The effect of a safe zone on energy level and populations size for predator prey relations

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July 2, 2024

Abstract

This report examines the impact of rabbit-only safe zones on energy levels and population sizes in predator-prey dynamics, particularly between foxes and rabbits. The study investigates how safe zones affect interactions between species and balance within the ecosystem. Simulations conducted under two scenarios: a baseline model in which both species has access to rabbit holes, and a test model with rabbit-only safe zones. The results show that the scenario with rabbit-only safe zones is more stable in terms of population sizes and energy levels of both species. In contrast, scenarios in which both species could enter safe zones show unbalanced energy levels and population sizes. Statistical analysis using T-tests confirmed the significant differences in energy levels and population sizes between the two scenarios. These findings emphasise that safe zones are important for maintaining ecosystem balance and suggest potential strategies for protecting natural habitats.

1 Introduction

In nature, predator-prey relationships are common and crucial for ecosystem balance. In general the number of predators and the number of preys fluctuate around a certain population mean. When the number of predators is below the mean, the population on prey can increase because they are not hunted a lot. Then there is a lot of food for the predators so the population of predators increases. But when there are more predators than average the prey population decreases. Then the food for the predators gets scarce so the predator population also decreases. This is the ecosystem balance in short.

Unfortunately, the ecosystem balance can get disturbed. If something disturbs the balance there can be too many predators or too little predators. On one hand, when there are too many predators the prey die out because they are all caught. Then the predators have no food and they also die out. On the other hand, when there are too little predators, there is nothing to stop the prey population from growing and the prey will dominate an ecosystem. Some reasons for a disturbance in the balance can be natural disasters or disease outbreaks. However, humans can also disturb the ecosystem balance.

Humans disturb the ecosystem balance for example by building infrastructure, pollution and over-exploitation. Therefore, it is important for humans to know how to restore this balance. For example, when humans want to build a road through a nature reserve. This then impacts the ecosystem balance. To still be able to make this road but not mess up the balance humans should know what influences this balance and how they could be able to restore this. A real life example where humans restored the ecosystem balance was in the Oostvaardersplassen. In the Oostvaardersplassen there were too many red deer (prey), because there were not enough predators. Therefore some of them had to be killed to keep the ecosystem in balance [Fle21].

A model that is often used to model predator prey relations is the Lotka-Volterra model. This model only involves rabbits (prey) and foxes (predators) . Rabbits are born and their population decreases due to predation. Foxes are also born, and their birth rate is influenced by the predation rate, while they also experience natural death. In this model, changes in predator and prey populations are interconnected. As the number of foxes increases, it decreases the rabbit population. Conversely, a larger rabbit population tends to support more foxes. This relationship shows how the populations of both species influence each other over time [SF08]. The idea that more foxes should decrease the rabbit population and the idea that more rabbits should increase the fox population are used for modeling the probabilities of reproduction and death in this study.

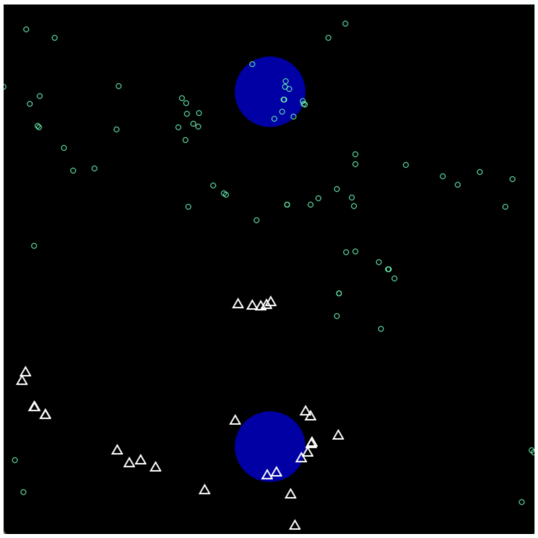
In this study the predator prey relationship between rabbits and foxes is modelled. However, to model a behavior it is important to understand it first. In this scenario the predators are the foxes. Foxes, compared to rabbits, have high energy demands primarily fulfilled through hunting. Naturally foxes also have a higher energy level compared to rabbits. Since rabbits have lower energy, they conserve some by utilizing safe zones to evade predators. This paper aims to explore the effects of rabbit-only safe zones on the energy dynamics and population dynamics of both species.

Research question

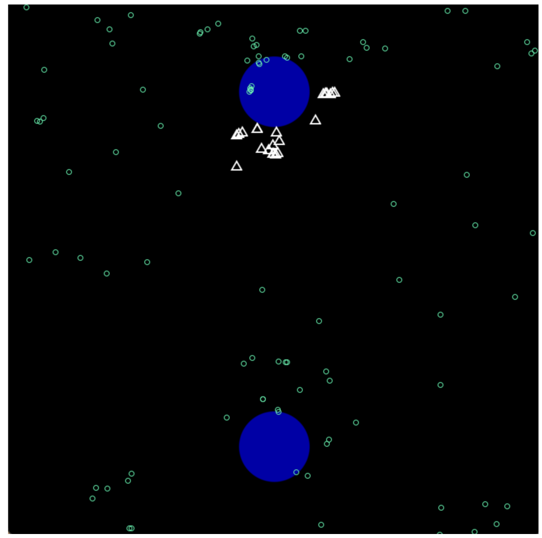
In this paper the following research question is adopted: "How do the energy levels and population sizes of foxes and rabbits differ between scenarios with and without rabbit-only safe zones?". Hereby, to clarify the research process, there are two null and alternative hypotheses for this research question.
Null Hypothesis (H0) 1: There is no significant difference in the energy levels of foxes and rabbits between scenarios with rabbit-only safe zones and scenarios where both species can enter the safe zones.
Alternative Hypothesis (H1) 1: There is a significant difference in the energy levels of foxes and rabbits between scenarios with rabbit-only safe zones and scenarios where both species can enter the safe zones.
Null Hypothesis (H0) 2: There is no significant difference in the population sizes of foxes and rabbits between scenarios with rabbit-only safe zones and scenarios where both species can enter the safe zones.
Alternative Hypothesis (H1) 2: There is a significant difference in the population sizes of foxes and rabbits between scenarios with rabbit-only safe zones and scenarios where both species can enter the safe zones. This difference significantly affects the population rates, leading to changes in the population dynamics of both species.

2 Methodology

In the simulations, both baseline model and test model have 2 circles that represent rabbit holes. Rabbits collect their food in these holes and rest in there too. Hereby, in the baseline model these rabbit holes are considered as not safe, which means that both foxes and rabbits can access the holes. Thus a rabbit can still be hunted in the rabbit hole. However, in the test model holes are completely safe and no fox can enter the holes.



(a) Baseline Model



(b) Test Model

Figure 1: Simulations of Baseline and Test Models

Both for the baseline and test models; whenever a rabbit enters a hole, they gain energy and whenever a fox eats a rabbit it gains energy. In each timestep, both rabbit and fox lose 1 energy unit. The initial energy of a fox is 160 units. When they hunt a rabbit, they gain 50 energy units and reproduce, which influences population dynamics. The gained amount of energy affect the death probability of a fox. The formula for probability death is as follows:

$$P_{\text{death}} = 0.05 \times \frac{\text{Number of Foxes}}{\text{Number of Rabbits} + \text{Number of Foxes}} \times \left(1 - \frac{\text{Energy}}{100}\right)$$

- **Energy Factor:** The ***term 1 - (Energy / 100)*** stands for how the fox's energy level affects its survival. A fox with lower energy has a higher energy factor, which indicates a higher risk of death. The term ***Energy / 100*** normalizes the energy to a fraction of 100.
- **Population Ratio:** The term ***Number of Foxes / Number of Rabbits + Number of Foxes*** stands for the ratio of foxes to the total population of foxes and rabbits. This ratio reflects the availability of food (rabbits) relative to the number of predators (foxes). A higher number of foxes compared to rabbits means more competition for food, increasing the probability of death. Moreover, more rabbits lower this ratio and thus increase the fox population which is in line with literature [SF08].
- **Constant Factor:** The constant ***0.05*** is a scaling factor to adjust the probability to a reasonable range. This is decided by running the program 30 times to find the best constant. In each run, the behaviors of the rabbits and foxes and their effect on the population ratio were checked. Thus, the best constant has been determined to prevent any errors or abnormalities in the behavior of the agents.
- **Absolute Value:** The absolute value ensures the probability of death is non-negative.

The initial energy of a rabbit is 130 units. Rabbits are gaining 100 energy units when they are in the holes with/without fox presence, this is because of the food and resting opportunity within the holes for rabbits. The energy level of a rabbit affects their reproduction probability. Hereby this formula is used:

$$P_{\text{reproduction}} = 0.005 \times \frac{\text{Number of Foxes}}{\text{Number of Rabbits} + \text{Number of Foxes}} \times \left(1 - \frac{\text{Energy}}{100}\right)$$

- **Energy Factor:** The term ***1 - (Energy / 100)*** stands for how the rabbit's energy level affects its reproduction. A rabbit with lower energy levels has a higher energy factor, indicating a higher risk of reproduction. The term ***Energy / 100*** normalizes the energy to a fraction of 100.
- **Population Ratio:** The term ***Number of Rabbits/ Number of Foxes+ Number of Rabbits*** stands for the ratio of rabbits to the total population of rabbits and foxes. This ratio reflects the availability of resources. A higher number of foxes compared to rabbits could indicate more competition and possibly a higher reproductive drive to ensure survival. Moreover, more foxes lower this ratio and thus decrease the rabbit population which is in line with literature [SF08].
- **Constant Factor:** The constant ***0.005*** is a scaling factor to adjust the probability to a reasonable range. Similar to the constant factor of *Pdeath*, it is decided by running the program 30 times to find the best probability constant.
- **Absolute Value:** The absolute value ensures the probability of reproduction is non-negative.

If the energy level of foxes or/and rabbits reaches zero, they would die. There are probabilities for rabbits to join or leave a hole. The probability of joining a circle is 0.09, and the probability of leaving a circle is 0.9. These constants were determined through 20 runs. In each run, the behavior of a rabbit and population rates of species was analyzed. To have a balanced death and reproduction rates for both species, the probability levels that suited best and seemed most natural were chosen.

As for the data collection, for each simulation the energy levels, populations and time steps of both species are captured as metrics. Additionally, data is logged each timestep, including agent energy and counts, and saved to CSV file for statistical analysis and plots. For the statistical analysis an independent t-test is used. The t-test is used to identify significant differences between the means of two groups, which in this case are the energy levels of foxes and rabbits and their population rates. The simulation runs for the baseline and test models are not paired, so with the independent t-test the comparison of the means of two independent groups, foxes and rabbits in baseline and test model, analysed to see whether there is a significance difference between their energy levels and population counts.

The formula for the independent t-test is given by:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where:
$\bar{X}_1$ and $\bar{X}_2$ are the sample means of group 1 (baseline model) and group 2 (test model), respectively. s_1^2 and s_2^2 are the sample variances of group 1 and group 2, respectively. n_1 and n_2 are the sample sizes of group 1 and group 2, respectively.
Explanation of variables:
$\bar{X}_1$ is the mean energy level or population rate of the baseline model (group 1) and $\bar{X}_2$ is the mean energy level or population rate of the test model (group 2). s_1^2 and s_2^2 stands for the variance of energy levels or population rates in the baseline model for group 1 and 2 respectively. n_1 and n_2 are the number of simulation runs in the baseline model for group 1 and 2 respectively. Before saving the data of the models for T-test, the simulation was run 20 times for each.

3 Results

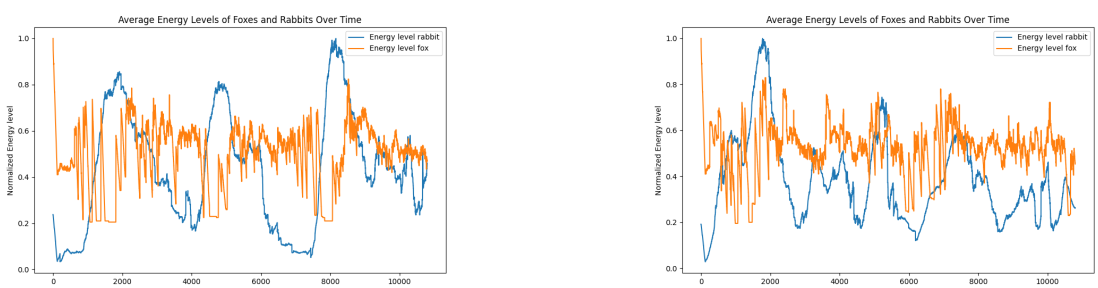
3.1 Experimental Setup

The simulations investigated predator-prey dynamics between rabbits and foxes under two scenarios: a baseline model where both foxes and rabbits can enter rabbit holes, and a test model where rabbit holes are exclusive safe zones for rabbits. Each simulation was run 20 times for both models, capturing metrics such as energy levels, population counts, and time steps. Data was logged at each timestep and saved to CSV files. Statistical analysis was performed using a T-test to compare the scenarios and to look for significance differences.

3.2 Energy Levels

3.2.1 Rabbit Energy Levels

The two graphs in Figure 2 show the average energy levels of rabbits and foxes over time for the baseline model without safe zones and for the test model with safe zones. In the baseline model without safe zones in Figure 2a, the energy levels of rabbits exhibit extreme volatility, with rapid declines observed between timesteps 2500-3000, 5900-6000, and 8000-9000. These declines are a result of high predation rates and or natural energy loss. Due to the low energy levels, the population sizes of rabbits and foxes are also affected (see Figure 3a between timesteps 6000-7000). In contrast, the test model with safe zones in Figure 2b demonstrates a more stable energy trend for rabbits. Compared to the baseline model, rabbits in the test model maintain relatively higher energy levels with less extreme fluctuations. There is one large peak around 2000 timesteps, but the rest of the fluctuations are less extreme than in the baseline model. Between approximately 3000 and 10000 timesteps, rabbit energy levels in the test model fluctuate but seem to be more stable than it the base model. This stability in energy levels is also reflected in the population size of rabbits, as shown in Figure **??**, where the population does not decrease significantly and remains more stable compared to the baseline model. An explanation for this is that foxes are unable to enter the rabbit holes, resulting in a lower death rate for the rabbits. This protection allows rabbits to preserve their energy levels, reproduce more effectively, and maintain a consistent intake of energy. The introduction of safe zones thus seems to contributes to a more stable energy level for rabbits on average. To test if there is a significant difference between the average energy level of the rabbits in the baseline model compared to the average energy level in the test model a t-test is performed. The T-test results showed a significant difference in rabbit energy levels between the two models, with a P-value of **0.0005** approximately, supporting the hypothesis that safe zones significantly impact rabbit energy levels.



(a) Average energy levels of rabbits and foxes without safe zones.

(b) Average energy levels of rabbits and foxes with safe zones.

Figure 2: Energy Plots of Baseline and Test Models

3.2.2 Fox Energy Levels

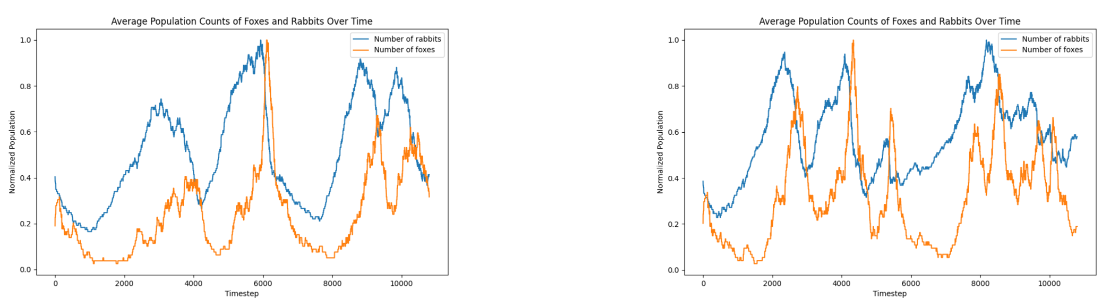
The energy levels of foxes exhibit different behavior compared to those of rabbits. Fox energy levels fluctuate more frequently but with less extreme changes. However, when comparing the fox energy levels between the baseline and test models, similar trends are observed as those seen in the rabbit energy levels. In the baseline model, foxes initially maintained low energy levels. This might be due to a lack of food. Since rabbits have low energy levels they are not able to reproduce which means low energy level and reproduction for foxes. In Figure 2a between timesteps 800-2000, foxes maintain low energy but this increases with the energy level and so the reproduction of rabbits. Approximately, at timesteps 2200, 5200 and 8700 the energy level of foxes after hunting can be monitored as high.

Additionally, between timesteps 6000-7000 the energy level of foxes maintain higher compared to rabbit energy levels which is extremely low, which states that the energy level of foxes after predation. However, after timestep 7000 foxes loses energy due to the decreasing population counts of rabbits, which can be seen in the population plot Figure 3a approximately between timesteps 7000-7900. In the test model, foxes show more stable energy levels. This might reflect a steady but higher rate of successful hunts due to the stable food sources which indicates stable population size of rabbits. In this case, rabbits are maintaining the energy levels due to the safe zones and reproduce stably which provides consistent food sources for foxes and more balanced hunting rates. Similar to the baseline model, whenever the energy level of rabbits is decreased , foxes energy levels and population size are also decreased. This can be seen in both Figure 2b and Figure 3b, as approximately between 6000-7000 timesteps, the energy level and population counts of the foxes remain low. To test if there is a significant difference between the average energy level of the foxes in the baseline model compared to the average energy level in the test model a t-test is performed. The T-test results showed a significant difference in fox energy levels between the two models, with a P-value of **0.003**, indicating that safe zones significantly affect fox energy levels by altering prey availability.

3.3 Population Dynamics

3.3.1 Rabbit Population

The two graphs in Figure 3 show the normalized population size of rabbits and foxes over time for the baseline model without safe zones and for the test model with safe zones. The rabbit population in the baseline model experienced severe declines around timestep 1000, 4000 and 8000. This might be due to high predation rates, as foxes were able to enter the holes and hunt rabbits before the rabbits could properly gain energy. In contrast, the test model maintained a more stable rabbit population, with less severe decreases in the population size. This can be explained by the fact that safe zones allow rabbits to reproduce effectively and to avoid predation. To test if there is a significant difference between the population size of the rabbits in the baseline model compared to the population size in the test model a t-test is performed. The T-test results showed a significant difference in rabbit population sizes between the two models, with a P-value of **2.105e-08**, suggesting the beneficial effect of safe zones on rabbit populations.



(a) Normalized population for model without safe zone

(b) Normalized population for model with safe zone

Figure 3: Population Plots of Baseline and Test Models

3.3.2 Fox Population

The fox population in the baseline model and in the test model can also be analyzed in Figure 3. In the baseline model without safe zones, foxes initially thrived but later faced starvation as the rabbit population declined sharply, resulting in significant peaks and troughs. The cyclical pattern shows that after each peak in the rabbit population, the fox population follows with a lag, indicating a direct predator-prey relationship. In contrast, the test model with safe zones exhibits more moderated fluctuations. The fox population shows slower but more stable growth, supported by the periodic availability of prey outside the safe zones. The energy levels of rabbits also affected the population rate of the foxes; higher rabbit energy levels contributed to increased population counts for both species. Notably, at timestep 2100 in the test model, the rabbit population peaks and then declines due to predation, followed by a corresponding increase in the fox population. The presence of safe zones seems to help buffer extreme fluctuations. To test if there is indeed a significant difference between the population size of the foxes in the baseline model compared to the population size in the test model a t-test is performed. The T-test results showed a significant difference in fox population sizes between the two models, with a P-value of **0.001**, indicating the impact of safe zones on predator population dynamics.

4 Conclusion

This study explored predator-prey dynamics between foxes and rabbits, focusing on the impact of rabbit-only safe zones on their energy levels and population rates. The research addressed the research question, "How do energy levels and population sizes of foxes and rabbits differ between scenarios with and without rabbit-only safe zones?" with two alternative hypothesis.

To investigate this questions, simulations compared a baseline model, where both foxes and rabbits could enter rabbit holes, to a test model with rabbit-only safe zones. Data collected from these simulations included energy levels and population counts, and an independent t-test was used for statistical analysis to determine significant differences.

The results showed that rabbit energy levels were more stable and higher in the test model with safe zones compared to the baseline model. This stability was evident in the reduced volatility and higher average energy levels in rabbits. The t-test results confirmed a significant difference with a P-value of approximately 0.0005, leading us to reject Null Hypothesis (H0) for rabbits. Similarly, fox energy levels were also significantly different between the two models. In the baseline model, fox energy levels were more volatile and lower overall due to fluctuating food availability. In contrast, the test model demonstrated more stable energy levels for foxes, reflecting a consistent but moderate hunting success. The t-test for fox energy levels yielded a P-value of 0.003, leading to the rejection of Null Hypothesis (H0) 1 for foxes as well.

In terms of population dynamics, the rabbit population exhibited severe declines in the baseline model, attributed to high predation rates. Conversely, the test model maintained a more stable rabbit population, which can be attributed to the protection offered by the safe zones. The t-test results showed a significant difference in rabbit population sizes between the models, with a P-value of 2.105e-08, resulting in the rejection of Null Hypothesis (H0) 2 for rabbits. For foxes, the baseline model showed significant population fluctuations with peaks followed by sharp declines, reflecting the direct predator-prey relationship. In contrast, the test model demonstrated more moderated fluctuations and a more stable fox population, supported by the periodic availability of prey outside the safe zones. The t-test results for fox population sizes indicated a significant difference with a P-value of 0.001, leading to the rejection of Null Hypothesis (H0) 2 for foxes.

In conclusion, the introduction of rabbit-only safe zones significantly stabilizes both the energy levels and population dynamics of foxes and rabbits. The presence of safe zones allows rabbits to maintain higher and more stable energy levels, resulting in a more consistent population size. This, in turn, provides a steady food source for foxes, leading to more stable energy levels and population sizes for the predators. These findings underscore the importance of implementing measures such as safe zones to maintain ecological balance and support the coexistence of predator and prey species in natural ecosystems.

4.1 Limitations

The current model has several limitations. Firstly, the rabbits and foxes both reproduce asexually. This is not realistic and it would make more sense to have sexual reproduction. A reproduction probability could be introduced depending on the energy level of two individuals close to each other. Another limitation in the model is that it does not include any food consumption for the rabbits. Including food sources in the environment could also increase their energy levels. By incorporating these changes, the model becomes more complex and realistic.

5 Author Contribution

All authors contributed equally to this work.

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