A Computer-Based Simulation Showing Balance of the Population of Predator and Prey and the Effects of Human Intervention

Ankit Kumar\(^1\), Kunal Jani\(^2\), Divyansh Khatri\(^1\), Hrishitva Patel\(^3\), Aditya Kumar Sharma\(^4\) and Nabin Kumar Sahu\(^1\)

\(^{1}\) DA-IICT, Gandhinagar, India  
\(^{2}\) Santa Clara University, USA  
\(^{1}\) DA-IICT, Gandhinagar, India  
\(^{3}\) SRM University, Chennai, India  
\(^{4}\) RTU, Kota, India  
\(^{1}\) DA-IICT Gandhinagar, India

e-mails: ankitaahil7743@gmail.com, kunaljani18@gmail.com, 201801012@daiict.ac.in, hrishitva26061998@gmail.com, aks16340ec2016@gmail.com, nabinkumar_sahu@daiict.ac.in

Abstract. In this paper, a computer-based simulation of the predator-prey model has been proposed. The prey is a source of food for the predator, which is necessary for the prey’s survival. Various models, such as the Lotka-Volterra model and the cellular automata model, have been used to simulate predator and prey movement in a population. These methods have been discussed briefly. The limitations of both these methods have been highlighted. After discussing the limitations of both these methods, a novel computer-based simulation has been proposed to address the previous models’ limitations. Since this model takes into account a more realistic movement of predator and prey, it has been used to study the harmful effects of human intervention on the environment. In this simulation, the birth of predators and prey by mating, the death of predators and prey due to starvation, and the death of prey due to attacks from predators are taken into consideration. In the first case, there is no human intervention. In the next two cases, human intervention is taken into consideration. In one case, the proportion of predators in the population increases, and in the other case, the prey population increases. A comparison has been made between all three cases, and a study has been done showing how human intervention affects the population of predators and prey over a long time.

1. Introduction
In ecological science, the study of a system involving a single predator and available prey is prevalent [1]. In such a scenario, the prey is generally dependent on food sources from nature itself. The predators are dependent on prey for food. Suppose the number of individuals of prey species is too less. In that case, there is little food available for predators, which means that many individuals from the predator species will die due to starvation and thus become extinct. If the number of individuals forms the prey species are too many, then there is a limited amount of food available for the prey available from nature. Thus, many individuals from the prey species die due to starvation, and therefore, once again, there is a
limited amount of food for the predator species. This once again leads to a reduction in the number of predator species.

In an ecological system such as a small wildlife sanctuary, various factors such as the predators attacking prey, the male and the female population of the predator species as well as the prey species [2], death of prey due to attack from predators [3], death of predators and prey due to starvation [4] and natural death of predators and prey [5] are taken into consideration. So, various parameters, as well as ecological factors, determine the development of computer-based simulation.

Sahoo et al. [1] described the dynamics which are involved in a harvested predator-prey model. Abdulghafoor et al. [6] conducted a disease model study based on the interaction between the predator and prey, considering the prey being attacked by the predator and prey seeking refuge. Jana et al. [7] described a mathematical predator-prey model to control the population of pests. Dubey et al. [8] described a mathematical model of the interaction between predator and prey within a reserved area. Obaid [9] described the predator-prey model using the Lotka Volterra Model. Li et al. [10] developed a simple version of the predator-prey model consisting of rich dynamics. Daga et al. [11] performed an analysis of the predator-prey system with the help of a modified transmission function. Chattopadhyay et al. [12] discussed a model that shows the interaction between predator and prey under the condition that there is a disease present in the prey. Al-Ruzaiza [13] described chaos and control in a predator-prey model consisting of unknown parameters. Alwan et al. [14] described the control of habitat destruction, which consisted of uncertain parameters. Gonzalez et al. [15] described a predator-prey model that involved social predation. Molla et al. [16] described a Holling type functional response predator-prey model. Deng et al. [17] described a version of the predator-prey model that considered the predator feeding on its species' individuals. Lin et al. [18] described the Leslie-Gower predator-prey model, which took into consideration predator cannibalism. Tang et al. [19] described the backward bifurcation in the case of the predator-prey model taking into consideration anti-predator behaviors. The aim of this project is to address limitations of previous mathematical models and to develop a computer-based simulation addressing these limitations.

2. **Previous mathematical models**

A lot of models showing the interaction between predator and prey have been studied using mathematical equations as given below [19]. x is the population of predator, y is the population of prey, a, b, c and d are positive parameters representing interaction between the 2 species.

\[
\frac{dx}{dt} = ax - bxy \quad (1) \\
\frac{dy}{dt} = dxy - cy \quad (2)
\]

This model is based on the following assumptions:

i. There is always a sufficient amount of food available for individuals from the prey species. However, if the prey population increases, then the number of food resources available for the prey would decrease causing starvation.

ii. It is also important to note that the food resources available in the environment are not finite. This means that when the number of predators or prey increases, there are fewer food resources available per individual. Therefore, these individuals die due to starvation when the population of any species becomes too high. This shows that the rate of population change is not proportional to the number of individuals in a species when the number of species is large, and the resources available are less.

iii. This model has considered that there is no limit to the quantity to the amount of food that the predator eats.

iv. This model does not capture the movement of predators and prey in a fixed natural environment.

v. This model does not thoroughly capture the effects of human intervention on the environment.
2.1. Cellular Automata Model
In this model, a two-dimensional lattice space of M cells in a row and N cells in a column has been considered. Cellular automata consist of two steps: reaction and movement. Based on the surrounding environment, the individual reacts and moves in a particular direction. A Von Neumann neighborhood is considered, which takes into account only the horizontal and vertical neighbors of a cell and not the diagonal neighbors of a cell. For modeling the prey’s movement, the prey moves in the direction where the number of predators is minimum, and a predator moves in the direction where the number of prey is maximum. Cellular automata take into consideration some of the limitations of the Lotka Volterra predator-prey model.

i. This movement captures the movement of predators and prey in the population based on the surrounding environment in the immediate neighbor cells.

ii. Since the number of prey in the environment is finite and prey moves in the direction where the number of predators is minimal, it is actually difficult for predators to find prey. Therefore, the quantity of food that is available for the predator becomes limited.

iii. The size of the environment is considered to be fixed. Therefore, it is possible to visualize the interaction between predator and prey in an environment.

iv. Up to some extent, this model can capture the effects of human intervention on the population of predator and prey species.

Even though the cellular automata model addresses the Lotka-Volterra model’s limitations, it is still based on several assumptions:

i. Even though this model considers movement based on the immediate movement of predator and prey based on the surrounding environment, it is assumed that the movement is possible in only a few fixed directions. However, in a real environment, predator individuals or prey individuals’ movement is not in a fixed direction.

ii. This model assumes that the distance moved by any individual at any time instant is fixed. However, in practice, the individual doesn’t need to move equal distances in equal intervals of time.

iv. The size of the environment where the predator and prey move is assumed to be strictly fixed. However, in practice, the environment’s size is not strictly fixed, and individuals belonging to the predator and prey species tend to move out of their natural environment at times.

v. This model does not take into account the meeting of males and females meeting and giving birth to young individuals.

vi. Even though this model can capture the effects of human intervention, limited work is done using cellular automata to capture the effects of human intervention.

For our model, we have used the Python programming language to develop our computer-based simulation mapping the model of predator and prey in a fixed area of study which is represented by a 2-dimensional plot. Random variables are used to simulate the random movement of predator and prey, the probability of birth and death of an individual, and other factors that are not deterministic. For our simulation, we take three different initial conditions where the population of the predator and prey vary and we analyze our experiments through a graphical visualization.

3. Proposed Computer-Based Simulation of the Predator-Prey Model
In our computer-based simulation, we consider the movement of predator and prey within a fixed population while addressing the limitations of the cellular automata model. The movement of predator and prey is assumed to be random. It has been assumed that the movement of one individual does not affect the movement of another individual in this fixed environment. Therefore during this movement, the distance between a predator and prey can reduce causing an interaction between these two individuals causing the death of the prey. The distance between a male and female individual of the same species can reduce causing them to participate in the process of reproduction and giving birth to a new individual. Our proposed computer-based simulation addresses limitations of the cellular automata model.
i. This model does not assume that the movement of predator and prey is in a fixed direction since the individual can move a variable distance in the horizontal direction as well as in the vertical direction at any time instant. Moreover, since the distance moved is variable, the individual does not move equal distances in equal intervals of time.

ii. This model takes into account the starvation death of predator and prey in the environment which was not included in previous models. In this model, only the natural death rate is not considered.

iii. Since the motion of predator and prey is assumed to be random, the size of the environment where the predator and prey move is not fixed. The individuals of both species may move outside their marked territory.

iv. This model takes into account males and females of both species coming into close contact and giving birth to individuals of their own new species.

v. This model thoroughly captures the effects of human intervention and shows how human intervention deliberately reducing or increasing the population of any species is harmful to both the species in an environment.

3.1. Computer simulation-based predator-prey model when no human intervention is present
A wildlife sanctuary with a fixed area of 10 km * 10 km is assumed for our study area. Generally, the population of predators is much lower than the population of prey, so we consider the Predator species to account for 10 % of the population while we account for prey species to be 90 % of the population. The wildlife sanctuary is populated with male and female species of the predator as well as the prey. The probability of an individual belonging to the predator species is considered to be 0.1 and the probability of an individual belonging to the prey species is considered to be 0.9. This means that approximately 10 percent of individuals belong to the predator species and approximately 90 percent of individuals belong to the prey species. For both species, the probabilities of an individual being a male or a female are equal. Initially, it is assumed that all the individuals are located at an equal distance from each other. In Fig. 1, the green dots show the male individuals from the prey species; the black dots show the female individuals from the prey species, the blue dots show the location of male individuals from the predator species and the red dots show the location of female individuals from the predator species.

![Plot showing the location of predator and prey in a wildlife sanctuary](image)

**Figure 1.** Figure showing the location of the individuals of the predator and prey species.

The variation of the number of individuals from the predator and the prey species is observed over a long time period of 30 months. We assume that the predator and prey travel an average of one meter per day. Every month, all the individuals travel a certain distance which follows a mean $\mu$ of 0 meters and a variance $\sigma$ of 1 km. The animals have a high probability of travelling smaller distances and a lower probability of travelling larger distances, therefore we can assume that the movement of animals in the population follows a Gaussian distribution. These values are based on the assumptions on the average
distance travelled by the animals while searching for food. If a male predator and a female predator come in close contact with each other, they mate with each other to give birth to a new individual of the predator species. The new individual has an equal probability of being a male or a female. The predator species has a low natural death rate, so for any given month, it is not very likely that a predator dies due to natural causes. The distance $d$ moved by an individual is given below.

$$d = \frac{1}{(2\pi\sigma)^2} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad (3)$$

where $x$ denotes the random variable generated by our simulation.

Similarly, if a male individual and a female individual belonging to the prey species come in contact with each other, they give birth to a new individual of the prey species. The prey species also has a very low natural death rate. If the number of individuals belonging to the prey species becomes extremely large, then the resources available reduce for the prey, and therefore an individual from the prey species dies with a probability of 0.9. Similarly, if the number of predators becomes extremely large, then a predator dies with a probability of 0.4. This means when the population of predator or prey becomes too large, approximately 90 percent and 40 percent of the individuals of predator and prey species die respectively as observed in real life scenarios. If a predator comes in close contact with the prey, then the predator attacks the prey. The prey may or may not survive the attack from the predator. If the prey does not survive the attack from the predator, the prey becomes a source of food for the predator, and the number of months the predator goes without food automatically returns to zero. Each and every month the predator is not able to catch an individual from the prey species, the number of months without food increases for that predator. If the predator goes without food for more than 4 months, the predator dies with a probability of 0.1 for each month after the fourth month without food. This case may even occur when the predator population is too large since it might be possible that the predator is far from the source of food and is therefore not able to get food quickly and therefore starves to death.

3.2. Computer simulation-based predator-prey model when human intervention causes a reduction in the number of individuals from the predator species

A wildlife sanctuary of the same area is taken in this case. However, while populating the wildlife sanctuary with individuals of the predator and the prey species, we assume that the probability of the individual being a member of the predator species reduces to 0.02 and the probability of the individual belonging to the prey species increases to 0.98. This means that approximately 2 percent of the individuals belong to the predator species, and 98 percent belong to the prey species. The simulation is run once again, keeping the other parameters the same as the ones in the previous case. The male predators’ location, the female predators, male prey, and female prey can be shown in Fig. 2.

![Figure showing the location of the individuals of the predator and the prey species when human intervention causes a reduction in the number of predators.](image)
3.3. Computer simulation-based predator-prey model when human intervention causes an increase in the number of individuals from the predator species

As considered in the two previous cases, the wildlife sanctuary area is taken to be the same. While populating the wildlife sanctuary, the individual is a predator with a probability assumed to be 0.2, and the individual is a prey with a population of 0.8. Then means that now approximately 20 percent of the individuals are predators, while 80 percent of the population are prey. The simulation is also run for this case without changing any other parameters. Fig. 3 shows male prey, female prey, male predators, and female predators.

![Plot showing the location of predator and prey in a wildlife sanctuary](image)

**Figure 3.** Figure showing the location of the individuals of the predator and the prey species when human intervention causes an increase in the number of predators.

4. Relating Our Experiments With a Real-Life Scenario

The area of study that was taken into consideration was the Mitkof, Kupreanof, and Kuiu islands. With the use of the night count technique, it was possible to determine the deer’s relative density. The trend in the total number of deer located was calculated using a log transformation regression with respect to time. The total number of wolves were counted by the use of various aerial surveys. When there was fresh snowfall or when local residents reported wolves’ sightings, then there was an increase in the count of the total number of wolves in the population. Radiotelemetry was used to calculate the fawn mortality rate. From this study, it was found out that the presence of wolves played a significant role in controlling the population of deer. This explains that our findings from a computer-based simulation are accurate since the presence of wolves would mean that the deer population is controlled. If the deer population is controlled, there are enough plant resources in the natural environment; therefore, the deer’s population would not become extinct due to a lack of natural resources. If the wolf population is controlled, it would mean that too many deer would not be hunted, and thus there would always be enough resources for the wolves.

5. Results

For every case which has been considered, the variation of the number of predators with time, the variation of the number of prey with time, and the scatter plot showing the location of predators and prey in the wildlife sanctuary have been displayed to show how human intervention affects the population of a species. When there is no human intervention, it can be seen that the people of predators and the prey follow a continuous cycle of increasing and decreasing over time. The predator and prey species population over time can be shown in Fig. 4 for 30 months. The density of predator and prey in the wildlife sanctuary at the end of 30 years can be shown in Fig. 5.
When human intervention causes the predator population’s proportion to decrease, the number of prey in the community initially shows a dramatic increase. Then due to the limited availability of resources, the prey population dramatically reduces. However, the predator population remains nearly constant. It can also be seen in Fig. 6 that since the individuals from the predators and the prey species are now scattered over a large distance due to their low population, the male and female individuals in both species can’t meet and reproduce. Therefore, the risk of extinction is much greater for both the predator species and the prey species. A reduction in both the species’ density due to deliberate human intervention causing a reduction in the proportion of predators can be shown in Fig. 7.

**Figure 4.** Graphs showing the population of the predator and the prey species over time when there is no human intervention.

**Figure 5.** Graph showing the predator and prey in the wildlife sanctuary at the end of 30 months without human intervention.

**Figure 6.** Graphs showing the population of the predator and the prey species overtime when human intervention caused a reduction in the proportion of predators.
Figure 7. Graph showing the predator and prey in the wildlife sanctuary at the end of 30 months with human intervention causing a reduction in prey proportion.

Similarly, when human intervention causes the predator population’s proportion to increase, there is a limited amount of food resources available for the predator. Due to this limited amount of food resources for the predators, the predator population rapidly decreases. The males and females can’t reproduce and bring back the community to original levels. Even since the number of individuals in the prey species has a lower proportion than the other two cases, the males and females do not frequently meet to reproduce more individuals of their kind. Thus there is also a steady decline in the prey population. Similarly, in this case, also, there is a risk of extinction of both the species. This is shown in Fig. 8. The density of the population of predator and prey can be shown in Fig. 9.

Figure 8. Graphs showing the population of the predator and the prey species over time when there is human intervention causing an increase in the proportion of predators.

Figure 9. Graph showing the predator and prey in the wildlife sanctuary at the end of 30 months with human intervention causing an increase in prey proportion.
6. Conclusions
In this paper, we have developed a computer simulation instead of using a mathematical model. It was possible to create a novel simulation of predator and prey movement in a population that addresses the limitations of previous models. This model could also be used to study the harmful effects of human intervention on the natural environment. When there was no human intervention, it was seen that the population of the predator and the prey remained relatively constant, and it kept on increasing and decreasing in cycles. In absence of humans, the ecosystem inside the wildlife sanctuary was balanced. However, in the other two cases, we see that if the predator population reduces or the prey population reduces, then the ecosystem gets disturbed inside the wildlife sanctuary. This behavior can be seen in the plots where the predator’s people and the prey reduce to nearly zero. Hence, it can be seen that affecting the people of one species harms another species’ population. Therefore efforts should always be made to ensure that a balanced ecosystem is subject to minimal disturbance by humans. In the future, we will work on more complex predator-prey models involving more than two species. In these models, we will show how removing one species affects other species in multiple predators and multiple prey models using similar computer-based simulations.

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