Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
B		2314525

Managing Masai Mara:Mitigating Human-wildlife Conflicts

Summary

As Kenya's parliament passed the Wildlife Conservation and Management Act, wildlife and other natural resources are being effectively protected. Nonetheless, the creation of nature reserves may result in economic losses. The report aims to propose policies and management strategies to protect wildlife and other natural resources, while also balance the interests of the people who live in the area. We established two models to analyze and compare them. We also evaluated the accuracy of the possible long-term outcomes.

Ecosystem model is established with **Cellular Automaton (CA)**. By gridding the density map of the ecosystem, we obtained the **state space** of Masai Mara, including the coverage of grassland, number of herbivore, number of carnivore and town distribution. The **Local Transition Function** of CA is established with our **Improved Lotka-Volterra Model**. To improve the accuracy of the Local Transition Function, we proposed some **Correction Factors** according to the special condition in Masai Mara, such as the Periodical Rainfall Factor, the Distance Correction Factor and Human Activity Intensity, etc.

Policies and Management Strategies are proposed and quantified. By analyzing the geographical information and employment distribution of Masai Mara, we divide the whole game preserve into **3 areas**: National Reserve, Pastoral Region and Cultivated Region. We propose specific policies and management strategies for each area. To better understand the effect of different policies and management strategies on the ecosystem, we **quantify** them as changes of the parameters predicted by our ecosystem simulation model. In this way, we can get some parameters for later evaluation.

Select the **indicators** and evaluate proposed policies and strategies with **Gray Relational Analysis (GRA)**. After considering the ecosystem, residents' interests and tourists' safety, seven indicators such as grassland cover dispersion, residents' gain and loss, and the dispersion of wildlife are finally selected. Through the simulation of the ecosystem model, we obtained the future changes of each parameter of the ecosystem under the influence of the policies and management strategies. We can finally rank the policies and strategies with GRA. As a result, we find that **maintaining healthy grasslands which surround the cities** is evaluated to be the best strategy. The income of residents increased about 84% and the grass coverage increased about 53.9% within five years with this strategy.

Finally, we optimize the strategies to find the best parameters. Then we predict the long-term outcomes of the best strategy combination with best parameters. We tested the robustness of the model by adding noise to the system. The same tests have also been performed in other regions, and similar results have been obtained, verifying the applicability of the model.

Keywords: Maasai Mara; policies and management strategies; cellular automaton; Lotka-Volterra; Gray Relational Analysis

Contents

1 Introduction

1.1 Background of the Problem

Kenya's wildlife preserves were originally created to protect wildlife and other natural resources. Kenya's parliament passed the Wildlife Conservation and Management Act in 2013 to provide more equitable sharing of resources and facilitate the adoption of community-based management approaches. Kenya has since added amendments to address gaps in the legislation to provide more clear governance, finance, and penalties for violators. However, in Masai Mara, a famous large game preserve, the implementation of policies and management strategies, and the establishment of preserve, may cause some economic impacts.

1.2 Restatement of the Problem

Focusing on the Masai Mara, we need to determine alternate ways to manage the resources and solve the following problems:

- Propose policies and management strategies for different areas to protect wildlife and other natural resources, mitigate impacts on local people and minimize negative interactions between animals and visitors.
- Establish a model to rank and compare the outcomes of our strategies.
- Predict the long-term trends with our recommendations and analyse the certainties and impacts of the possible long-term outcomes
- Describe how to apply our strategies to other wildlife management areas.
- Write a non-technical report to the Kenyan Tourism and Wildlife Committee for explain our proposed plan and its value

1.3 Our Work

- Based on extensive data collection of geographic and social factors in the Masai Mara, we divide the game preserve into three areas and recommend specific policies and management strategies for each area.
- In order to evaluate our policies & management strategies and predict the long-term trends, we established a ecosystem simulation model based on Cellular Automaton. With the work of Ngaga about the ecosystem equations in Tanzania[3], we proposed some correction factors to adapt to the characteristics of Masai Mara.
- We quantify the policies and management strategies in order to evaluate them properly. Also, we define seven scoring indicators, which involves in three aspects: the benefits of resident (mainly about economic), the tourist's safety and the ecosystem's condition.
- In this way, we get some parameters from our ecosystem simulation model to evaluate the policies and management strategies. Then we select the indicators and evaluate policies and strategies with Gray Relational Analysis.
- We simulate the ecological environment under the long-term effects of the chosen optimal policy combination.
- We test the robustness of the modle with noise added to the original data. Meanwhile, test the applicability of our model through an entirely different preserve.

In summary, the whole modeling process is shown in Figure 1.

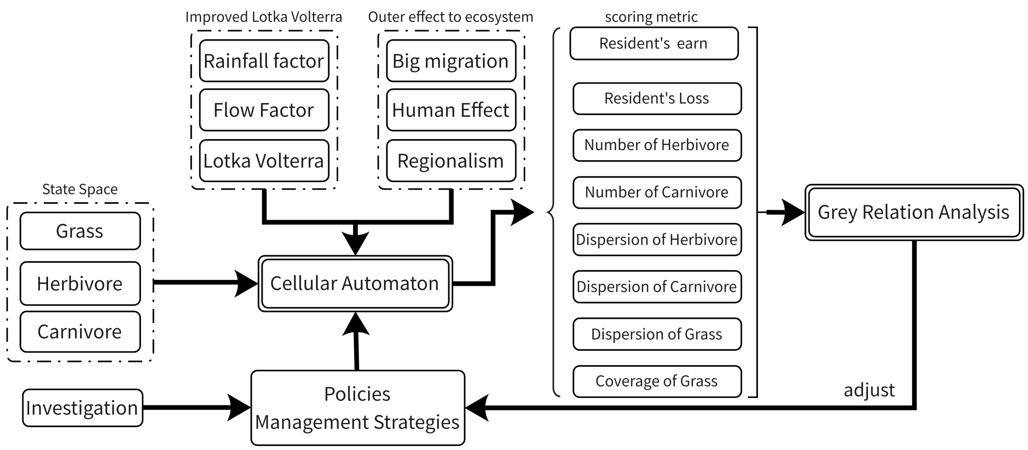


Figure 1: The framework of our model.

2 Preparations of the Model

2.1 Assumptions and Justifications

To simplify the problem, we make the following assumptions, each of which is properly justified.

- **Assumption:** We assume that when considering policies and management strategies, there are no other extra factors or policies that may have a confounding effect on the ecosystem.

  Justification: Because other factors' influence will make the result different, which will disturb us.

- **Assumption:** Assuming that the policy can be strictly implemented and meets our requirements

  Justification: Because the model predicts the best outcome of our proposed policies. The rigorous implementation of policies can maximize the manifestation of predicted outcomes, facilitating analysis and evaluation of the results.

- **Assumption:** We assume that no small probability events such as extreme weather, infectious animal diseases, etc. will occur during the time period we predict.

  Justification: Because the model predict a longer-term trends, while likelihood of the aforementioned events is low and impact is short. Despite the potential for a significant short-term impact, the ecosystem will eventually return to a state of equilibrium over the longer time horizon.

2.2 Nations

Symbol	Definition
D_k	Colour indicator
G	The coverage of Grass
H	Number of Herbivore
C	Number of Carnivore
$P2G$	Impact from people to grass
$P2C$	Impact from people to carnivore
$P2H$	Impact from people to herbivore
DCF	Distance Correction Factor
IOR	Interests of Residents
$LOSS$	Average loss of encountering wildlife
DOC	Dispersion of Carnivore
DOG	Dispersion of Grass
DOH	Dispersion of Herbivore

3 A Model to Simulate Ecosystem Dynamics

3.1 Model of Cellular Automaton

Cellular automaton are dynamic models that are discrete in time, space and state, which is widely used in ecosystem simulation.

$$A =< L, Q, \delta, f > \tag{1}$$

A is a simple cellular automaton. It's defined by a lattice L, a state space Q, a neighbourhood template δ and a local transition function f. [1]

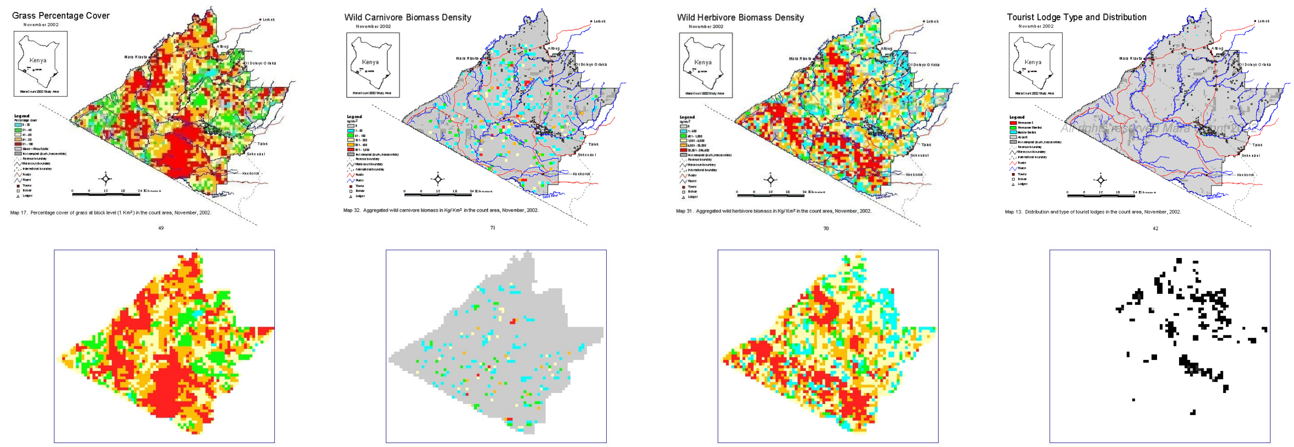
3.1.1 Get State Space

All the original data was collected by Reid, R.S., Rainy, M., Ogutu, J., etc. in 2003.[2] They counted nearly all kinds of wildlife. Definitely we can build a larger and precise model with that database. However, it would be a significant workload for us to discuss the habits of wildlife and parameters in our model.

Therefore, we condense the database into the following four important data in order to mainly focus on the interactions between animals and people, as well as the effect of policies.

To obtain the grid model from the original figure (shown in Figure 2), which included rivers, houses, mixed information, and other disturbances, we developed a image process model with the definition of distance function to identify the value of each grid. The image was divided into 6 by 6 pixel grids to facilitate analysis.

$$D_k = \sum(|Red_i - Red_k| + |Green_i - Green_k| + |Blue_i - Blue_k|) \tag{2}$$



(a) Grass Percentage Cover (b) Carnivore Biomass Density (c) Herbivore Biomass Density (d) City Distribution

Figure 2: Gridded State[2]

R_i means the red channel of each grid. R_k means the red channel of each level of data. i and k respectively represent the grid and each level. Similarly, G and B respectively means the green and blue channel value. The smaller the value of D_k, the more likely it is for the grid to be of level k. In this way we get the grid map.

3.1.2 Local Transition Function

In our model, we choose Moore-neighbourhood, which is composed of the central cell and eight adjacent cells. Thus, the local transition function is:

$$S_{t+\Delta t}(x,y) = f(S_t(x-i,y-j),...) \quad i,j=-1,0,1 \tag{3}$$

Our model is mainly based on the following model established by Janeth James Ngana, which contains Grass, Herbivores, Lions and Crocodiles.[3] We regard Lions and Crocodiles as one group: Carnivores.

$\psi e^{-G/H}$ means the herbivores move out of the area. When $G/H \to 0$, ψ herbivores in this area will move out of the area every time step. Similarly, $\sigma(1-e^{-G/H})$ represents the number of herbivores that move in.

$$\begin{cases} \dfrac{dG}{dt} = k_0 cos(\theta t)G - \alpha HG \\ \dfrac{dH}{dt} = \eta GH + \gamma H - \omega CH - \psi e^{-G/H} + \sigma(1-e^{-G/H}) \\ \dfrac{dC}{dt} = -\epsilon C + \delta HC \end{cases} \tag{4}$$

G, H and C respectively represent the coverage of grass, the number of herbivores and the number of carnivores. k_0 : the rainfall constant. θ : related to the period of rainfall, $T = \frac{2\pi}{\theta}$. α : the efficiency rate of herbivores predation on grass. η : the interaction rate of grass prey on herbivores. γ : the intrinsic logistic rate of herbivores. ω : the efficiency rate of lion predation on herbivores. ϵ : the natural death rate of carnivores. δ : the efficiency rate of the carnivores in the presence of herbivores.

On this basis, we also need to address some issues.According to the current equation for changes in grass coverage, the amount of grass will significantly decrease during the dry season. This analysis was based on Tanzania, in reality, the grass in Kenya should not completely stop growing or even wither, otherwise there would be a large-scale migration in Kenya. Therefore, a growth correction ϕG can be added to the equation.

Meanwhile, Janeth's model is lack of inter-specific competition factor cause the competition is mainly reflected in some wildlife migrating to other areas. However, since we are using a cellular automaton model, most part of the wildlife still exist in the system, which is not reasonable. Therefore, compared to Janeth's model, we have added the Inter-Specific Competition Factor.

$$\begin{cases} \dfrac{\Delta G}{\Delta t} =k_0 sin(\dfrac{2\times\pi}{12\times\Delta t}t)G - \alpha H^+ G + \phi G \\ \dfrac{\Delta H}{\Delta t} =\eta G^+ H + \gamma H - \omega C H - \psi e^{-G/H} + \sigma(1-e^{-G/H}) - c_1 H^+ H \\ \dfrac{\Delta C}{\Delta t} = -\epsilon C + \delta H^+ C - c_2 C^+ C \end{cases} \tag{5}$$

The ϕ here represents the fundamental grow rate of grass. c_1 and c_2 respectively represent the Intra-Specific Competition Parameter of herbivores and carnivores.

H^+represents the sum of herbivores within a 3x3 range surrounding each grid cell. Similarly, G^+ and C^+ represents the sum of grass coverage and carnivores within a 3x3 range surrounding each grid cell. This actually means that the grass in the center cell will be eaten by herbivores around it. The same situation to herbivores and carnivores.

The $k_0 cos(\theta t)G$ rainfall factor is changed into $k_0 sin(\frac{2*\pi}{\Delta t*12}t)G$, cause our simulation begin at November. According to the climate situation (shown in Figure 3), the phase is almost 0. We choose Δt to be a month, so $\theta = \frac{2*\pi}{\Delta t*12}$

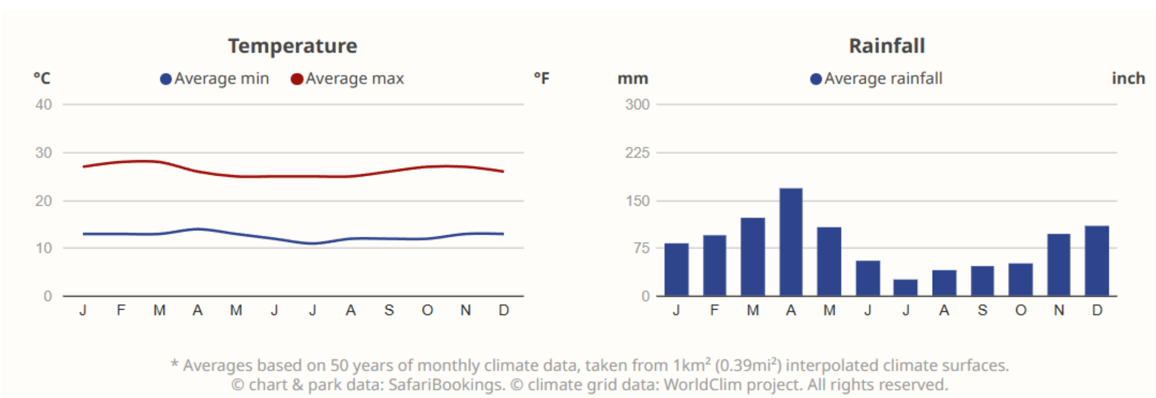


Figure 3: Climate Chart Masai Mara National Reserve[5]

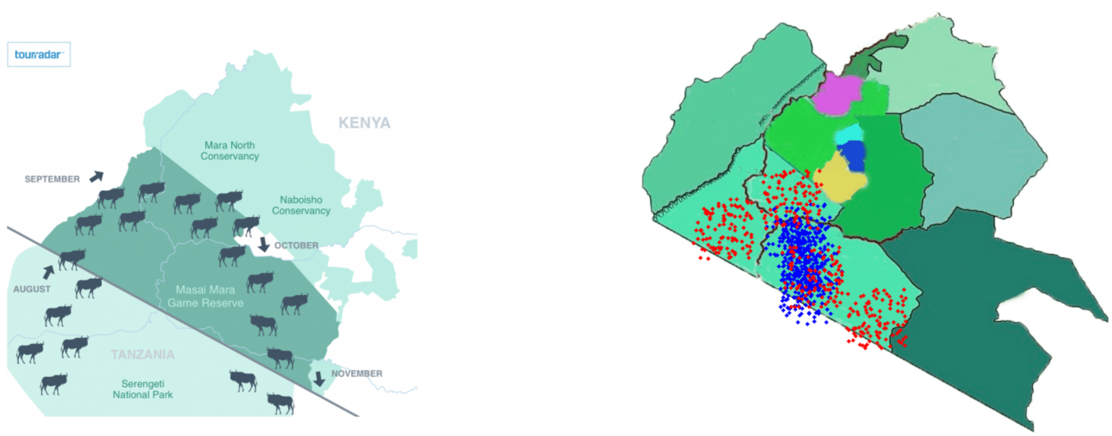
3.1.3 The Impact of Regionalism

Our model doesn't consider the water sources and different climatic conditions in different areas, so it's necessary to reconsider the impact of natural geographic factors on plant growth. Therefore, the previous growth correction is revised again to $\phi G \frac{G^+/9}{G_{max}}$. $G^+/9$ represents the average growth situation around the center cell. In this way, the cells with more grass coverage at the beginning would be more likely to grow more grass under the influence of regionalism.

3.1.4 The Impact of Migration

The Great Migration is one of the "Seven New Wonders of the World". We abstract the overall impact of migration by reducing the fundamental growth rate of grass in the national preserve during the annual migration period.

We propose migration movements in the simulation from July to November and add random factors. These migrations will directly affect the local organisms, increasing the biological density of the cells of the cellular automaton they pass through, thus enhancing competition for local organisms. The migrating organisms are represented by particles, and we can intuitively obtain their migration progress from the graph. We simulate the migration process so that the effects of migration can be applied to our model. As shown in the Figure 4, the blue dots represent migratory organisms, and the red dots represent native organisms.



(a) migration-real (b) migration-simulation

Figure 4: Migration

3.1.5 The Impact of Residents

The impact of local people can be divided into three aspects: hunting, the influence on the surrounding environment of human settlements, and the impact of human protection within protected areas.

$$P2G = G \cdot u \tag{6}$$

P2G represent the impact from people to grass. u represent all the city's influence factor to current cell.

$$DCF = \sum_j \frac{1}{dis(i,j)^2} \tag{7}$$

$$u = P2GC \cdot DCF \tag{8}$$

Considering that the further away from city, the smaller the impact is, a Distance Correction Factor is introduced. P2GC is the people to grass constant. DCF is a distance correction factor.

Similarly, we can define people's impact to herbivores and carnivore.

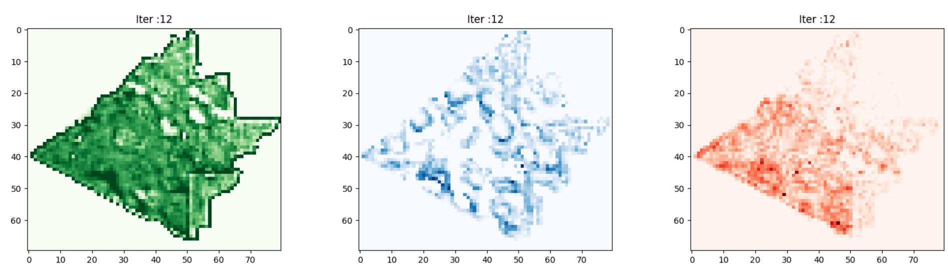
$$\begin{cases} P2H = H \cdot DCF \cdot P2HC \\ P2C = C \cdot DCF \cdot P2CC \\ P2G = G \cdot DCF \cdot P2GC \end{cases} \tag{9}$$

3.2 Results of Simulation

$$\begin{cases} \dfrac{\Delta G}{\Delta t} =k_0 sin(\dfrac{2\times\pi}{12\times\Delta t}t)G - \alpha H^+ G + \phi G \dfrac{G^+/9}{G_m ax} + P2G \\ \dfrac{\Delta H}{\Delta t} =\eta G^+ H + \gamma H - \omega CH - \psi e^{-G/H} + \sigma(1-e^{-G/H}) - c_1 H^+ H + P2H \\ \dfrac{\Delta C}{\Delta t} = -\epsilon C + \delta H^+ C - c_2 C^+ C + P2C \end{cases} \tag{10}$$

We referenced Ngana J J's work[15] for the selection range of most of our parameters.

we can observe the current vegetation coverage, herbivores coverage, and carnivores coverage during simulation.



(a) Grass Percentage Cover (b) Herbivore Biomass Density (c) Carnivore Biomass Density

Figure 5: The Distribution of Grass, Herbivore, and Carnivore During Simulation

For the calculation of human impact, the following Pseudo code provides a simple calculation method used in our model.

We first calculate the total human impact on the current location as the sum of the reciprocal of all distances. The impact is updated based on different strategies.

$human\_effect\_cells$ is the matrix of human impact factors, $human\_cells$ is the matrix of human distribution, and $mode$ is the method of calculating the human impact factor

- If the human policy is ”random”, animals are allowed to freely enter, and interference with animals at any location is only due to the residents’ basic activities.
- If the human policy is ”normal”, a driving policy is used. For areas far from human settlements, animals are gained as a result of the driving policy, increasing their numbers, while for areas near human settlements, animals are driven away, reducing their numbers.
- If the human policy is ”elec”, an electric grid policy is used, and the degree of driving near human settlements is infinitely large (we take 1000 to prevent overflow).
- If the human policy is ”hunt”, humans increase their impact on all areas, and the degree of hunting is significantly negatively correlated with the distance to human settlements.

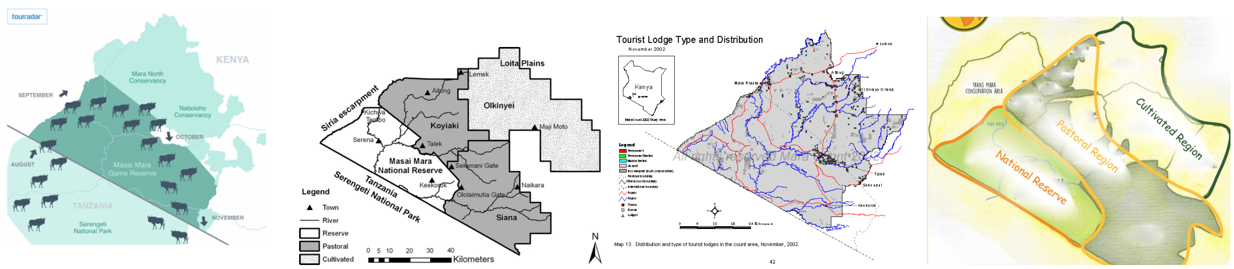
Algorithm 1: the caculation of human effect

```
Input: human_cells, mode
Output: human_effect_cells
human_effect_cells = matrix(shape of human_cells);
foreach human_effect_cell in human_effect_cells do
    foreach human_cell in human_cells do
        human_effect = distance(human_effect_cell,human_cell);
        if human_effect == 0 then
            human_effect_cell+=10;
        else
            human_effect_cell += 1/human_effect;
        end
    end
end
if mode == "normal" then
    human_effect_cells = human_effect_cells-average(human_effect_cells);
else
    if mode == "elec" then
        human_effect_cells=human_effect_cells-average(human_effect_cells);
        human_effect_cells[index of human_effect_cells >0] = 1000;
    else
        if mode == "random" then
            ;
        else
            if mode == "hunt" then
                human_effect_cells *= 10;
            end
        end
    end
end
Result: human_effect_cells
```

4 A Model for Policy and Management Strategy Analysis

4.1 Establish Policies and Management Strategies

We collect the information (shown in Fig.6) about wildlife migrations, climate, agricultural land use types and city distributions of Maasai Mara. Annually, from July to October and November to February, approximately 2 million animals migrate between the Serengeti and the Maasai Mara in search of food and water, which becomes a spectacular wildlife scene and an important local tourist attraction. Beyond tourism, agriculture is the primary industry, and the geographical distribution of agriculture follows a zonal pattern. Based on them, we divided the whole game preserve into 3 areas: National Reserve, Pastoral Region and Cultivated Region. (shown in Figure 6(d))



(a) Masai Mara Wildlife Migration[6]
(b) Masai Mara Agricultural Land Use Types[7]
(c) Masai Mara City Distribution[2]
(d) Masai Mara Division Area

Figure 6: Masai Mara Information

In National Reserve:

1. Prohibition on hunting.
2. Designing fixed tour routes while enhancing infrastructure and security measures along the way
3. Establish a buffer zone at the junction of a National Reserve and Pastoral Region during wildlife migration.
4. Protect wildlife by guiding and repelling animals on the migration route in before the annual wildlife migration
5. Establishing wildlife corridors to facilitate animal movement and promote biodiversity conservation.

In Pastoral Region:

6. Designate grazing areas for herders and enhance protection around there.
7. Installing an electrified power grid in the boundary of Pastoral Region, which can cause injury or even death to wild carnivores if they try to intrude.
8. Establish a management organization to guide wild herbivores away, while establishing a buffer zone between National Reserve and Pastoral Region, and planting high-quality forage at the boundary for wild herbivores.
9. Expanding the buffer zone during wildlife migration

In Cultivated Region:

10. Arranging patrols near city to guide wildlife away from human settlements

11. Installing an electrified power grid in the boundary of citywhich can cause injury or even death to wildlife if they try to intrude.
12. Hunting near city to prevent wildlife from approaching
13. Maintain healthy grasslands and vegetation in the area that away from city town to reduce wildlife populations close to residential areas.

Table 1: **parameters adjusting**

strategy num	calculate method	human effect ratio	migration rate(month)	protected area ratio	buffer protected ratio	animal ratio	buffer animal ratio	farm ratio	grow ratio
nothing	random	0.01	5	-1	-1	-1	-1	-1	0.6
strategy 1	random	0.01	5	0	0	0	0	0	0.6
strategy 2	random	0.01	5	2	0	0	0	0	0.6
strategy 3	random	0.01	5	2	1.5	0	0	0	0.6
strategy 4	normal	0.01	5	2	0	0	0	0	0.6
strategy 5	random	0.01	10	2	0	0	0	0	0.6
strategy 6	random	0.01	5	2	0	1	0	0	0.6
strategy 7	random	0.05	5	2	0	0	0	0	0.6
strategy 8	normal	0.01	5	2	0	1	0	0	0.6
strategy 9	random	0.01	5	2	0	1	0.5	0	0.6
strategy 10	normal	0.01	5	2	0	1	0	0.5	0.6
strategy 11	elec	0.01	5	2	0	0	0	0	0.6
strategy 12	hunt	0.01	5	2	0	0	0	0	0.6
strategy 13	random	0.01	5	2	0	1	0	0	0.9

4.2 Definition of Target

To better understand the targets and simplify the model, we have established the following definitions before modeling.

4.2.1 The Residents' Interests

We define the interests of the people living in this area as their needs for a livable environment, employment and personal income.

A safe living and working environment that supports grazing and farming is urgently needed by local people, who face a large number of wildlife and a growing human-animal conflict in recent years. Local people's interests are mostly focused on basic survival needs such as employment and income security due to the low level of development in the region, and secondly on psychological well-being.

The tourist income varies due to differences in animal populations. So we predict the income to be $\frac{\sum NOA_{now}}{\sum NOA_{standard}} \cdot Gain$. The human losses can be calculated based on the frequency of encounters between humans and animals as well as the average financial loss per encounter.

$$IOR = \Gamma \cdot Gain \cdot \sum \frac{NOA_{simulation}}{NOA_{standard}} - ENC \cdot LOSS \tag{11}$$

The IRO represent the interests of residents, which is consisted of forwards and backwards impacts from wildlife. The Gain is the annual income from tourism. Γ is the management coefficient, because as the scale increases, the management cost also increases. The NOA is the number of animals. ENC is a simulated data about how many times the wildlife get close to the cities. LOSS is the average loss of local people.

Table 2: **percentage contribution of each conflict type[9]**

Human attack	crop raiding	Livestock attack	Property damage	Other
36.9%	33.0%	23.5%	3.1%	3.5%

Over a period of 16 years, there were a total of 2,438 livestock attack incidents, accounting for 23.5% of all attacks. So we can get the overall incidents.

For livestock attack, In a year, a total of 450 sheep and 50 cows were reported stolen by wildlife, and based on their market value and average weight [13], we can estimate the financial losses caused by each livestock attack incident.

For human attack incidents, we used the average GDP of Kenya [9], assuming that 50% of the attacks resulted in minor injuries and 50% in serious injuries, and calculated the economic losses based on the duration of the impact of these injuries [12].

For crop attack incidents, the data shows that each incident costs approximately $132 USD [11].

4.2.2 Ecosystem Condition

Protecting wildlife and other natural resources aims to enhance the diversity of wildlife and preserve the vegetation cover while maintaining the overall balance of the ecosystem.

To measure the effect of wildlife conservation, we use the number of wildlife because it is really hard to collect data about Masai Mara. We also use grass coverage to show how well we protect natural resources. Because vegetation is a primary producer that reflects the condition of the local ecosystem.

4.2.3 Tourist's Safety

The main target for tourists who are attracted to the protected area is to ensure their safety and reduce the occurrence of casualties.

Each year, visitors predominantly arrive during the migration period, when large crowds of people and animals on the move can create conditions that increase the likelihood of accidents and injuries. Therefore, our policy should primarily prioritize the safety of travelers during this time.

We chose to use current wildlife dispersion as our metric of measurement, because we recognized that the difficulty of ensuring traveler safety increases more than proportionally as wildlife concentration rises, rather than following a linear relationship [7]. To account for this, we calculated wildlife dispersion, which allowed us to determine that under the same quantity conditions, more concentrated wildlife are harder to manage and more likely to pose a risk to travelers. Our calculation for wildlife dispersion is as follows:

$$\begin{cases} DOC = \sum C \cdot dis(C, C_c) \\ DOG = \sum G \cdot dis(C, G_c) \\ DOH = \sum H \cdot dis(C, H_c) \end{cases} \tag{12}$$

C_c, C_c and C_c respectively represent the center of gravity to carnivores, grass and harnivore. DOC, DOG and DOH represent the dispersion of each one.

4.3 Analysis and Comparison Model

4.3.1 Indicators for Evaluation

Important indicator used in this section are listed in Table 2 Firstly, we quantify policies and management strategies as changes in the parameters of the simulation system. Different policy parameter settings are shown in the Table 1. We utilized these parameters to predict the conditions after five years and obtained information on various factors, including the corresponding coverage of grass, the degree of grass dispersion, the number of herbivores, the degree of herbivores dispersion, the number of carnivores, the degree of carnivores dispersion, and the amount of economic growth. The outcomes of different policies are presented in Figure (Already normalized).

Table 3: **Important notations used**

notations name	meaning
Coverage of Grass	Describes how much of an area is covered by grass plants
Dispersion of Grass	Describes the degree of dispersion of grass
Number of Herbivore	Describes how much of an area is covered by herbivores
Dispersion of Herbivore	Describes the degree of dispersion of herbivores
Number of Carnivore	Describes how much of an area is covered by carnivores
Dispersion of Carnivore	Describes the degree of dispersion of carnivores
Economy Profit	The revenue of Kenya minus the monetary costs and opportunity costs it pays

Next, we apply weighting with the incorporation of a Time Factor. By utilizing all data over the five-year period, we can get much more reliable results. We are looking forward to sustainable development, so the future condition is more important.

$$\Omega = year / \sum_{i}^{5} i \tag{13}$$

Ω is the Time Factor. $year$ is the current year of data.

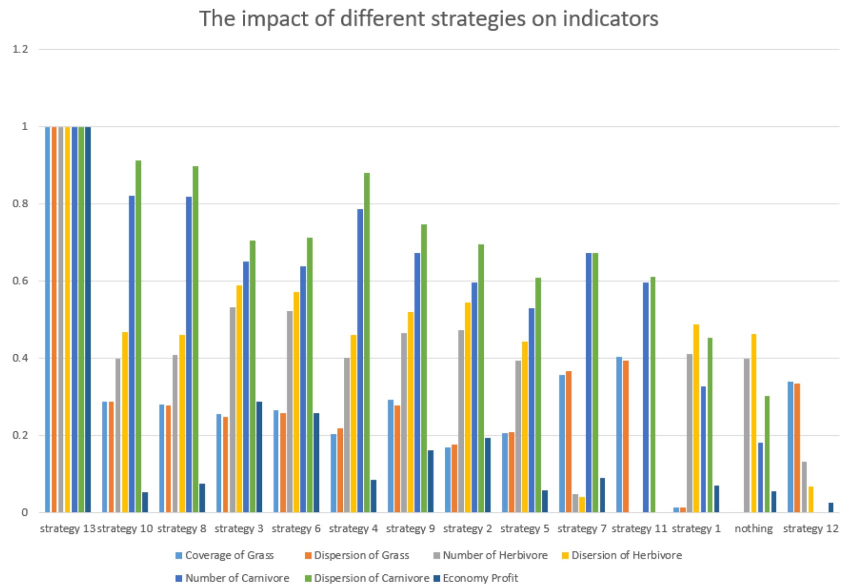


Figure 7: The impact of different strategies on indicators

4.3.2 Gray Relational Analysis

The gray relational analysis is a superior model when dealing with relatively small amounts of data [14]. Due to the limited availability of actual data in this region, using this model allows us to obtain more accurate analysis results.

The grey relation is calculated as follows:

$$\zeta_i(k) = \frac{\min_i |x_0'(k) - x_i'(k)| + \rho \max_i |x_0'(k) - x_i'(k)|}{|x_0'(k) - x_i'(k)| + \rho \max_i |x_0'(k) - x_i'(k)|} \tag{14}$$

We set that the parameter ρ in the formula is 0.5[14], and get the score shown in figure 8.

4.4 Results of Evaluating Strategies

For each individual indicator, we have obtained the situations under different policies (Take policy 13 as an example, the x-axis and the y-axis represent 6 indicators and 60 months respectively).

After the analysing, we rank the outcomes of all strategies. The results are as follows:

Table 4: Rank of different strategy

rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14
strategy	13	10	8	3	6	4	9	2	5	7	11	1	0	12
score	0.892	0.481	0.479	0.475	0.472	0.469	0.467	0.453	0.429	0.422	0.411	0.403	0.388	0.366

According to the policy setting, we can find that planting grasses always have a high score, Besides, guidance and increased protection can also enhance the final benefit to a high score.

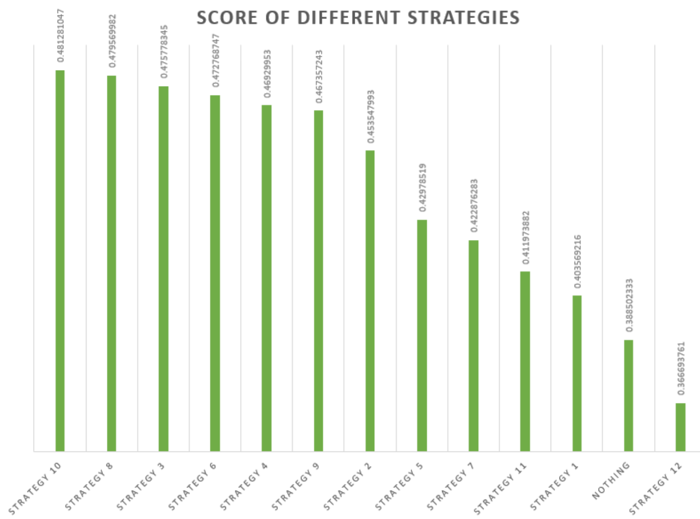


Figure 8: Score of different strategies

Since today's Kenyan policies have banned hunting, we exclude all strategies below strategy one. Comparing strategies 2 and 7, all policies below strategy 7 can be excluded. And now, we refer to all policies above strategy 7 as ”positive policies”.

5 Long-term trends and Application

5.1 Parameters Adjustment

Before making predictions, we try to optimize the rest of the quantified factors (e.g. protected area protection intensity) except for some factors that are only right and wrong. So we run the same analysis of section4 using different factors and finally get the best parameters. We will take the protected area protection intensity and grass growth coefficient as example.

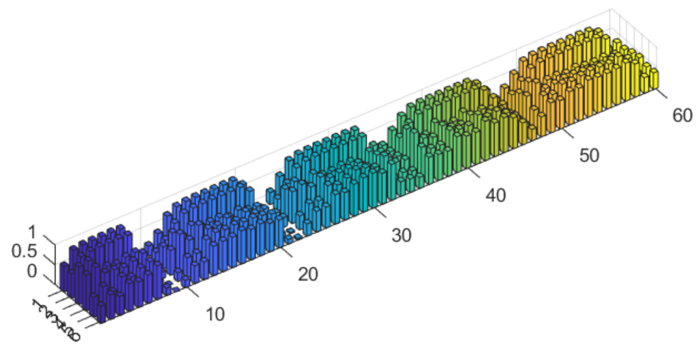
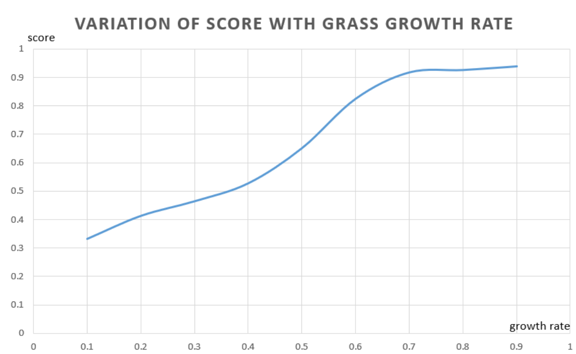
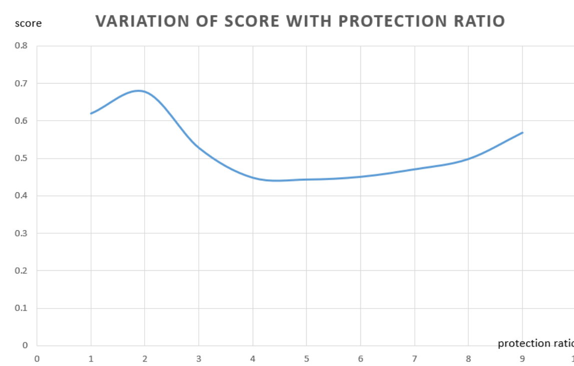


Figure 9: The situations under strategy 13



(a) grass growth rate



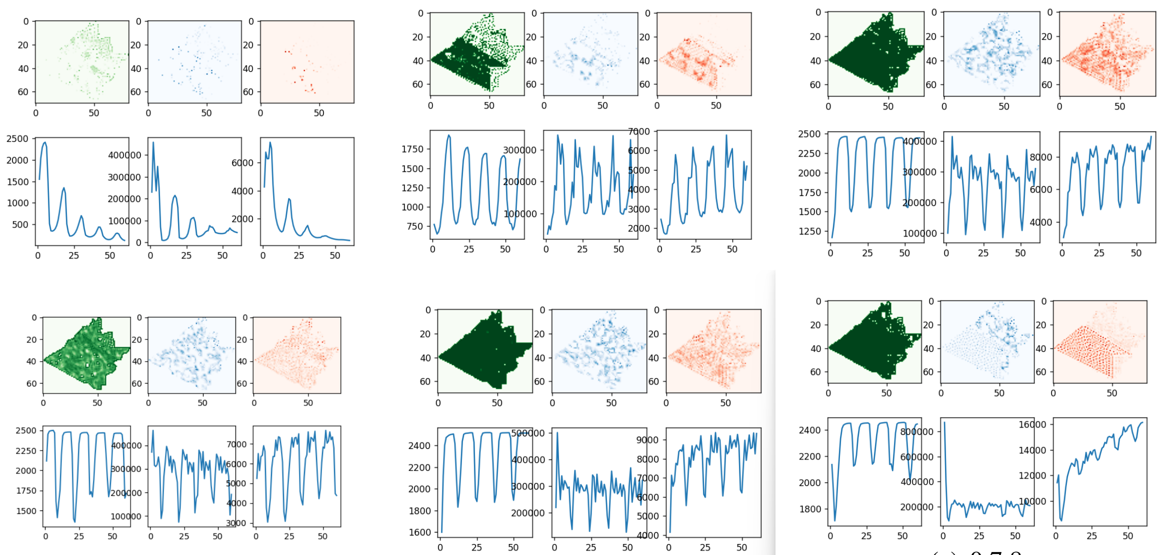
(b) protection ratio

Figure 10: Variation of score with two parameters

We can visualize through the Figure 10 that the final scores vary roughly as a logistic Stiff function with the grass growth coefficient, showing a decreasing and then increasing trend as the conservation coefficient increases. And the figure can also visually reflect some problems. For example, when the grass growth coefficient is too low, then all three are in decreasing trend, and when the protection coefficient is too large, there are a significant increase in predators. According to both, we choose the highest point of the score, which is also the value with the best intuitive effect. So we choose the point when the grass growth coefficient is 0.9 and the protection intensity of the reserve is 2 as the relevant parameter value for long-term prediction.

5.2 Long-term Forecast

According to the previous analysis, we know that some policies have negative impacts, so we ignore these negative policies and choose the sum of all positive policies as the final policy. We use



(a) 0.1,0 (b) 0.3,2 (c) 0.7,8

Figure 11: Variation of situation with two parameters

these policies and the best point of all quantifiable parameters which is described above, to predict the development of the next 20 years and get the following results:

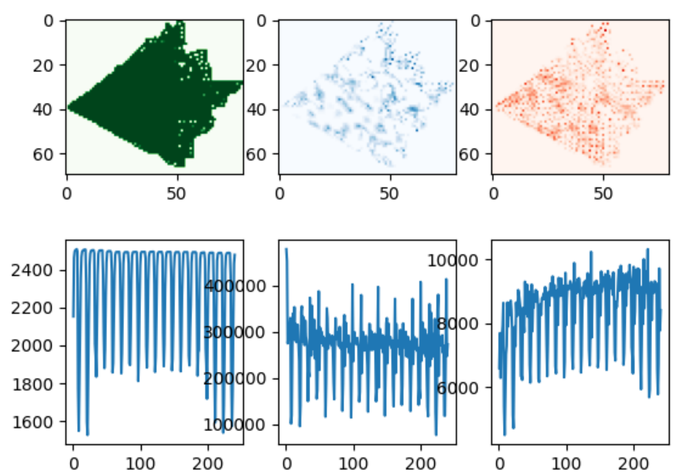


Figure 12: Long-term prediction

As we can see, the number of grass, herbivores and carnivores are stable in a cyclical manner.The area covered by grass and the number of herbivores remaining almost constant at the same time of the same month of a year and the number of carnivores will increase slightly.

Table 5: **Best strategies' Long-term Prediction**

	Grass coverage	Number of herbivores	number of carnivore	economical income
original value	1212	155657	3754	3954
long-term	2478	272479	8405	6215
increase rate	104%	75%	123%	57%

6 Sensitivity Analysis

To test the robustness of the model, we added noise to the system to get the confidence coefficient of the results. We add noise on the factor of grass growth, and such noise will be carried to higher predators due to the predation relationship. By adding noise, we performed 20 rounds of the same analysis as in section4 and obtained different results (shown in Figure 13, take Coverage of Grass as an example)

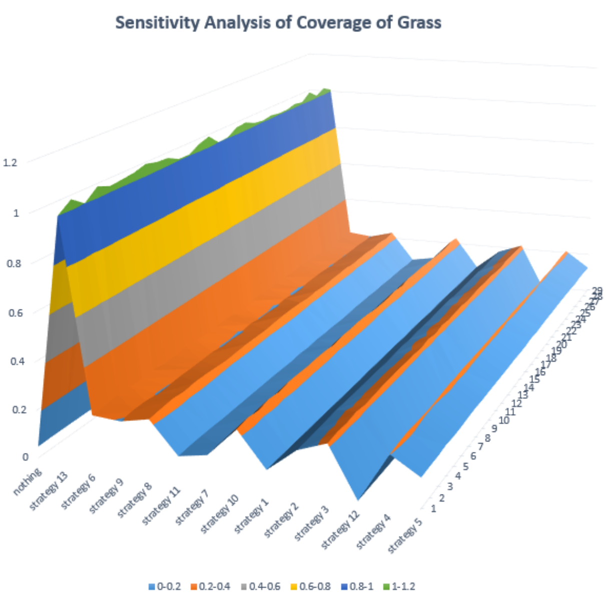
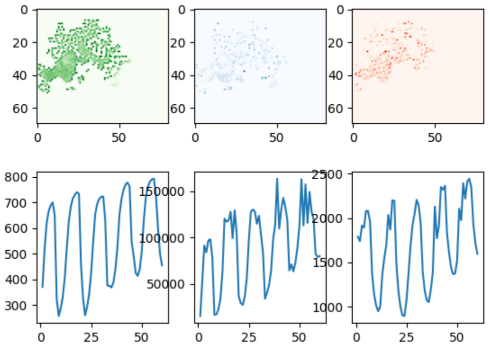


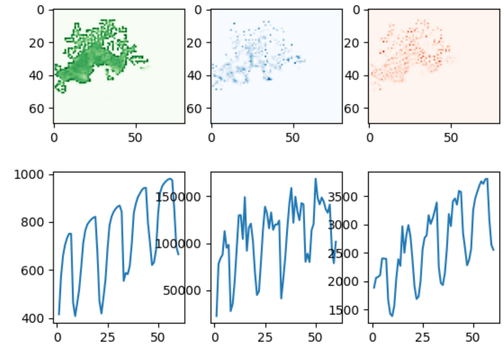
Figure 13: Sensitivity Analysis of Coverage of Grass

To examine the applicability of our policy, we replicated the same experiment in another area. We calculated various parameters of this area based on its historical data, and applied our proposed policy (the "positive policy" mentioned earlier), which yielded similar results (as shown in Figure 14).

From the data, before the policies was implemented, the area covered by grassland was 455.2826975, there are 80006 herbivores and 1597 carnivores. The total revenue for 5 years was 142.42 million USD. After the policy was implemented, the area covered by grass was 665.6268024, the number of herbivores was 101485, and the number of carnivores was 2554, with a total return of $210.69 million in 5 years. This is an increase of 46%, 26%, 60%, and 48%, respectively.



(a) Before our strategy



(b) After our strategy

Figure 14: The situation change before and after our strategy

7 Conclusion

7.1 Strengths

- We adjust the ecosystem simulation model according to the specific situation of Masai Mara, so the model is much more suitable for Masai Mara.
- We set the parameters reasonably, and the parameters can be adjusted to change the weight of the relevant factors, so that our model can easily extend to problems in similar scenarios. Moreover, in the sensitivity analysis, we introduce random interference factors according to the actual situation, which makes the analysis process very logical.
- Through reasonable assumptions, our problem solution can be in line with the problem setting scenario and it help to simplify the calculation.

7.2 Weaknesses

- Due to time constraints, we don't have enough time to tune the parameters, so it's possible that our model is not yet optimal.
- Due to time constrains, we have simplified the model into Grass, herbivores and carnivores, which do simplify the calculation and modeling, but also make the simulation model not that accurate. Though it don't severely affect the evaluation part.

7.3 Further Discussion

- Some approximate analysis methods are applied to model the management of human activity intensity and economic impacts to residents, which may lead to the situation contrary to the actual in extreme cases.
- We can divide carnivores and herbivores into different species to make the model more accuracy.

References

[1] Balzter, Heiko, Paul W. Braun, and Wolfgang Köhler. ”Cellular automata models for vegetation dynamics.” Ecological modelling 107.2-3 (1998): 113-125.

[2] Reid, Robert S., et al. ”People, wildlife and livestock in the Mara ecosystem: The Mara count 2002.” International Livestock Research Institute, Nairobi, Kenya (2003).

[3] Ngana, Janeth James, Livingstone Serwadda Luboobi, and Dmitry Kuznetsov. ”Modelling the migratory population dynamics of the Serengeti ecosystem.” Applied and Computational Mathematics 3.4 (2014): 125-129.

[4] Chen, Yanqiu, and Guangchong Yang. ”Numerical Simulation of Lotka-Volterra Competition Model with Diffusion Term.” Journal of Chengdu University of Information Technology, vol. 36, no. 5, 2021, pp. 564-569.

[5] Anthony Ham. Weather & Climate – Masai Mara NR

[6] Masai Mara migration map. tourradar. Retrieved from `https://www.tourradar.com/sg/masai-mara-map`

[7] Bhola, N., Ogutu, J.O., Piepho, HP. et al. Comparative changes in density and demography of large herbivores in the Masai Mara Reserve and its surrounding human-dominated pastoral ranches in Kenya. Biodivers Conserv 21, 1509–1530 (2012). https://doi.org/10.1007/s10531-012-0261-y

[8] Mao A, Mason W, Suri S, Watts DJ (2016) An Experimental Study of Team Size and Performance on a Complex Task. PLoS ONE 11(4): e0153048. https://doi.org/10.1371/journal.pone.0153048

[9] Joseph M. Mukeka, Joseph O. Ogutu, Erustus Kanga, Eivin Røskaft, Human-wildlife conflicts and their correlates in Narok County, Kenya, Global Ecology and Conservation, Volume 18, 2019, e00620, ISSN 2351-9894,https://doi.org/10.1016/j.gecco.2019.e00620.

[10] https://ourworldindata.org/grapher/maddison-data-gdp-per-capita-in-2011us?tab=chart&country= KEN

[11] http://www.chinanews.com.cn/gn/2021/12-04/9622227.shtml

[12] https://gkml.samr.gov.cn/nsjg/bgt/202106/t20210610_330502.html

[13] https://www.amazon.cn/

[14] Lu Yi. Research and application of grey prediction model [D]. Zhejiang Sci-Tech University, 2014.

[15] Ngana, Janeth James, Livingstone Serwadda Luboobi, and Dmitry Kuznetsov. ”Mathematical model for the population dynamics of the serengeti ecosystem.” Applied and Computational Mathematics 3.4 (2014): 171-176.

Appendix

```python
class Caculate(object):
    k = 0.15
    theta = 6
    alpha = 0.0002
    fei = 5
    delta = 5
    yita = 0.25
    gama = 0.002
    omiga = 0.04
    psi = 0.05
    v = 0.0001
    w = 0.6
    n1 = 0.001
    n2 = 0.001
    human_effect_herbivores = -0.05
    human_effect_carnivores = -0.005
    migration_rates = 1
    migration_num = 300
    migration_grass_rates = 0.2
    grass_cost_rate = 0.01
    herbivores_cost_rate = 0.01
    carnivores_cost_rate = 0.01
    grass_protect_rate = 0.01
    herbivores_protect_rate = 0.1
    carnivores_protect_rate = 0.01
    national_protect = 2
    animal_protect = 1
    farm_protect = 0
    t = 0
    def caculateAll(cellular):
        Caculate.t += 1/12
        return Caculate.caculateGrass(cellular.grass_cells, cellular.herbivores_cells, cellular.carnivores_cells, cellular.human_effect_cells, cellular.part
        ), Caculate.caculateHerbivores(cellular.grass_cells, cellular.herbivores_cells, cellular.carnivores_cells, cellular.human_effect_cells, cellular.part
        ), Caculate.caculateCarnivores(cellular.grass_cells, cellular.herbivores_cells, cellular.carnivores_cells, cellular.human_effect_cells, cellular.part
        ), Caculate.caculateHumanCost(cellular.grass_cells, cellular.herbivores_cells, cellular.carnivores_cells, cellular.human_effect_pos, cellular.human_cost
         )
    def caculateGrass(grass_cells, herbivores_cells, carnivores_cells, human_effect_cells, part):
        grass_neighbor = Caculate.getNeighborNum(grass_cells)
        herbivores_neighbor = Caculate.getNeighborNum(herbivores_cells)
        for i in range(grass_cells.shape[0]):
            for j in range(grass_cells.shape[1]):
                motion = Caculate.k*math.sin(Caculate.theta*Caculate.t)*(grass_cells[i][j]/np.max(grass_cells)) * \
                    grass_neighbor[i][j] - Caculate.alpha * \
                    herbivores_neighbor[i][j] + \
                    Caculate.w * \
                    grass_cells[i][j] + Caculate.getProtectGain(
                        i, j, part, "Grass")*grass_neighbor[i][j] + Caculate.caculateGrassMigration(part)*grass_cells[i][j]
                grass_cells[i][j] = min(max(grass_cells[i][j] + motion, 0), 1)
        return grass_cells
    def caculateHerbivores(grass_cells, herbivores_cells, carnivores_cells, human_effect_cells, part):
        grass_neighbor = Caculate.getNeighborNum(grass_cells)
        herbivores_neighbor = Caculate.getNeighborNum(herbivores_cells)
        carnivores_neighbor = Caculate.getNeighborNum(carnivores_cells)
        for i in range(grass_cells.shape[0]):
            for j in range(grass_cells.shape[1]):
                if herbivores_neighbor[i][j] == 0:
                    index = 1
                else:
                    index = math.exp(max(min(-grass_neighbor[i]
                                             [j]/herbivores_neighbor[i][j], 10), -10))
                motion = Caculate.yita*grass_neighbor[i][j]*herbivores_neighbor[i][j] + Caculate.gama*herbivores_cells[i][j] - \
                    Caculate.omiga * \
                    carnivores_neighbor[i][j]*herbivores_neighbor[i][j] - \
                    Caculate.fei*index + Caculate.delta * \
                    (1-index) + Caculate.human_effect_herbivores * \
                    human_effect_cells[i][j] * herbivores_neighbor[i][j] - \
                    Caculate.n1 * \
                    herbivores_neighbor[i][j]*herbivores_neighbor[i][j] + Caculate.getProtectGain(
                        i, j, part, "Herbivores")*herbivores_neighbor[i][j]
                herbivores_cells[i][j] = max(
                    herbivores_cells[i][j] + motion, 0)
        return herbivores_cells
    def caculateCarnivores(grass_cells, herbivores_cells, carnivores_cells, human_effect_cells, part):
        herbivores_neighbor = Caculate.getNeighborNum(herbivores_cells)
        carnivores_neighbor = Caculate.getNeighborNum(carnivores_cells)
        for i in range(grass_cells.shape[0]):
            for j in range(grass_cells.shape[1]):
                motion = -Caculate.psi * \
                    carnivores_neighbor[i][j] + Caculate.v * \
                    herbivores_neighbor[i][j]*carnivores_neighbor[i][j] + \
                    Caculate.human_effect_carnivores * \
                    human_effect_cells[i][j] * carnivores_neighbor[i][j] - \
                    Caculate.n1 * \
                    carnivores_neighbor[i][j]*carnivores_neighbor[i][j] + Caculate.getProtectGain(
                        i, j, part, "Carnivores")*carnivores_neighbor[i][j]
                carnivores_cells[i][j] = max(
```

```python
                    carnivores_cells[i][j] + motion, 0)
        return carnivores_cells
    def caculateHumansEffect(humans_cells, mode="normal"):
        human_effect_cells = np.zeros(humans_cells.shape)
        for i in range(human_effect_cells.shape[0]):
            for j in range(human_effect_cells.shape[1]):
                for l in range(humans_cells.shape[0]):
                    for r in range(humans_cells.shape[1]):
                        if humans_cells[l][r] == 1:
                            human_effect = Caculate.caculateDistance(
                                i, j, l, r)
                            if human_effect == 0:
                                human_effect_cells[i][j] += 10
                            else:
                                human_effect_cells[i][j] += 1/human_effect
        human_effect_pos = human_effect_cells > np.mean(human_effect_cells)
        if mode == "normal":
            human_effect_cells = human_effect_cells-np.mean(human_effect_cells)
            return human_effect_cells, human_effect_pos
        if mode == "elec":
            human_effect_cells = human_effect_cells-np.mean(human_effect_cells)
            human_effect_cells[human_effect_cells > 0] = 1000
            return human_effect_cells, human_effect_pos
        if mode == "random":
            return human_effect_cells, human_effect_pos
        else:
            human_effect_cells *= 10
            return human_effect_cells, human_effect_pos
    def caculateDistance(i, j, l, r):
        return (i-l)*(i-l)+(j-r)*(j-r)
    def caculateGrassMigration(part):
        if int((Caculate.t*12) % 12) >= 7 and int((Caculate.t*12) % 12) <= 9:
            return -Caculate.migration_grass_rates
        else:
            return 0
    def caculateHumanCost(grass_cells, herbivores_cells, carnivores_cells, human_effect_pos, human_cost):
        grass_cost = np.sum(grass_cells[human_effect_pos])
        herbivores_cost = np.sum(herbivores_cells[human_effect_pos])
        carnivores_cost = np.sum(carnivores_cells[human_effect_pos])
        return human_cost + Caculate.grass_cost_rate*grass_cost + Caculate.herbivores_cost_rate*herbivores_cost + Caculate.
            carnivores_cost_rate*carnivores_cost
    def caculateFinalScore(cells):
        x = 0
        y = 0
        fs = 0
        tot = np.sum(cells)
        for i in range(cells.shape[0]):
            x += np.sum(cells[i, :])*i/tot
        for j in range(cells.shape[1]):
            y += np.sum(cells[:, j])*j/tot

        for i in range(cells.shape[0]):
            for j in range(cells.shape[1]):
                fs += math.sqrt(Caculate.caculateDistance(i,
                                j, x, y))*cells[i][j]
        return fs
    def getNeighborNum(cells):
        neighbor = np.zeros(cells.shape)
        for i in range(1, cells.shape[0]-1):
            for j in range(1, cells.shape[1]-1):
                neighbor[i][j] = cells[i-1][j-1] + cells[i-1][j] + cells[i-1][j+1] + \
                    cells[i][j-1] + cells[i][j] + cells[i][j+1] + \
                    cells[i+1][j] + cells[i+1][j+1]
        return neighbor
    def getProtectGain(i, j, part, type):
        if type == "Grass":
            if Check.isPoiWithinPoly((i, j), part.national_part):
                return Caculate.grass_protect_rate * Caculate.national_protect
            if Check.isPoiWithinPoly((i, j), part.animal_part):
                return Caculate.grass_protect_rate * Caculate.animal_protect
            if Check.isPoiWithinPoly((i, j), part.farm_part):
                return Caculate.grass_protect_rate * Caculate.farm_protect
        if type == "Herbivores":
            if Check.isPoiWithinPoly((i, j), part.national_part):
                return Caculate.herbivores_protect_rate * Caculate.national_protect
            if Check.isPoiWithinPoly((i, j), part.animal_part):
                return Caculate.herbivores_protect_rate * Caculate.animal_protect
            if Check.isPoiWithinPoly((i, j), part.farm_part):
                return Caculate.herbivores_protect_rate * Caculate.farm_protect
        if type == "Carnivores":
            if Check.isPoiWithinPoly((i, j), part.national_part):
                return Caculate.carnivores_protect_rate * Caculate.national_protect
            if Check.isPoiWithinPoly((i, j), part.animal_part):
                return Caculate.carnivores_protect_rate * Caculate.animal_protect
            if Check.isPoiWithinPoly((i, j), part.farm_part):
                return Caculate.carnivores_protect_rate * Caculate.farm_protect
        return 0
```