presence of predators. It was noted behavioral, physiological and morphological changes in lizards, which were not previously planned, but emerged from the simulated process of evolution through natural selection. For instance, in all scenarios it is noted a small decrease in the size of the bodies and heads of the lizard, their speed was significantly increased, and variations in their thresholds and food preferences were observed.

Comparing Scenarios 1 and 2, in which predators were excluded, there was a significant increase in longevity, fecundity and population size in the three environments, as well as a decrease in the number of deaths from malnutrition and dehydration (around four times smaller). It is noteworthy that the only difference between these two scenarios is the evolution enabled in Scenario 2.

Comparing Scenarios 3 and 4, a visible increase in longevity, fecundity and population size is observed as also occurs in the previous comparison between Scenarios 1 and 2. In Scenario 4 it is observed that the evolution of species over the generations led to adaptations that ensured the survival of the organisms throughout the simulation in three levels of environment, unlike Scenario 3, where there was no evolution and it was observed the extinction of lizards in hostile and balanced environments. It could also be observed a general decrease in the number of deaths from dehydration, malnutrition and predation.

5. Conclusions

By running the proposed simulator it is possible to observe significant differences between the results of the four different scenarios, and also that the genetic-evolutionary model and the presence of predators visibly affect the survival and reproduction probabilities of lizards. In all scenarios and environments it is observed patterns of behavior very similar to models studied in biology [Berryman1992; May 1972; Smith and Slatkin 1973], as well as the Lotka-Volterra model.

In these comparisons, it is concluded that there are significant differences between scenarios with and without evolution. Extrapolating the simulations for the game, one can show the player the effects of evolution on the successful survival of the species over time, as well as the relationships and balances between predators and prey in nature. These results should serve as a basis for the game Calangos and may also serve to model the gameplay and the modeling of game characters. With the knowledge obtained during both modeling and prototype development and experimentation with the simulator, a better planning and development of the remaining phases of the game can be made.

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