An Extended Predator-Prey EcoSystem with Cannibalism and Omnivory

Başar Uğur*
Department of Computer Engineering, Boğaziçi University, 34342 Bebek, Istanbul, Turkey

We present a predator-prey based ecosystem with predators having a chance of being omnivorous or cannibalistic. The ecosystem contains plants as food for preys and omnivorous predators. These three items (plants, preys and predators) are represented by their typical living parameters such as reproduction / mating rate, energy consumption and food-finding capabilities. The experiments show the effects of these parameters and extended model parameters on the evolution of the ecosystem.

I. INTRODUCTION

A typical ecosystem of countable biological forms consists of plants and animals. Their feeding habits are tightly related to each other as peers. At the bottom of the food chain, a plant produces its own food (=energy) from natural resources such as sun and water. However, a herbivorous animal eats parts of plants, a predaceous animal eats other animals and an omnivorous animal feeds either way. As all these creatures -including human beings- stay alive by their feeding *habits* and can co-exist, one can assume a mathematical mechanism lying under the current instance of biological evolution.

According to studies related to complex systems, since the beginning of the 20th century, there has been much interest in cyclic population fluctuations. First grabbing attention from real-life statistics, several studies have been conducted for both examining and experimenting. Cyclic population fluctuations have been intensively studied in various ecological systems during 1970s. Stabilizing and destabilizing mechanisms are identified for predator-prey systems, parasitoid-host interactions and competitive interactions.

In this paper, we focus on predator-prey systems. Most previous theoretical analyses of predator-prey systems have taken Volterra's equations [1] as their starting point. In this study, predator and prey populations are noted as two variables related to each other with differential equations. These equations are now known as *Lotka-Volterra (LV) equations*:

$$\frac{dN}{dt} = N(a - bP)$$
$$\frac{dP}{dt} = P(cN - e) \tag{1}$$

where a, b, c, and e are constants characterizing the populations of prey N and predators P. However, the LV equations are the *simplest* equations for describing the time evolution of two interacting populations. They have some obvious drawbacks [2]. Firstly, the LV equations say that without the predators, the prey population will grow in an unlimited way. This is not realistic, there should be an upper limit, a *carrying capacity* for the prey so that they can live by occupying some space in a given habitat. Also, assuming that the feeding an breeding is continuous, is not exactly what happens in the biological sense. There are hunting and breeding seasons, hybernating, pregnancy times etc.

There are several enhancements added to the first mathematical observations of Lotka and Volterra, regarding predator-prey models. The models are mostly constructed with *cell*s to be occupied by predators and preys, while biological interactions occur within a specific cell. Escaping and hunting strategies are studied by the help of statistics-related frameworks [2]. Although they mostly remain within the boundaries of this simplistic model, there have been other studies which should be named as *extensions* to the model as well.

As a subject of biology, one inevitably thinks about extensions to the model representing real-life information. For example, can we introduce the food for the prey, how would the populations fluctuate? Can we apply a more realistic reproduction mechanism for the peers, how much would it affect the model? Most of these questions have been conquered, but there have been other questions which may not come to mind at first thought. The following two are examples of these types of questions, and are the focus of this paper, too.

First question is, how can we represent *omnivorous* animals in these models? Omnivory is eating both plants and animals as primary food source. Eubanks has a book chapter about the studies based on this approach [5]. He concludes that although it may be a survival-increasing strategy for the predators, little is known about the effect of omnivory on the herbivorous preys. It is natural to wonder if this *diet mixing* affects the plant resources and the predator-prey relation turns into a rivalry of the species, in an evolutionary manner.

Second question is, how can *cannibalism* add to this relation? Cannibalism is defined as eating conspecifics (members of the same species). Cannibalistic behavior is said to have a stabilizing effect on predator-prey models, according to an early study by Kohlmeier et. al [3]. The study explains the possibility of population stabil-

*basar.ugur@boun.edu.tr

ity being enabled by sometime cannibalistic behavior of the predator. Furthermore, age-structured cannibalism is also introduced in PP models [4], where cannibalism is developed further by a more realistic approach, where a specific age group is allowed to feed on another specific age group of their conspecifics.

Although these two behaviors are said to be rare in nature, their effect can be seen on a typical PP system easily. Our study tries to construct a more realistic and parametric approach, introducing the behaviors by adding a few parameters and functions on the ecosystem implementation. The next section discusses our model, and the implementation of it follows. Then we present and discuss some of the results obtained and conclude the paper with future work.

II. THE MODEL

Our model consists of three types of creatures as introduced in the previous section: *Plants*, *Preys*, and *Predators*. Feeding and energy consumption are the main concerns. However, contrary to some simulations concerning the energy sources of plants, we assume an infinite amount of them. Therefore the "feeding" of plants is out of concern. We tried to construct the creature representations and the ecosystem with an *object-oriented* approach, as they usually encourage and exemplify object-oriented software architecture.

Furthermore, the model is constructed thinking of the ecosystem simulation. The attributes of the creatures are generally thought in terms of discrete time. Using such an approach, implementation of simulation becomes faster. We will denote unit discrete time as t in the following subsections.

A. Plant

A plant consists of five attributes:

1. Reproduction rate
2. Age
3. Lifetime
4. Population capacity
5. Nutrition value

Reproduction rate is represented as a time value, which equals to the time to pass between consecutive reproductions. *Age* is also represented by means of t. *Lifetime*, *population capacity* and *nutrition value* are used as ecosystem constants. Lifetime is represented again in terms of t. Nutrition value is used in the feeding functions of preys and omnivorous predators.

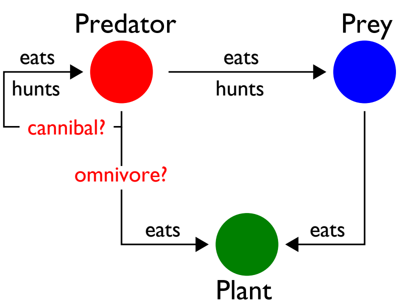

FIG. 1: The functional relationship between ecosystem nodes. A predator can either be normal, cannibalistic, or omnivore.

B. Prey

A prey is represented by eight attributes:

1. Mating rate
2. Age
3. Lifetime
4. Energy
5. Energy consumption rate
6. Population capacity
7. Nutrition value
8. Feeding probability

We use "*mating rate*" –which is also represented as a time value–, because we assume a mating process within the simulation for the reproduction of a new prey. Attributes such as age, lifetime, nutrition value and population capacity are similar to plants. *Energy*, *energy consumption* and *feeding probability* are attributes related to feeding habits. When a prey feeds, it gets the nutrition value of the plant immediately, and consumes it in time according to his energy consumption rate. It feeds with a chance of its feeding probability added with a value inversely proportional to his age. This probability is the way we introduce *food-finding behavior* in this study. Instead of searching for food in cells (in lattice models), we use a feeding probability value.

C. Predator

A predator is represented by 10 attributes:

1. Mating rate
2. Age
3. Lifetime
4. Energy
5. Energy consumption rate

6. Population capacity
7. Nutrition value
8. Feeding probability
9. Hunting probability
10. Feeding behavior

Shared attributes are similar to those of preys (that is why `prey` class is the parent of `predator` class). Only interestingly, nutrition value is used in cannibalistic feeding. *Hunting probability* is similar to feeding probability, a predator hunts with a chance of its hunting probability added with a value inversely proportional to his age. Finally, *feeding behavior* is a value assigned at "birth", which denotes whether the member is normal, cannibal or omnivore.

Beyond these attributes, there are two general parameters attributed to the predator species:

1. Cannibalism ratio
2. Omnivory ratio

These values are used for assigning the feeding behavior at birth. A newborn becomes cannibal with a probability equal to the "cannibalism ratio", or omnivore with a probability equal to the "omnivory ratio".

D. EcoSystem

The ecosystem is the common ground where the generic parameters and functional rules are defined. It contains simulation-specific constants like the initial population of the species, initial energies of newborns. It also contains the available food resulting from successful hunting.

Feeding happens in three different ways:

1. A prey or omnivore predator finds a plant according to his *feeding probability*, terminates it and adds the nutrition value of it to his energy immediately.

2. A *normal* predator hunts for a prey according to his *hunting probability*. If successful, he adds it to the *available prey stock* of the ecosystem. All predators (of normal, cannibalistic or omnivorous behavior) can feed from the stock, and at one instance they feed with a %20 amount of *prey nutrition value*.

3. Similar to 2, a *cannibalistic* predator hunts for a predator according to his *hunting probability*. If successful, he adds it to the *available predator stock* of the ecosystem. Cannibals can feed from the stock, and at one instance they feed with a %10 amount of *predator nutrition value*.

This feeding model is inspired by the biological behavior where hunting results in large amounts of meat which is shared by several members of the species.

Reproduction in plants occurs as follows: The "reproduction counter" of a plant is decremented at each time step. When it becomes less than 0, the plant reproduces one new member immediately and resets its own reproduction counter. However, mating in preys and predators occurs as follows: Each member has a "mating counter" according to the mating rate of their species, and it is decremented at each time step. When it is less than 0, the member searches for another member with a mating counter less than 0, similarly. If he finds, they "mate" and a new member is added to the community immediately, resetting the "mating counter" of the partners.

All individuals die when their ages exceed the lifetime of their species. Furthermore, predators and preys die if their energies fall below 0.

III. IMPLEMENTATION

The model is implemented as a software simulation with graphical user interface (GUI). It is written in an object-oriented manner, as the design was made thinking of similar terms.

`Plant`, `Prey` and `Predator` are separate classes. `Predator` is derived from `Prey`, actually. They have the necessary methods such as `iterate()`, `feed()` and `hunt()`. `iterate()` is the common method for all three classes. It is called at each time step, where "counter"-like attributes such as age, energy, mating / reproduction counter are incremented or decremented.

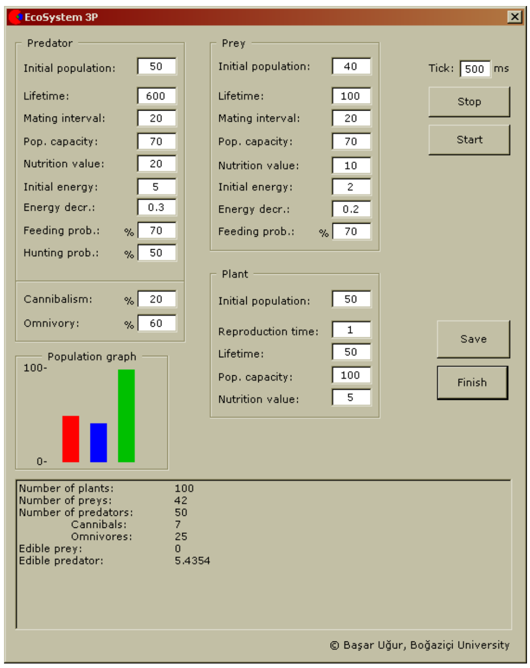

FIG. 2: EcoSystem 3P simulation software GUI.

The program flow is as follows: An ecosystem is created with the values obtained from the GUI and it prepares the lists containing members of each species. These lists are *doubly linked lists*, container structures which enable fast insertion and removal of elements. Simulation starts when the main timer is triggered by GUI components. At each time step, the ecosystem is triggered to iterate. In one ecosystem iteration, plants, preys and predators are `iterated` respectively. After their iteration, the ecosystem checks the available food stock (namely *prey* and *predator*) and depreciates them to a 80% amount. This 80% value is assumed from real-life information, as specific depreciation / decomposition rates of meat in open-air are not commonly known (or studied).

IV. RESULTS AND CONCLUSION

Several experiments have been conducted, adjusting the parameters at low or high precisions. Many mathematical relations were visible during the conduction of the experiments but the large number of parameters formed a barrier in the way of deducing exact relations.

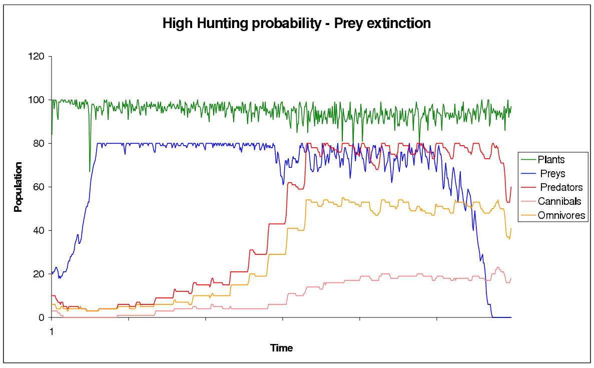

FIG. 3: Effect of high hunting probability of predator on the eventual extinction of the prey.

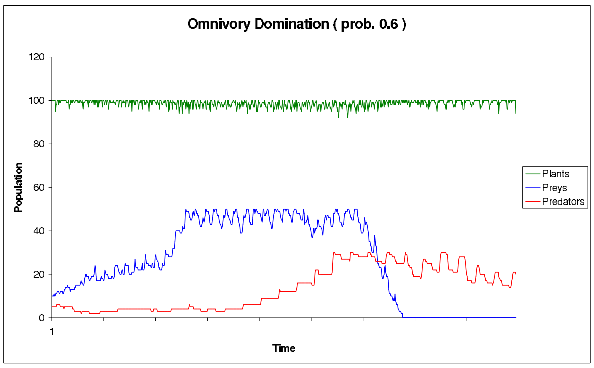

FIG. 4: Effect of high omnivory ratio for the predator on the eventual extinction of the prey.

Obviously there were some redundancies on specific occasions; for example, increasing the nutrition value of the food was equal to decreasing the energy consumption of the consumer (in a two-species food-consumer society, such as prey-plant, omnivore-plant). But on large scale, having several parameters is an advantage, where you can see the effect of one value on the population of all three species.

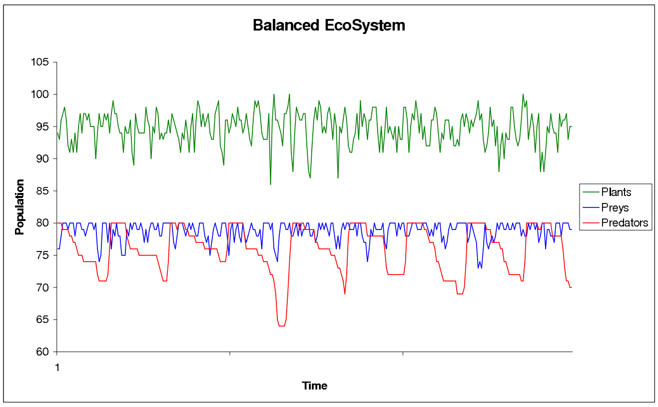

FIG. 5: A balanced ecosystem where predator and prey capacities are equal to each other.

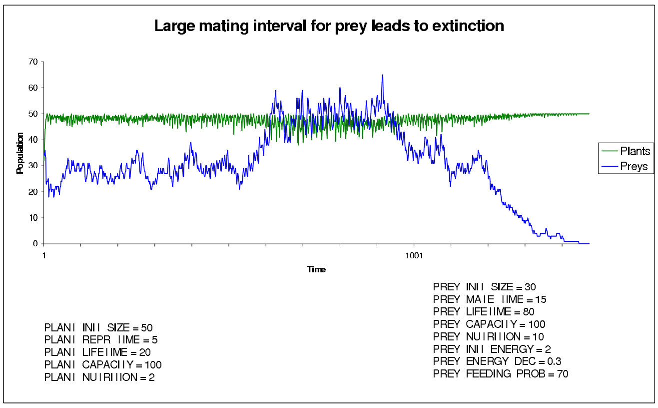

FIG. 6: Although both plant and prey seem balanced, prey becomes extinct after some point, in the absence of predators. There may be several causes. One possible cause is the difference in reproduction rates. (Plant population is halved for observation purposes)

Verbally, some important results were as follows:

- Mating / reproduction rates affect the population mostly. The relation between the rates of two species, affect their relative population (Fig. 6).
- Initial values are important, especially because a healthy group of individuals should keep reproduction at a good level so that the species do not extinct unexpectedly at the beginning.

- Small population values lead to small fluctuations. If larger numbers are used, the results may be observed at a larger time scale.

- Hunting and feeding probabilities affect the species at the lower levels of the food pyramid. In a seemingly stable system, a prey or plant may become extinct after some time (Fig. 3).

Finally, we can also deduce from the experiments that cannibalism has a stabilizing effect on these three-species systems, but omnivory remains a sensitive aspect. Most of the experiments conducted with omnivory as a dominant strategy have resulted in the extinction of either predator or prey.

We have presented a study on hybrid strategies for predators in a three-species ecosystem. Experiments have shown that parameters should be in well accordance for the system to remain stable for long periods of time. Mainly, mating and reproduction rates, nutrition values and energy consumption rates are the affective parameters for such ecosystems.

[1] Vito Volterra, "Variazioni e fluttuazioni del numero d'individui in specie animali conviventi," Mem. R. Accad. Naz. dei Lincei 2. **31-113**, (1926).

[2] Andrzej Pekalski, "A Short Guide To Predator-Prey Lattice Models", Computer Simulations, **62-66**, (2004).

[3] C. Kohlmeier and W. Ebenhöh, "The stabilizing Role of Cannibalism in a Predator-Prey System", Bul. Math. Biol, **401-411**, (1995).

[4] F. Van Den Bosch and W. Gabriel, "Cannibalism in an Age-Structured PP System", Bul. Math. Biol., **551-567**, (1997).

[5] Micky D. Eubanks, "Predaceous Herbivores and Herbivorous Predators - The Biology of Omnivores and the Ecology of Omnivore-Prey Interactions", Ecology of predator-prey interactions, OUP, **3-16**, (2005).