Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
B		2300136

From Poachers to Conservationists: Community-Based Wildlife Preservation in Maasai Mara

As the emerald in Kenya's crown, the Maasai Mara is a haven for wildlife. We develop a community-based approach to wildlife preservation in light of the need to better protect nature and achieve sustainable development. By considering human interests as well as preservation goals, we determine the optimal policy for each land type in the Mara and its corresponding long-term outcomes.

We construct a net-work based evaluation model to depict the conditions in the Maasai Mara preserve. The model is composed of four sections, including wildlife protection, natural resources conservation, local financial interests and animal tourism interactions. The sections are interdependent and linked through various variables. We measure the wellbeing of each section using a score ranging from zero to one after normalization, higher scores indicate better performances. To determine the weight of the four sections in different land types, we employ the Analytical Hierarchy Process (AHP) to calculate specific parameters for each section. The weighed scores are summed up to produce a final score as our objective. This final score takes into account all sections in their determined weights to measures the wellbeing of the Maasai Mara preserve.

We divide the Maasai Mara preserve into three different land types: a core wildlife preservation zone, a human settlement zone and a livestock grazing zone. Three policies are proposed for each land type, according to their principal functions. In order to analyze the counteractions between different policies, we combine the three policies in a given land type to produce twenty-four policy scenarios. The scenario with the highest final score is chosen to be our optimal policy.

Based on previous data and researches, we use linear and exponential regression analysis to determine future trends in our input variables. These trends can have an effect on our long-term outcome. The future outcomes of policies are predicted over a timespan of twenty years. To minimize error through errant parameters, we apply random residuals in our model to capture unobserved heterogeneity. Stochastic elements that follow a normal distribution are randomly generated, increasing the precision and authenticity of our future predictions.

Our results show that the optimal policy in the wildlife preservation zone is the combination of enforcing hunting quotas, increasing grazing fines and restricting tourism. Focusing on the human settlement zone, the best policy for most years is providing conservation job opportunities combined with establishing bridging organizations. In the livestock grazing zone, the scenario that produces the highest score is the combination of the three policies or the combination of restricting livestock grazing and controlling invasive species. These policies can greatly enhance the welfare of the preserve, generating long-term benefits for wildlife and people alike.

The results from our sensitivity analysis show that the model is stable and robust. We set varying parameters to change the values of our input variables and assess the impact of these changes on our final score. We also tested the universality of the model by putting forward a method to adjust our parameters in order to befit the alternative preservation area. As a result, we validate our model's conformance with reality, determining that it can be of versatile use with certainty.

By incorporating known numerical values about wildlife conservation into net-work based modelling, we shed light on the key factors that influence wildlife protection and propose optimal policies to balance the interests of human and wildlife for sustainable development.

Key words: Wildlife conservation; Community-based management; Net-work based modelling.

Report to the Kenyan Tourism and Wildlife Committee

Dear Committee representatives,

We, MCM team #2300136, were tasked with helping the Kenyan Tourism and Wildlife Committee (KTWC) to develop better wildlife conservation policies in the Maasai Mara Preservation. By considering the interests of local residents as well as wildlife protection, we built an evaluation model to offer suggestions on the preserve's management policies and propose the optimal strategy for sustainable development.

We take into consideration wildlife protection, natural resources conservation, local financial interests and the negative interactions between wildlife and tourists. The prior two goals are set to preserve the grassland ecosystem while the latter two examine human interests. We balance these objectives carefully according to the land use type in the Mara, which we divide into a core wildlife preservation zone, a human settlement zone and a livestock grazing zone. We propose three different policies for each land type, and test the interactions between policies by combining them into eight scenarios. Nine policies are suggested in total, including diverse perspectives such as hunting quotas, grazing fines, the adoption of bridging organizations and invasive species control. We collect data from the Kenya Wildlife Service, the Kenya National Bureau of Statistics, the Kenya State of Wildlife Conservancies, the official website of the Maasai Mara National Park and various researches done on the area. Using data from the past, we simulate the effects of different policy scenarios from 2002 to 2041, providing predictions about the long-term outcomes of policies on a twenty-year basis from 2022-2041.

According to our results, in the core wildlife preservation zone, **the best policy is to enforce hunting quotas, increase grazing fines for residents and restrict tourism simultaneously.** If there are budgeting limits and the three policies cannot be applied at once, we suggest the duo-combination of establishing hunting quotas while restricting tourism for short-term benefits and enforcing hunting quotas while increasing grazing fines for long-term's sake. If one policy were to be selected, we would recommend increasing grazing fines because it produces the best outcomes in 2041. We expect that the establishment of hunting quotas can reduce poaching and other forms of trading illegal animal products by 50%, causing wildlife numbers to increase 2% annually. Grazing fines are a means to prevent local residents from grazing livestock in wildlife preservation zones, which can increase grassland pasture resources for wildlife by 5%. By restricting the number of tourists in the Mara, a 30% decrease in tourists' populations can result in a 0.5% annual increase in wildlife numbers and a 5% surplus in the amount of water resources. Because the welfare of wildlife outweighs all other considerations, policies that will facilitate thriving of wildlife are all highly recommended.

As for the human settlement zone, **the best policy for most years is providing conservation job opportunities.** However, the outcomes of providing conservation job opportunities combined with establishing bridging organizations, solely establishing bridging organizations and not implementing any policies come close behind to the results of our suggested best policy. It can be indicated that more possible policies should be explored in the future to generate more distinctive results. Yet, the plan of constructing a wildlife corridor through human settlement areas will backfire and reduce regional welfare. This is a very noteworthy result as it excludes the probability of a seemingly possible policy. We believe that although the construction of a wildlife corridor can increase wildlife numbers by 0.5% annually, it will reduce livestock populations as a result of competition for grasslands. Additionally, this loss of opportunities will cause locals to violate regulation rules more often to stive for their economic compensation. It can be expected that negative interactions such as poaching and grazing within the prohibited areas will increase significantly. Therefore, we conclude that the policy of setting up a wildlife corridor within human settlement areas will actually threaten wildlife development when considering all aspects.

In the livestock grazing zone, **the optimal policy is to compensate livestock loss, restrict livestock grazing and control invasive species at once.** The scenario combining livestock grazing restrictions and invasive species control follows the trio-combination hard on its heels. All policies and combination of policies produce better results than our base-line scenario with no policies. This proves the effectiveness of our policy selection. Of the three discussed policies, restricting livestock grazing is the most advantageous because it can preserve grassland pastures and water resources in the long run by 10% and 8%, respectively. Invasive species control has similar yet milder applications as it increases grassland pasture resources and water resources by 0.5% annually. In addition, we also expect a 0.7% increase in biodiversity as aboriginal species can obtain more resources. The third policy we discuss is the compensation for livestock loss. Locals report that they lose an average of USD$310 due to livestock killed by predators. Increased livestock predation can create increased conflict between residents and the conservancies, and also between people and wildlife. However, our model determines that compensations have a minimal effect on the preserve's welfare because the amount of loss is relatively insignificant on a regional level. Despite these results, we contend that the benefits of compensating livestock losses go beyond measurable numbers and that it is vital in building the trust between locals and the conservancies. All in all, we recommend all of the three policies to ensure the sustainable development of the region.

Our model is built upon the principal foundation that wildlife preservation should include the harmonious balance of human and nature. Most of the measures we adopted consider the interests of locals and tourists as well as natural conservations in a community-based approach. Policies such as increasing grazing fines, establishing bridging organizations and compensating for livestock loss highlight the complexities in considering locals into wildlife conservation. We believe that wildlife preservation will require the combined efforts of government authority and local people. In order to achieve this goal, conservancies should give locals an economic and social incentive to become conservationists instead of poachers. However, presently, institutional shortcomings constrain the capacity of the conservancies to deliver satisfactory services to a varied cross-section of the locals. Therefore, it is crucial to take into consideration our proposed policies as they aim to mitigate this gap in co-management preservation.

We sincerely hope that our policy recommendations can be of use in the development of an integrate and effective policy system that will benefit the Maasai Mara and achieve a sustainable future.

MCM #2300136
2023.2.20

Content

I. Introduction 5
1.1 Background 5
1.2 Literary review 5
1.3 Restatement of the problem 5
II. Foundations of the Model 6
2.1 Assumptions and justifications 6
2.2 Nomenclature 7
III. Model Design 8
3.1 The net-work based model 8
3.1.1 *Wildlife protection section* 8
3.1.2 *Natural resources conservation section* 10
3.1.3 *Local financial interest section* 12
3.1.4 *Animal tourism interactions section* 14
3.1.5 *Constructing the final objective* 15
3.2 Policy scenarios 16
IV. Results and Discussion 18
4.1. Core wildlife preservation zone 18
4.2 Human settlement zone 19
4.3 Livestock grazing zone 20
V. Sensitivity Analysis 21
VI. Testing the Model 22
VII. Strengths and Weaknesses 23
7.1 Strengths 23
7.2 Weaknesses 23
VIII. Conclusions 24
IX. References 25

I. Introduction

1.1 Background

With rolling hills and sprawling savannahs, the Maasai Mara National Reserve in Kenya is a haven for African wildlife. The Maasai Mara is home to 95 species of mammals, reptiles and amphibians; as well as over 400 species of birds [1]. Historically, Kenya had spent great efforts in wildlife protection and the conservation of other resources. However, since the 1970s, it was found that establishing islands of isolated protection areas were inadequate for maintaining spatially heterogeneous biodiversity. Therefore, the involvement of local communities in co-management were incorporated into the protection of natural resources [2]. In 2013, Kenya's parliament established the Wildlife Conservation and Management Act, stressing the need for more equitable share of resources and community-based management efforts [3].

Since the passing of this legislation, numerous efforts including policy amendments and stakeholder's regulations have been made to better preserve wildlife. Yet, the concept of community-based conservation was established and put in use fairly recently, the impact of specific policies on wildlife preservation within and outside the boundaries of the park remain inadequately discussed. Therefore, to allow more efficient preservation, we should take into account the interactions between humans and animals as well as the economic impacts of certain policies.

1.2 Literary review

Previous research demonstrated that the interests of local residents are of great importance in wildlife conservation. The costs and benefits of local residents near protected areas had been estimated in a number of studies conducted in Kenya, Uganda and Nepal [2,4,5]. These studies focused on local profits, suggesting that locals can be given the economic incentive to participate in wildlife preservation. When taking a co-management perspective, Ward et al. [6] studied the livelihood impacts of establishing a co-management system in Madagascar. Brehony et al. [7] identified seven barriers from successfully implementing wildlife conservation policies in Kenya. The efficacy of government agencies and bridging organizations were also discussed in detail [8,9]. However, the aforementioned studies were conducted under a very general approach without implementing any specific policies. Therefore, their results were mostly based upon surveys of local residents instead of results of evaluation modelling. Here, we provide a solution to this problem by constructing a net-work based evaluation model to assess and compare the outcomes of different management strategies.

1.3 Restatement of the problem

We are tasked with providing optimal policies and management strategies in wildlife preservation zones for long-term trends. **Our objective is to balance wildlife protection, the sustainable development of natural resources, interests of local residents and the negative interactions between animals and tourists.**

There are at least two definitions of what the "interests of the people who live in the area" should be: (1) financial profit, which maximizes household income; or (2) social profit, which focus on social equity, employment and education [2]. Here, we focus exclusively on the first notion because it is easy to quantify into a mathematical model. Similarly, the "negative interactions between animals and the people attracted to the preserve" have multiple meanings. We define "the people attracted to the preserve" as tourists, since tourism accounts for most of the Mara's non-native population.

Consequently, the problem can be analyzed in six parts:

- Build an evaluation model with related constraints and variables to determine the mechanism of community-based wildlife preservation.
- Establish four objectives. The objectives should represent inclinations in wildlife protection, natural resources conservation, financial gains of local residents and the negative interactions between animals and tourists, respectively.
- Construct a final objective by summing the normalized four objectives listed above and assigning each a weight. The weight between different areas of the preserve should be different to indicate the distinctions in land use.
- Find the optimal policies or management strategies for each area in the preserve by maximizing its final objective.
- Predict long-term trends of the given recommendation by evaluating the outcomes of the four objectives.
- Test the model on other wildlife management areas to ensure its universality.

II. Foundations of the Model

2.1 Assumptions and justifications

- **The sectoral structure of Maasai Mara's economy is consistent within our study period.**
  The two main pillars of the Mara's economy are tourism and pastoralism, making up 85% of its residents' household income [10]. We assume that the sectoral structure of the preserve's economy stays consistent. The Mara is expected to attract tourists continuously while regions within and adjacent to the Mara are rich in good quality grasslands, which are ideal for cattle farming [2]. Because of this consistency and the dominance of tourism and pastoralism in local profits, we take in these two factors exclusively in our model when considering local occupations.
- **We classify three different land types within the Maasai Mara preserve.**
  It was reported that 25% of the preserve's land represents the Maasai Mara National Reserve while the remaining 75% is owned partly as private and partly as communal lands, mostly by Maasai pastoralists [11]. When selecting specific policies and management strategies for different areas of the preserve, we divide the preserve into three land types: 1) a core wildlife preservation zone, which is strictly protected, 2) a zone for human settlement, which enables housing and lodging 3) and a prescribed livestock grazing zone [12]. These different land types are expected to have disparate policy emphasis.
- **The borders of the Maasai Mara National Reserve and surrounding conservancies are unchanged within our study period.**
  We assume the area of the reserve and other conservancies stay constant. We will need the area of each different land type to calculate livestock density in a time span of twenty years in the following sections.
- **The population of human and wildlife in the preserve do not experience precipitous changes.**
  Unexpected incidents that cause human and wildlife populations to dramatically escalate or plummet are not included in our model. These incidents include but are not limited to possible outbreak of wars and conflicts, natural disasters, infectious pandemics and the sudden influx of refugees/immigrants.

When calculating human and wildlife population, we expect that both factors are subject to gradual and moderate changes. The outcomes of unexpected incidents are not predictable; therefore, we do not incorporate them in our model.

- **The fundings of government agencies and local conservation groups are adequate to support any proposed policy scenario and/or the combination of scenarios.**
  We assume that there are no budget constraints for preservation stakeholders. All possible policy options—even the combination of multiple options at once—can be carried out without monetary concerns. Our task is to select the best policies and strategies, and some of the policies may counteract the effects of other strategies in reality. To fully understand the interactions between such policy combination, it is reasonable to suggest that the government is able to fund our proposed policies.
- **Conservation policies are able to be fully implemented within a given time period.**
  Different policies and management strategies may vary in the time they need to be fully implemented. For example, the policy of offering compensations for livestock loss can be quickly taken into action; enforcing hunting quotas, on the other hand, can have a longer cycle. However, we assume that the policies will be carried out efficiently within their given time period. The impact of policy delays and inadequate implementation are not included in our model.

2.2 Nomenclature

Table 1. Major notations

Notation	Description
k	The number of mammal species in the preserve
α_{i}	The percentage coefficient of species *i* in total populations
$\mathrm{n_i}$	The population of species *i*
p_i	The fractional abundance of wildlife species *i*
N	Total number of wildlife populations
κ	The pasture herbage mass in kilograms dry matter per hectare
s	The stocking density in animal per hectare
M	Total number of livestock populations
A	Total area of the preserve
V_{supply}	Total amount of water supply
V_{demand}	Total amount of water demand
$\mathrm{R_{lease}}$	Income from land lease
$\mathrm{R_{job}}$	Income from conservancy job
$\mathrm{R_{tourism}}$	Income from cultural services to tourists
$\mathrm{R_{livestock}}$	Net income from raising and selling livestock
$T_{tourists}$	Total population of tourists
T_{locals}	Total population of local residents
$B_{\mathrm{livestock}}$	Gross income from raising and selling livestock
$C_{\mathrm{livestock}}$	Additional costs of raising livestock due to conservancy
C_{fines}	Grazing fines
C_{conflict}	Losses from wildlife predation
p	Probability of interspecies encounter
$\rho_{wildlife}$	Density of all wildlife
$\rho_{tourists}$	Density of tourists
λ	The impact factor of wildlife on tourists
σ	The impact factor of tourists on wildlife

III. Model Design

3.1 The net-work based evaluation model

We construct a net-work based evaluation model with four sections, including wildlife protection, natural resources conservation, local financial interests and animal tourism interactions. The sections interact with each other through various variables. Each section produces a score of zero to one to indicate its performances. Higher scores indicate more sustainable and health section performances. We then divide the Maasai Mara into three different land types, and set a different set of weights for the four sections in each land type. Three policies were proposed in each land type, with a combination of twenty-four possible scenarios. We test the effectiveness of each scenario over a timespan of twenty years (2022-2041), using scores as indicators. Figure 1 demonstrates our model using a flowchart.

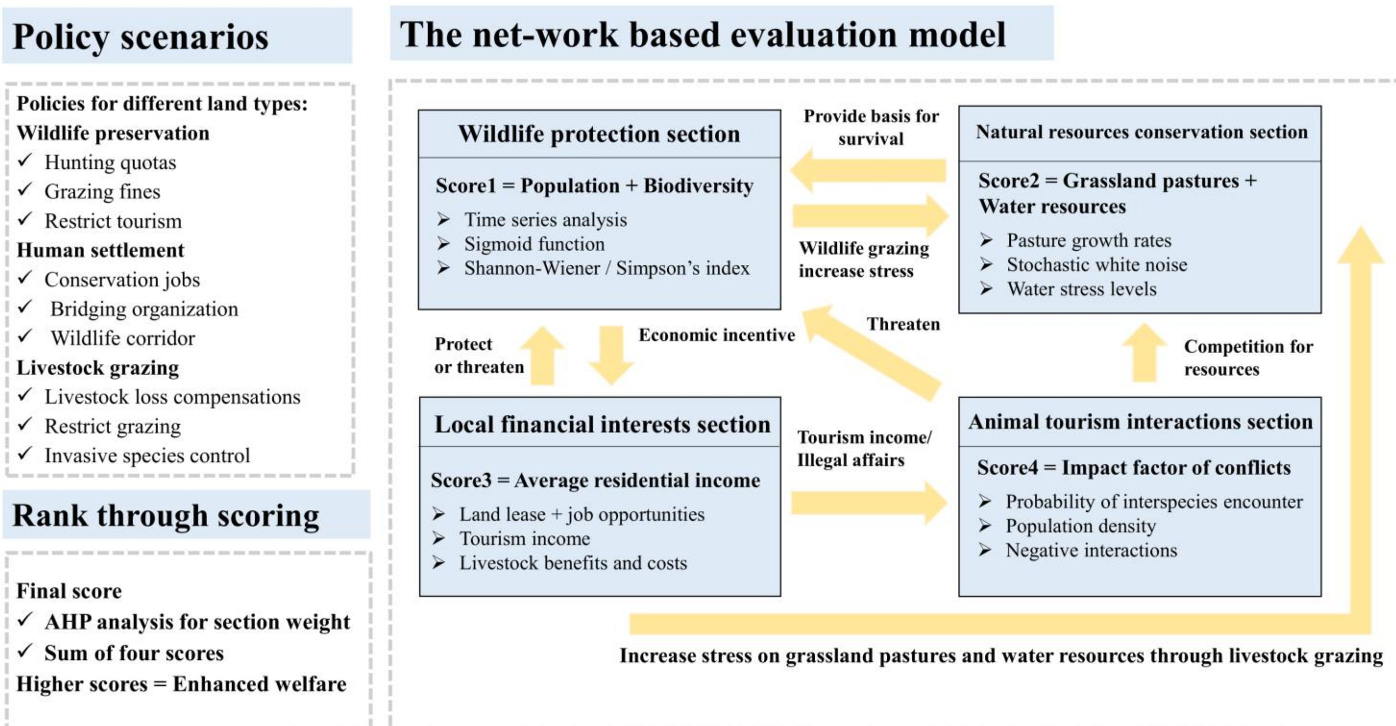

Figure 1. *Flowchart of the net-work based evaluation model*

3.1.1 *Wildlife protection section*

1) Modelling ideas

We use **wildlife populations and regional biodiversity** separately to measure the effectiveness of wildlife preservation. The combination of the two factors allows us to gain a fuller picture of regional bio-conditions. Specifically, we can avoid situations where the model determines that there is an abundance in wildlife numbers yet only a few species, or vice versa.

2) Supplementary assumptions and justifications

- **When considering wildlife numbers and biodiversity, we use the number/diversity of mammals as an indicator for all wildlife.**

  Data on large mammals are more accessible as they are listed in various rangeland reports based on aerial surveillance. The exact number and species of reptiles/amphibians, birds and smaller mammals are difficult to obtain. We believe that the richness in mammal numbers/species can indicate the health of a bio-ecosystem.

3) Calculations

a) Wildlife populations

Ottichilo et al. [13] and Lamprey et al. [11] analyzed the population trends of wildlife and livestock during 1977-2000. We combined this analysis with more recent data published by the Kenya Wildlife Service [14] to determine the trends in wildlife populations using exponential time series analysis, 2002 is set as Year 0 and 2041 as Year 40.

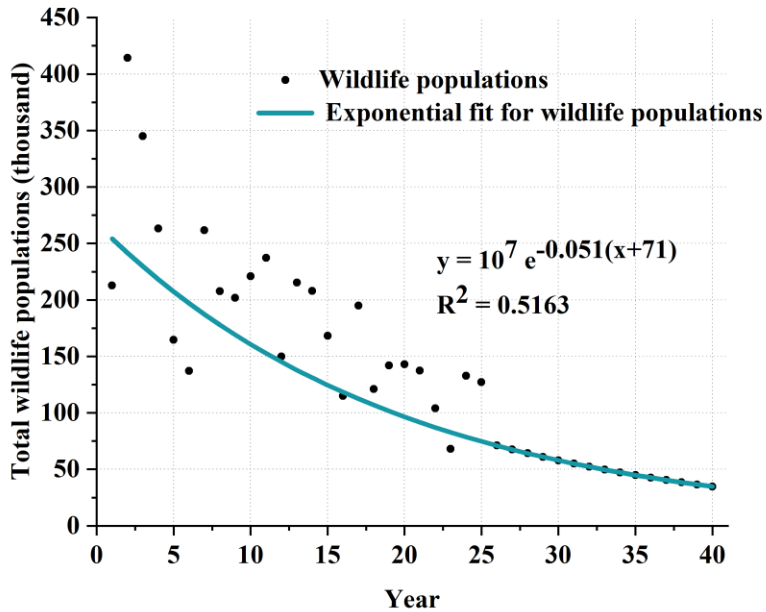

Figure 2. *The exponential fitting curve of wildlife populations.*

After we analyze the trends of wildlife population. We use a sigmoid function to normalize all populations according to their percentage in total wildlife population:

$$P = \frac{1}{k}\sum_{i=1}^{k}\frac{1}{1 + e^{-\alpha_i n_i}}$$

Where k is the number of mammal species; α_i is the percentage coefficient of species *i* in total populations and n_i is the population of species *i* for *i=1,2…k.* We obtain our score P to illustrate wildlife populations.

b) Biodiversity

We employ the Shannon-Wiener index (H') and Simpson's index (D) to calculate biodiversity [15]:

$$H' = -\sum_{i=1}^{k} p_i \ln p_i$$

$$D = \frac{1}{\sum_{i=1}^{k} p_i^2}$$

Where p_i represents the fractional abundance of wildlife species *i* for *i=1,2…k.* It can be calculated using

$$p_i = \frac{n_i}{N}$$

Where n_i is the population of species *i* and *N* is total number of wildlife populations $N = \sum_{i=1}^{k} n_i$ for *i=1,2…k.*

We normalize each index so that it falls under the range of 0 to 1. We assume that wildlife populations and biodiversity are equally important, so the weight of the two factors are both 1/2 (The biodiversity indicators Shannon-Wiener and Simpson's index add up to 1/2). Our score for the wildlife protection section is:

$$\mathrm{Score1} = \frac{1}{2}\mathrm{P} + \frac{\mathrm{k}}{4\ln \mathrm{k}}\mathrm{H}' + \frac{1}{4}\frac{\mathrm{D}}{\mathrm{k}}$$

3.1.2 *Natural resources conservation section*

1) Modelling ideas

We incorporate the conservation of natural resources in our model to ensure the Mara's **sustainable development**. Wild animals and livestock alike depend on the welfare of the grassland ecosystem. By setting natural resources preservation as an objective, we can ensure that our proposed policies do not generate short-term benefits at the cost of degrading savannah grasslands and threatening long-term development.

2) Supplementary assumptions and justifications

- **We use water and grassland pastures to indicate the conservation of natural resources.**

  Although natural resources contain a wide variety of assets including water, soil, plantations, solar energy and minerals, we only consider water and fertile land resources in the Mara because other resources show less significancy in wildlife preservation. Grassland pastures are an effective measure of fertile land resources. In the Mara, wildlife and livestock compete for water and grassland pastures, easily resulting in water shortage and grassland degradations. Therefore, it is necessary to use these factors as indicators in natural resources conservation.
- **The grass intake per herbivore animal in the wild is on average twice that of grass-eating livestock.**
  We estimate grass intake based on the biomass data of wildlife and livestock proposed by Stelfox et al. [16]. In our referenced research, the biomass of related wildlife and livestock are: cattle, 180 kg; sheep/goat, 23 kg; wildebeest, 123 kg; zebra, 200 kg. We can calculate the average grass intake ratio of wildlife and livestock based on the numbers of different species.
- **The growth rate of grass pastures follows the logistic growth curve (the Verhulst model) and the amount of grazing is positively correlated with the growth of grass.**
  Due to the existence of dry seasons and grazing, we expect that grass pastures will not reach its saturation pasture mass. Therefore, we assume that a linear relationship exists between herbage mass and the intake rate of grazers [17].

3) Calculations

a). Grassland pastures

We calculate the net herbage accumulations of grassland pastures to indicate the richness of natural resources [17]. The equation is given as

$$\frac{d\kappa}{dt} = 4gb\kappa(1 - b\kappa) - sr\kappa$$

Where κ is the pasture herbage mass in kilograms dry matter per hectare (kgDM/ha), g is the maximum herbage growth rate in kgDM/ha/day, $1/b$ is the ceiling pasture yield in kgDM/ha, s is the stocking density in animal/ha, r is the relative per animal intake rate in ha/animal/day. Previous researches determine that g = 41.9 kgDM/ha/day, b = l/4000 ha/kgDM, and r = 0.47 % ha/animal/day for an average pasture.

We then calculate the stocking density of animals s using

$$s = \frac{\eta N + M}{A}$$

Where A is the area of the Mara preserve, N is the aforementioned total population of wildlife in the wildlife protection section. M is the total number of livestock. η is the average grass intake ratio of wildlife and livestock, which we deem as two according to our assumptions. We use regression analysis to determine M on a twenty-year basis. To increase our modelling authenticity and precision, we set a stochastic element, the random residual, to add white noise into our predictions. Random residuals are generated following a normal distribution. The linear fitting is shown in Figure 3.

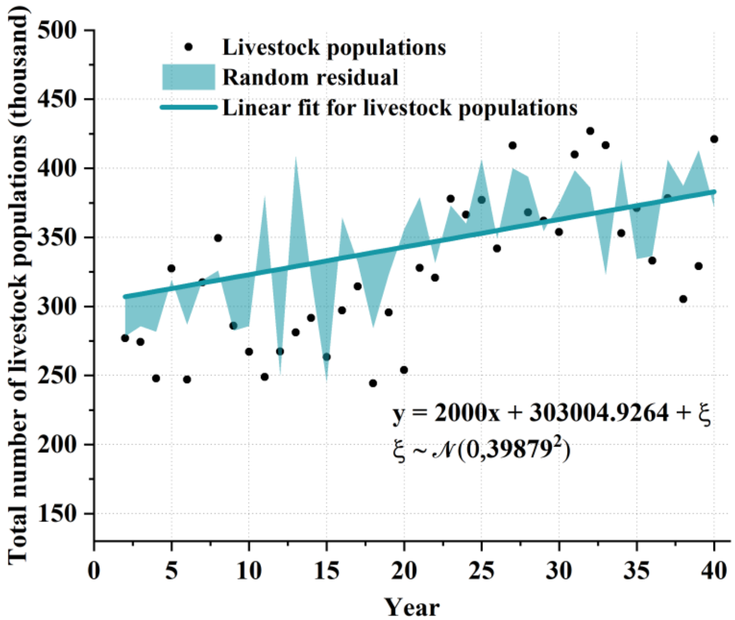

Figure 3. *The linear fitting curve of livestock populations.*

We give our score for grassland pastures. For each given M and N, we can calculate a corresponding stock density s. We then maximize $\frac{d\kappa}{dt}$ subject to all κ, which is the numerator of the following equation. The denominator of the equation maximizes $\frac{d\kappa}{dt}$ subject to all κ under the assumption that there are no grass-eating wildlife and herbivores, i.e., $M=N=0$. We assume that grass will reach its saturation level of growth when it is not grazed by animals. Therefore, our score for grassland resources falls under the range of 0 to 1.

$$Score_{grass} = \frac{max\left(\frac{d\kappa}{dt}\right)}{max\left(\frac{d\kappa}{dt}\right)\Big|_{M=N=0}}$$

b). Water resources

We determine water stress based on previous calculations done by Dessu et, al. [18]. Water stress is defined as the difference between water supply V_{supply} and water demand V_{demand}. Its full definition can be written as

$$V_{shortage} = V_{supply} - V_{demand}$$
$$= V_{terrestrial} + V_{rainfall} - V_{basic} - V_{normal} - V_{flood}$$

Where $V_{terrestrial}$ is the sum of surface water and ground water, $V_{rainfall}$ is the amount of precipitation, V_{basic} includes basic human needs and wildlife demands, V_{normal} is defined as the water demand for domestic households, livestock and tourism and V_{flood} is the flood volume demand for irrigation and the industry sector. All listed variables are in million cubic meters.

Based on water resources data on the Maasai Mara sub-basin of the Mara River, we can determine regional water supply and demand. We then categorize water stress based on methods proposed by Vorosmarty et al. [19] according to the percentage of demand in total water resources supply. To quantify water stress, we give each water stress state a stress level, which are shown below.

- Low stress <10%. Stress level=0.
- Moderate stress 10%-20%. Stress level=1.
- Medium-high stress 20%-40%. Stress level=2.
- High stress >40%. Stress level=3.

According to the water resources status of the Mara sub-basin. Water stress levels for each month are currently

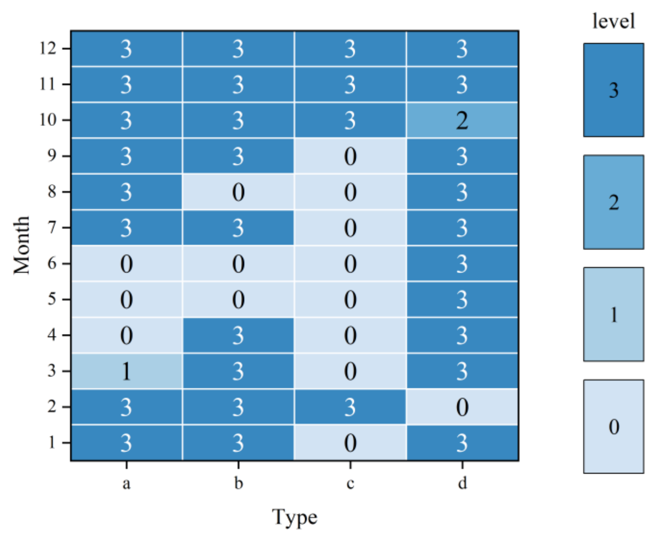

Figure 4. *Water stress levels for each month under different standards. (a) Total available water vs. total demand (b) the reserve volume vs. basic demand, (c) the normal available volume vs. normal demand, and (d) the flood volume vs. the flood demand.*

We calculate the frequency of each water stress level using the figure shown above. The appearance frequency of the four water stress levels are s_{low}, $s_{moderate}$, $s_{medium-high}$ and s_{high}, respectively.

Our score for the water resources section can be denoted as

$$Score_{water} = 0.6 \times s_{low} + 0.3 \times s_{moderate} + 0.1 \times s_{medium-high} + 0 \times s_{high}$$

We assume that grassland pastures and water resources are equally important in terms of natural resources conservation. Our final score for this section is

$$Score2 = \frac{1}{2} Score_{grass} + \frac{1}{2} Score_{water}$$

3.1.3 *Local financial interest section*

1) Modelling ideas

We take into account the interests of indigenous people through financial measurements. The foundation of community-based wildlife conservation is to **give local residents an economic incentive to participate in preservation**. The loss of opportunities from setting up the reserve should be at least compensated. By gaining from co-management, locals can turn away from illegal affairs that yield profits such as poaching, and benefit from the sustainable protection of wildlife.

2) Supplementary assumptions and justifications

- **We assume that the currency exchange rate between Kenyan shillings to US Dollars stays constant at 1 USD=100 Kenyan shillings (2020 data).**

The data we have obtained includes monetary measurements in both Kenyan shillings and US Dollars. We unified the currency to USD. The currency exchange rate between the two monetary units in 2012-2022 was observed and we discovered that except for 2021-2022 (due to the COVID-19's impact on tourism), the exchange rate remains relatively constant at 1 USD=100 Kenyan shillings. We have sufficient reason to believe that the exchange rate will return to its prior level since tourism is recovering from the pandemic.

- **We have selected a social discount rate of 2% to take into consideration the time value of money in our model.**
  The concept of the time value of money holds that the present value of money is more than the future value of money due to possible risks and uncertainties. In order to predict financial outcomes more precisely in a long-term span, we incorporate a social discount rate in our model. The selection of 2% is based on a survey consensus of 200 experts [20].

3) Calculations

We consider multiple aspects that compose a local's financial income and define the total yearly revenue in USD for an average resident R_{total} as

$$R_{total} = R_{lease} + \mu R_{job} + R_{tourism} + R_{livestock}$$

- R_{lease} is the income from land lease. Survey respondents from group conservancies noted that they earn extra income by leasing out parts of their landholdings for wildlife conservation [8].
- R_{job} is the job income from working at the conservancies/reservation. Rules of the conservancy regulates that 75% of employees must be from the local community [2]. μ is percentage of locals who have a job at the conservancy.
- $R_{tourism}$ is the extra income locals earn from providing cultural services to tourists. For example, selling handcrafts, performing traditional dances and acting as tour guides. This income can be calculated using

$$R_{tourism} = \frac{T_{tourists} c_{tourism}}{T_{locals}}$$

Where $T_{tourists}$ is the number of tourists entering the Maasai Mara preserve. $c_{tourism}$ is the amount of money an average tourist spends at the preserve and T_{locals} is the number of locals. We determine $c_{tourism}$ as 350 USD for 3 days using data from the Maasai Mara travel website [21]. $T_{tourists}$ and T_{locals} can be obtained using regression analysis.

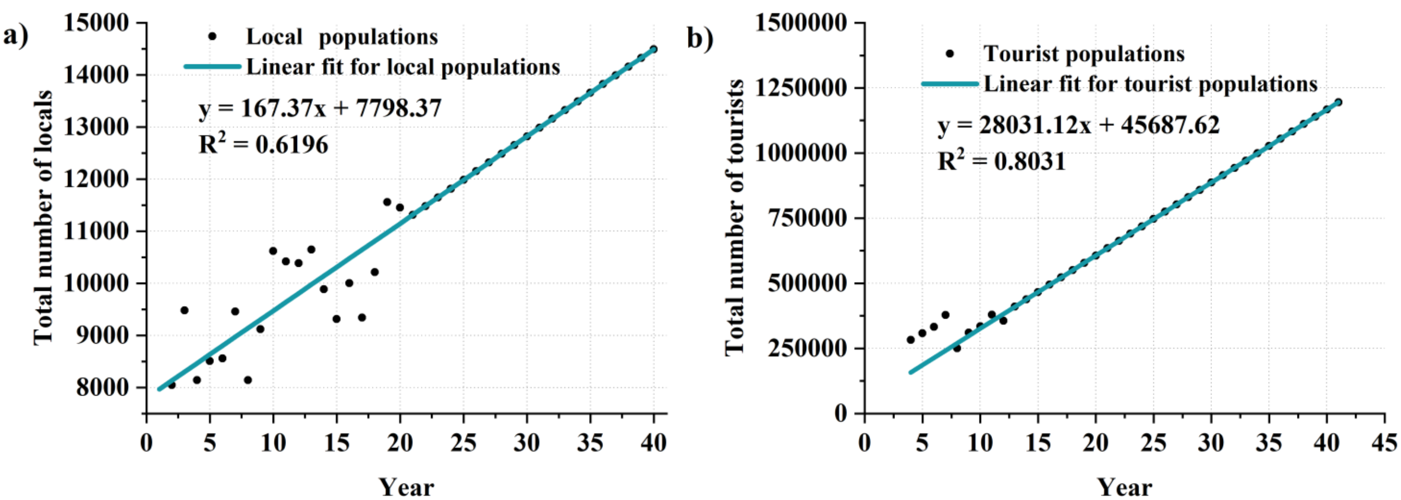

Figure 5. *The linear fitting curves for local populations and tourist populations.*

- $R_{livestock}$ is the average net income locals earn from the selling of livestock and dairy products.

$$R_{\text{livestock}} = B_{\text{livestock}} - C_{\text{livestock}}$$

$$B_{\text{livestock}} = \frac{\gamma M}{T_{locals}}$$

$$C_{\text{livestock}} = C_{\text{fines}} + C_{\text{conflict}}$$

Where $B_{\text{livestock}}$ is the gross income earned from the selling of livestock. It is defined using the aforementioned number of livestock M, the percentage of livestock sold each year γ and the number of locals T_{locals}. $C_{\text{livestock}}$ is the cost of fines from grazing inside the reservation C_{fines} and the loss from human-wildlife conflicts C_{conflict}. It was reported from surveys conducted in past researches that these costs make up a large percentage in household expenditures. The annual fines are 100.53 USD/person and the annual loss from wildlife predation is 247.74 USD [10]. We assume 10% of livestock is sold each year.

We subsequently construct a sigmoid function to obtain our third score. Q is a constant number that equals 15000 USD, derived from normalization.

$$\text{Score3} = \frac{1}{1 + \mathrm{e}^{-\frac{\mathrm{R_{total}}}{\mathrm{Q}}}}$$

3.1.4 *Animal tourism interactions section*

1) Modelling ideas

We wish to minimize the negative impacts of tourist-wildlife interactions, reducing human influence on the welfare and natural behaviors of wild animals. On the other hand, we also wish to keep tourists safe from possible wildlife attacks and disease transmissions. Therefore, we calculate the **probability of interspecies encounter (PIE)** to reduce these negative interactions.

2) Supplementary assumptions and justifications

- **We assume that the harmful interactions between tourists and animals are positively correlated with tourist/animal populations.**
  We assume that a larger number of both groups will aggravate existing conflicts. The reason is because when population density increases, different species are more likely to encounter. The conflict for existing land and resources will increase interactions.

3) Calculations

We calculate the negative interactions between tourists based on the PIE. Here, we consider tourists as the first "species" and all wildlife as the second "species". The known model [22] on interspecies encounter gives us

$$p = \rho_{wildlife} \times \frac{T_{tourist}}{N + T_{tourist} - 1} + \rho_{tourists} \times \frac{N}{N + T_{tourist} - 1} \approx \frac{2T_{tourist}N}{(T_{tourist} + N)^2}$$

Where p is the PIE, $T_{tourist}$ is the aforementioned number of tourists in the local financial interest section and N is the previously mentioned total number of wildlife populations. The density of wildlife $\rho_{wildlife}$ and the density of tourists $\rho_{tourists}$ can be represented as

$$\rho_{wildlife} = \frac{N}{N + T_{tourist}}$$
$$\rho_{tourists} = \frac{T_{tourist}}{N + T_{tourist}}$$

We introduce the concept of an impact factor to assess the negative interactions between tourists and wildlife. We define an impact factor as "how much a certain species is affected by interspecies encounters". This may seem as a very abstract notion. But it can be clearly represented using equations and solved after normalization. Here, the impact factor of tourist-wildlife interactions on tourists is λ and the impact factor on wildlife is σ. The two impact factors are given as follow

$$\lambda = \lambda_{attack} + \lambda_{disease} + \lambda_{prevent} = \rho_{wildlife} p \times \vec{\beta} + c_{prevent}$$
$$\sigma = \sigma_{product} + \sigma_{poaching} + \sigma_{invasive} + \sigma_{feeding} = \rho_{tourists} p \times \vec{\gamma}$$
$$\vec{\beta} = (\beta_{attack}, \beta_{disease})$$
$$\vec{\gamma} = (\gamma_{product}, \gamma_{poaching}, \gamma_{invasive}, \gamma_{feeding})$$

Where $\lambda_{conflict}$, $\lambda_{disease}$ and $\lambda_{prevent}$ are the impact factors on tourists caused by wildlife attacks, disease transmissions and prophylactic costs of disease prevention. $\sigma_{product}$, $\sigma_{poaching}$, $\sigma_{invasive}$ and $\sigma_{feeding}$ are the impact factors on wildlife caused by trading illegal animal products, poaching, the introduction of invasive species and feeding the animals. Each impact factor is either a constant (meaning that it does not change with wildlife populations and tourist populations) or is correlated with the PIE p and species density $\rho_{wildlife}/\rho_{tourists}$. We use $\vec{\beta}$ and $\vec{\gamma}$ to determine "how severe the impact is once interspecies encounters occur". After normalizing, $\vec{\beta}$ and $\vec{\gamma}$ turn out to be constant parameters.

Our score for the final section is measured in terms of impact factors

$$\text{Score4} = \frac{(1-\lambda) + (1-\sigma)}{2}$$

3.1.5 *Constructing the final objective*

As previously mentioned in our assumptions, we divide the Maasai Mara preserve into three land use types: a core wildlife preservation zone, a human settlement zone and a livestock grazing zone. The wildlife preservation zone (WPZ) expands over most of the Maasai Mara National Reserve's interiors while human settlement zones (HSZ) and livestock grazing zones (LGZ) mainly exists outside the reserve in surrounding conservancies.

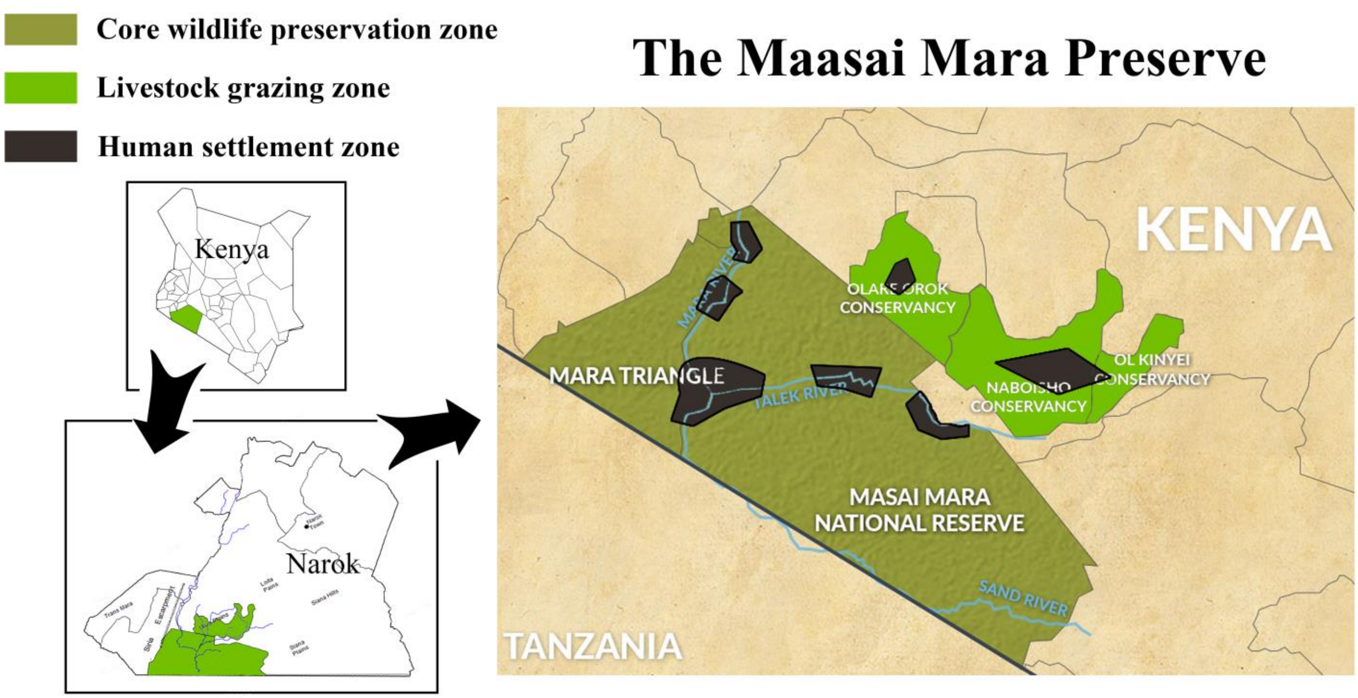

Figure 6. *The three land types in the Maasai Mara Preserve*

When we determine the weight of the four sections to construct the final objective, we take into consideration the difference between the three land use types. The weight of the four sections should vary for each zone because of its unique function. Therefore, we apply the Analytical Hierarchy Process to avoid being overly subjective on weight selection.

We built three matrices for the three different land types; each element shows the extent of preference between factor *i* and *j*. We use S1, S2, S3 and S4 in order to represent the four sections.

$$\begin{array}{c} \\ S1 \\ S2 \\ S3 \\ S4 \end{array} \begin{array}{c} \begin{matrix} S1 & S2 & S3 & S4 \end{matrix} \\ \begin{pmatrix} 1 & 2 & 7 & 4 \\ 1/2 & 1 & 3 & 2 \\ 1/7 & 1/3 & 1 & 1/5 \\ 1/4 & 1/2 & 5 & 1 \end{pmatrix} \end{array}$$

(a) Comparison matrix for WPZ

$$\begin{array}{c} \\ S1 \\ S2 \\ S3 \\ S4 \end{array} \begin{array}{c} \begin{matrix} S1 & S2 & S3 & S4 \end{matrix} \\ \begin{pmatrix} 1 & 1 & 1/2 & 1/3 \\ 1 & 1 & 1/4 & 1/5 \\ 2 & 4 & 1 & 1 \\ 3 & 5 & 1 & 1 \end{pmatrix} \end{array}$$

(b) Comparison matrix for HSZ

$$\begin{array}{c} \\ S1 \\ S2 \\ S3 \\ S4 \end{array} \begin{array}{c} \begin{matrix} S1 & S2 & S3 & S4 \end{matrix} \\ \begin{pmatrix} 1 & 1/2 & 1 & 1/2 \\ 2 & 1 & 3 & 1/2 \\ 1 & 1/3 & 1 & 1/4 \\ 2 & 2 & 4 & 1 \end{pmatrix} \end{array}$$

(c) Comparison matrix for LGZ

We obtain the weight of each section by calculating the maximum eigenvalue and normalizing its corresponding eigenvector. We test the consistency of each matrix using the Consisting Ratio (CR), given $CR = \frac{CI}{RI}$ where $CI = \frac{\lambda_{max} - n}{n-1}$ and $RI = 0.90$ ($n = 4$). The CRs of the three matrices are 0.0612, 0.0223 and 0.0301, respectively. Because they are all lesser than 0.1, the consistency of the matrices is confirmed. Therefore, the weight of the four sections in our model is shown in Figure 7.

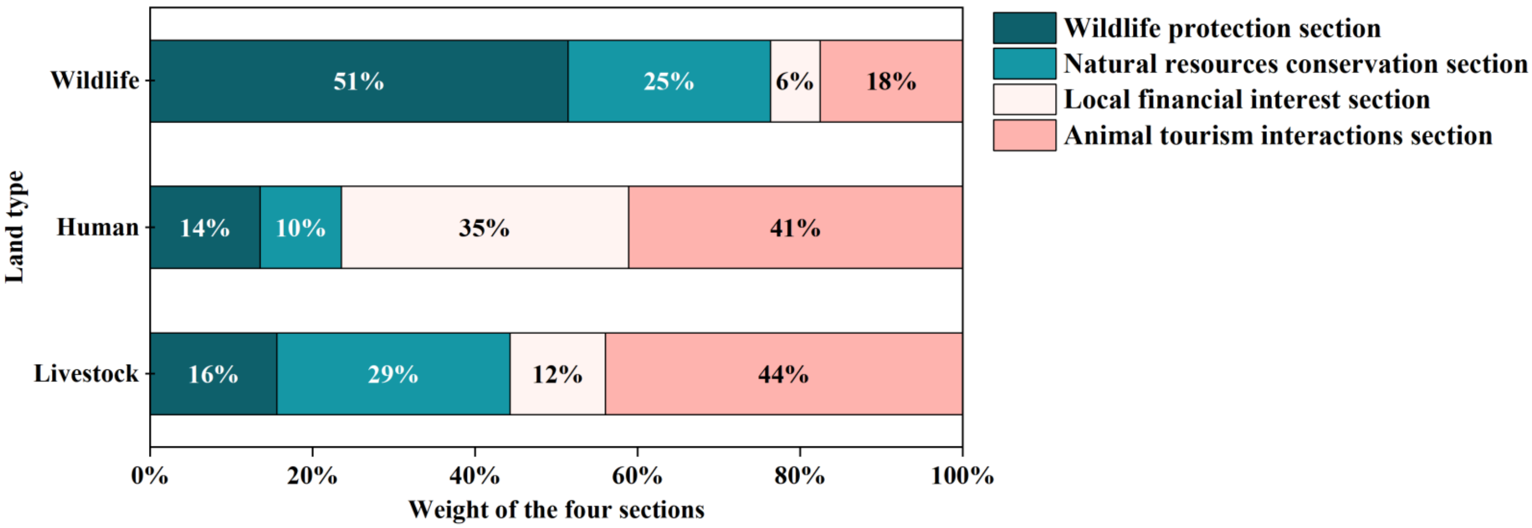

Figure 7. *The weight of the four sections in different land types*

Our final score is defined as

$$Final\ score = \omega_1 Score1 + \omega_2 Score2 + \omega_3 Score3 + \omega_4 Score4$$

Where ω_1, ω_2, ω_3 and ω_4 represent the weight of the four scores, which can be derived according to different land types listed in Figure 7.

3.2 Policy scenarios

We set up nine different policies according to different land types in the preserve. These policies aim to balance our four objectives while taking the main purpose of the given land types into consideration. The three policies within each land type can be combined into eight scenarios (Either enforcing zero, one, two or three policies) to assess the interactions between different policies. This offers us a more intact approach when apply more than one policy within the same period of time. We simulate all policies from 2002 to 2041, predicting twenty years starting from 2022.

There are two policies in Table 2 which we would like to give a supplementary explanation because they may seem counterintuitive and/or irrelevant.

- **Establishing bridging organizations.** It was found that locals generally mistrust the management team of the conservancy because information is not openly conveyed and they have an insufficient voice in decision making. Therefore, locals often act against the interests of the conservancy [2]. Bridging organizations are a well-researched method to enable co-operation by providing a forum for bring together different actors and networking [8]. We hope that this policy can help resolve the conflicts between locals and the conservancy.

- **Control invasive species.** Invasive species can threaten the sustainable development of the grassland. Notably, some invasive grasses are poisonous to livestock and wildlife alike, putting both groups of animals in peril. We demonstrate the invasive species control can have a positive effect on biodiversity and contribute to a healthier grassland ecosystem.

Table 2. Policy scenarios

Land Type	Policy content	Descriptions
Core wildlife preservation zone	①Enforce hunting quotas	1. Reduce illegal trading of animal products and poaching by 50% 2. Increase wildlife populations by 2% annually
	②Increase grazing fines	1. Increase grazing fines by 50% 2. Increase grassland pasture resources by 5%
	③Restrict tourism	1. Decrease the number of tourists by 30% 2. Increase wildlife populations by 0.5% annually 3. Increase the amount of water resources by 5%
Human settlement zone	④Increase conservation job opportunities	1. The percentage of locals who have a job at the conservancy increases to 90% 2. Increase wildlife populations by 0.3% annually 3. Decrease livestock populations by 0.5% annually
	⑤Establish bridging organizations	1. Income from land leases increase by 20% 2. Grazing fines reduce by 30% 3. Increase wildlife populations by 0.1% annually
	⑥Construct a wildlife corridor	1. Increase wildlife populations by 0.5% annually 2. Decrease livestock populations by 20% 3. Increase grazing fines by 20% 4. Increase the probability of interspecies encounters by 40%
Livestock grazing zone	⑦Compensate livestock loss	Eliminate the costs of livestock loss for local residents
	⑧Restrict livestock grazing	1. Livestock populations decrease by 10% 2. Increase grassland pasture resources by 10% 3. Increase the amount of water resources by 8%
	⑨Control invasive species	1. Increase biodiversity by 0.7% annually 2. Increase grassland pasture resources by 0.5% annually 3. Increase the amount of water resources by 0.5% annually

IV. Results and Discussion

4.1. Core wildlife preservation zone

The three proposed policies for the core wildlife preservation zone are enforcing hunting quotas, increasing grazing fines and restricting tourism. Our results show simulations from 2002-2041, mapping the final score of the weighed sections in Figure 8.

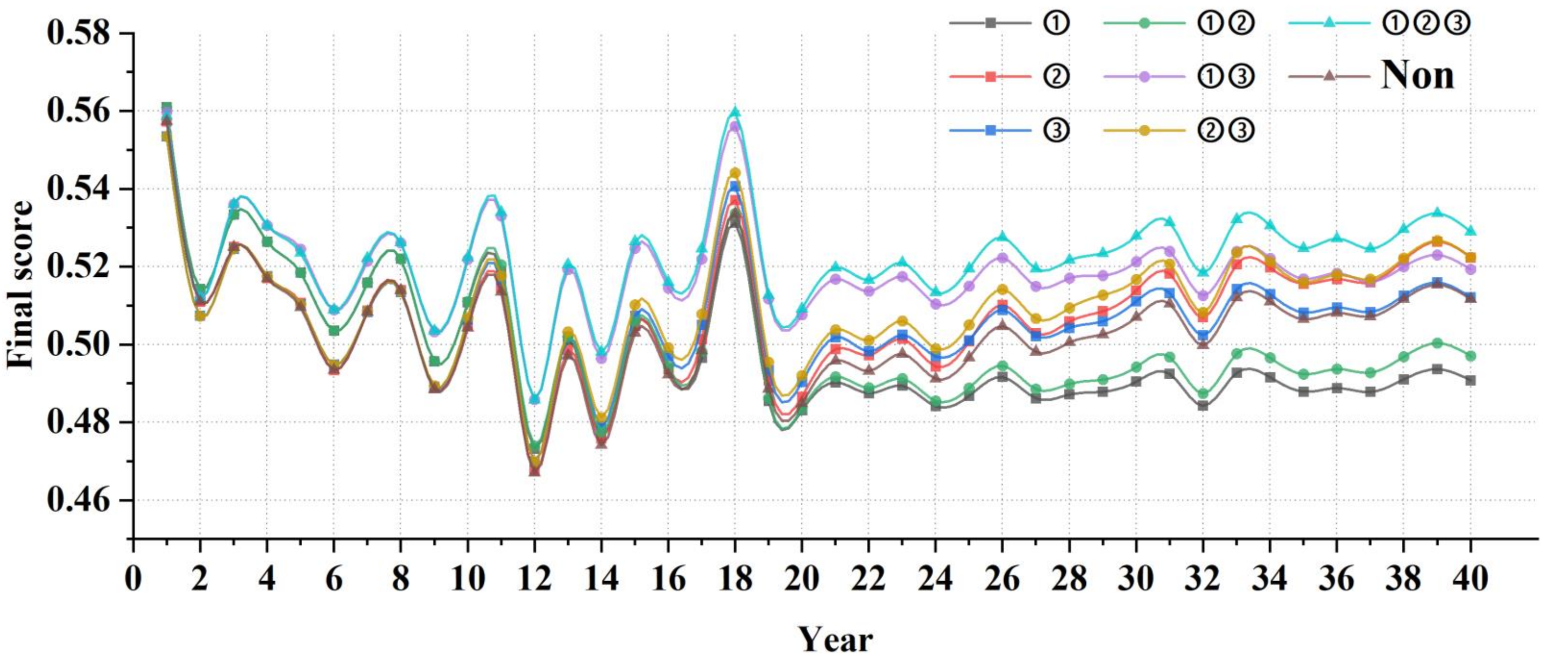

Figure 8. *Final score of the eight scenarios in the core wildlife preservation zone.*

It can be inferred that **the optimal scenario is the combination of three policies**. When two policies are enforced in a group, establishing hunting quotas and increasing grazing fines yields poor outcomes while the other two combinations are significantly beneficial. When looking at the policies one by one, results demonstrate that enforcing hunting quotas is actually a negative policy when acting alone. This is a very counter-intuitive result. We believe the reason is that the parameter we set for increasing wildlife populations when hunting quotas are enforced will put severe pressure on the grassland ecosystem, producing degrading results in the long-run. However, this result is extremely dependent upon our predetermined parameter, reducing the certainty of this possible outcome. Another interesting result can be reached when comparing grazing fines and tourism restrictions. Restricting tourism quickly produces salutary results until 2030 but slowly declines in the further future due to loss of residential income. Grazing fines, however, are slow to induce satisfying outcomes but is proven to be extremely advantageous in a long span of time. This implies that different policies can take varying time lengths to bring out the best of its outcomes.

We provide a ranking for the eight scenarios in 2022, 2032 and 2042.

Table 3. Rankings of the eight policy scenarios in the wildlife preservation zone

	1	2	3	4	5	6	7	8
2022	①②③	①③	②③	③	②	Non	①②	①
2032	①②③	①③	②③	②	③	Non	①②	①
2042	①②③	②③	②	①③	③	Non	①②	①

4.2 Human settlement zone

The three proposed policies for the human settlement zone are increasing conservation job opportunities, establishing bridging organizations and constructing a wildlife corridor. We run the model eight times and map the final score of 2002-2041 on the figure shown below.

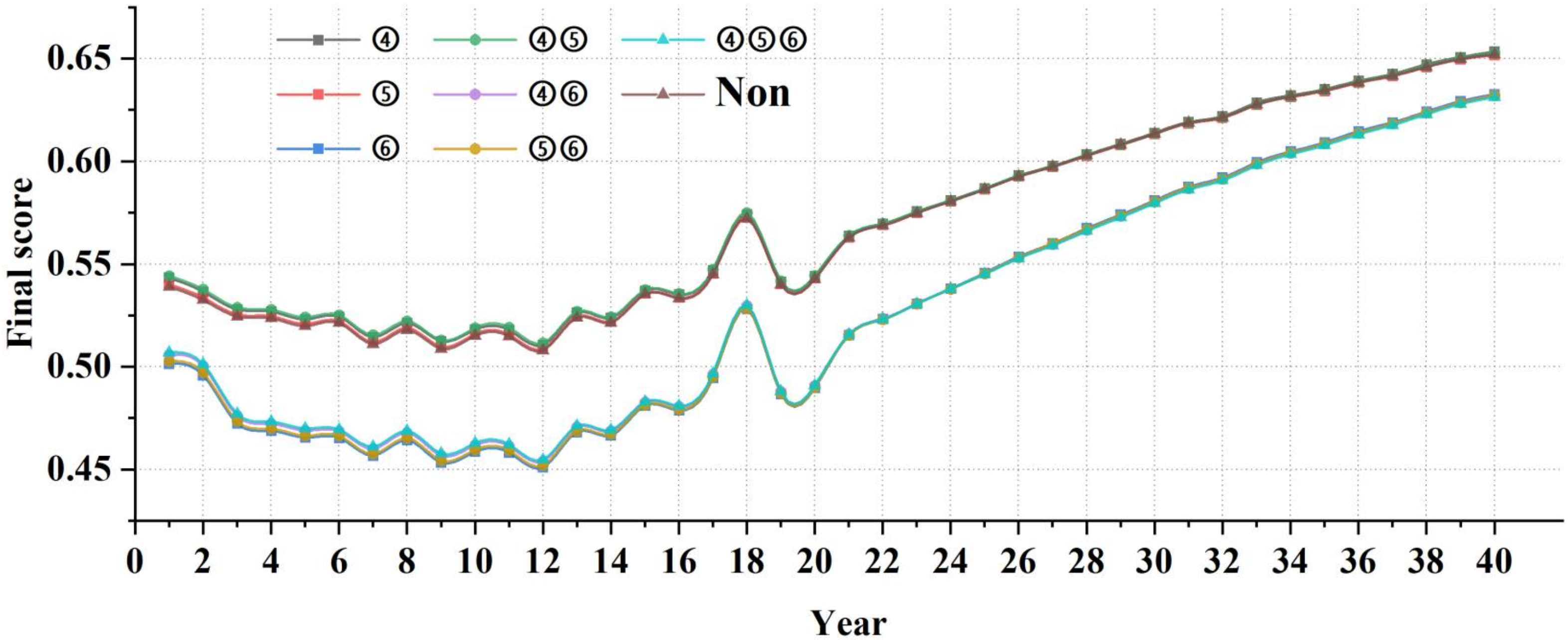

Figure 9. *Final score of the eight scenarios in the human settlement zone.*

Results illustrate that, **the best policy for most years is providing conservation job opportunities solely.** The eight scenarios are divided into two apparent groups with four scenarios in each group. The distinctions between scenarios without a wildlife corridor are almost indiscernible. Scenarios that include constructing a wildlife corridor perform significantly worse than scenarios without this policy. It can be indicated that although the construction of a wildlife corridor may seem like a beneficial policy at first glance, it is in fact a deleterious strategy. The reason is because a corridor for wildlife in human settlement zones can increase competition for natural resources between wildlife and livestock. Reduced livestock numbers and lost income opportunities will lead to more frequent illegal affairs in the corridor such as poaching and illegal grazing. Additionally, the probability of human-animal contacts will significantly increase. These adverse effects offset the benefits of increase wildlife population. In conclusion, instead of establishing “no-go” zones that will disturb the livelihood of locals, the best approach in human settlement zones is to **make sure local residents gain socially and economically from conserving resources and can take on management responsibilities over conservation.**

We provide a ranking for the eight scenarios in 2022, 2032 and 2042.

Table 4. Rankings of the eight policy scenarios in the human settlement zone

	1	2	3	4	5	6	7	8
2022	④⑤	④	⑤	Non	④⑤⑥	⑤⑥	④⑥	⑥
2032	④	④⑤	Non	⑤	⑥	⑤⑥	④⑥	④⑤⑥
2042	④	④⑤	Non	⑤	⑥	④⑥	⑤⑥	④⑤⑥

4.3 Livestock grazing zone

The three policies for the livestock grazing zone are compensating livestock loss, restricting livestock grazing and controlling invasive species. We map out the final score for the eight scenarios on Figure 10.

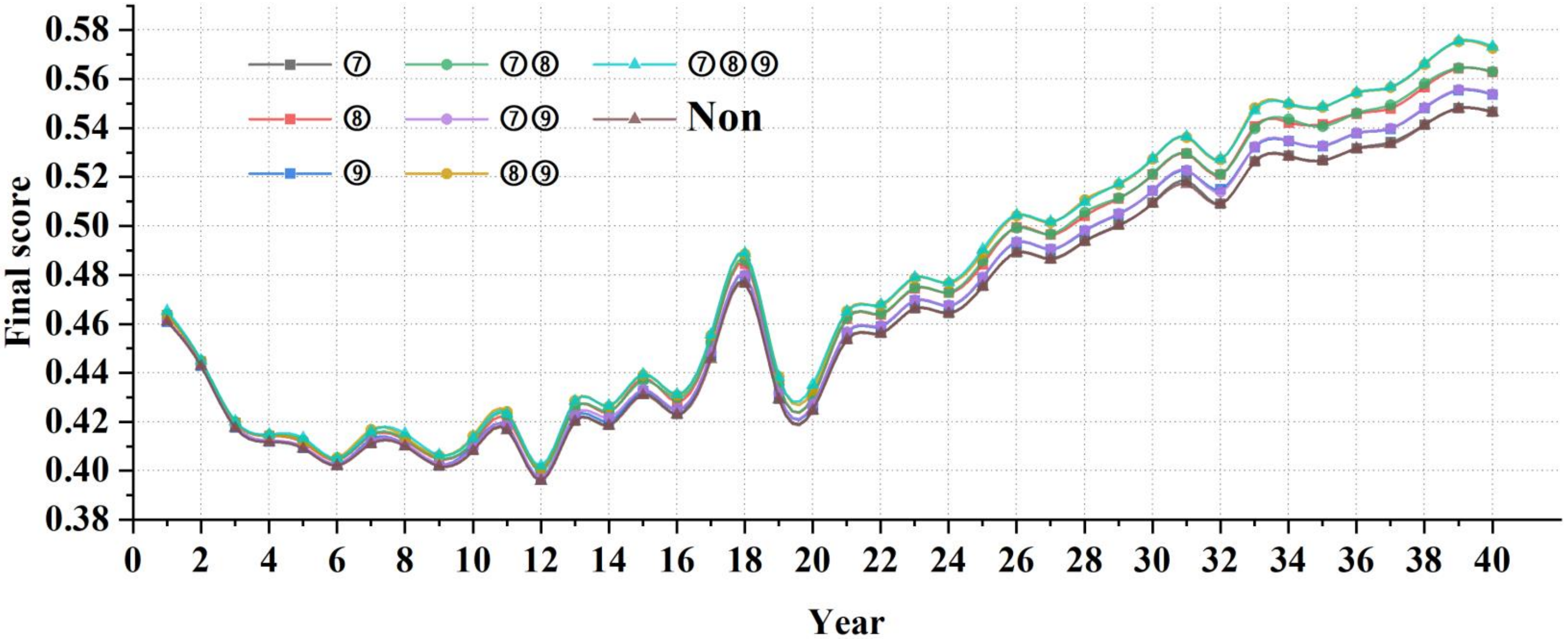

Figure 10. *Final score of the eight scenarios in the livestock grazing zone.*

The scenario that produces the highest score is the combination of the three policies. Results show that the compensation for livestock loss has a negligible effect on the final score. However, we believe that despite these results, compensation for livestock loss is important in another immeasurable aspect. We argue that although the measurable economic profits are small, this policy is crucial in building trust between the government and local residents and has an underlying impact on the establishment of community-based co-management. Additionally, when applying each policy solitarily, restricting livestock grazing is proven to be the most effective strategy as it assures sustainable development of water and grassland pasture resources. Yet, the certainty of this policy is dependent upon how locals react to such constraints. The control of invasive species has the similar effect but in a less significant degree. Since all scenarios that adopt policies outdo our baseline scenario where there are no policies implemented, we can infer that the selection of policies is effective for this region.

Table 5. Rankings of the eight policy scenarios in the livestock grazing zone

	1	2	3	4	5	6	7	8
2022	⑦⑧⑨	⑧⑨	⑦⑧	⑧	⑦⑨	⑨	⑦	Non
2032	⑦⑧⑨	⑧⑨	⑦⑧	⑧	⑦⑨	⑨	⑦	Non
2042	⑦⑧⑨	⑧⑨	⑦⑧	⑧	⑦⑨	⑨	⑦	Non

V. Sensitivity Analysis

As described in section III, we use exponential regression analysis to determine the future trends in wildlife populations and livestock populations. These estimations largely depend on the coefficient we obtained from the fitting curve. To assess the certainties of our results, we perform the process of sensitivity analysis on regional wildlife populations and livestock populations by changing the exponential coefficient in their fitting curves.

We have the fitting function of the two variables as

$$y = Ae^{-Bt}$$

Where A and B are constant values for fitting and t is the number of years.

We then modify the exponential coefficient B by using

$$y = Ae^{-Bt}\alpha^t = Ae^{(ln\alpha - B)t}$$

Now, the "rate of decrease/increase" for the fitting curve is $(ln\alpha - B)$ instead of B.

We graph the impact of changing exponential coefficients within a timespan of forty years from 2002 to 2041, considering the fitting curve of wildlife populations and livestock populations.

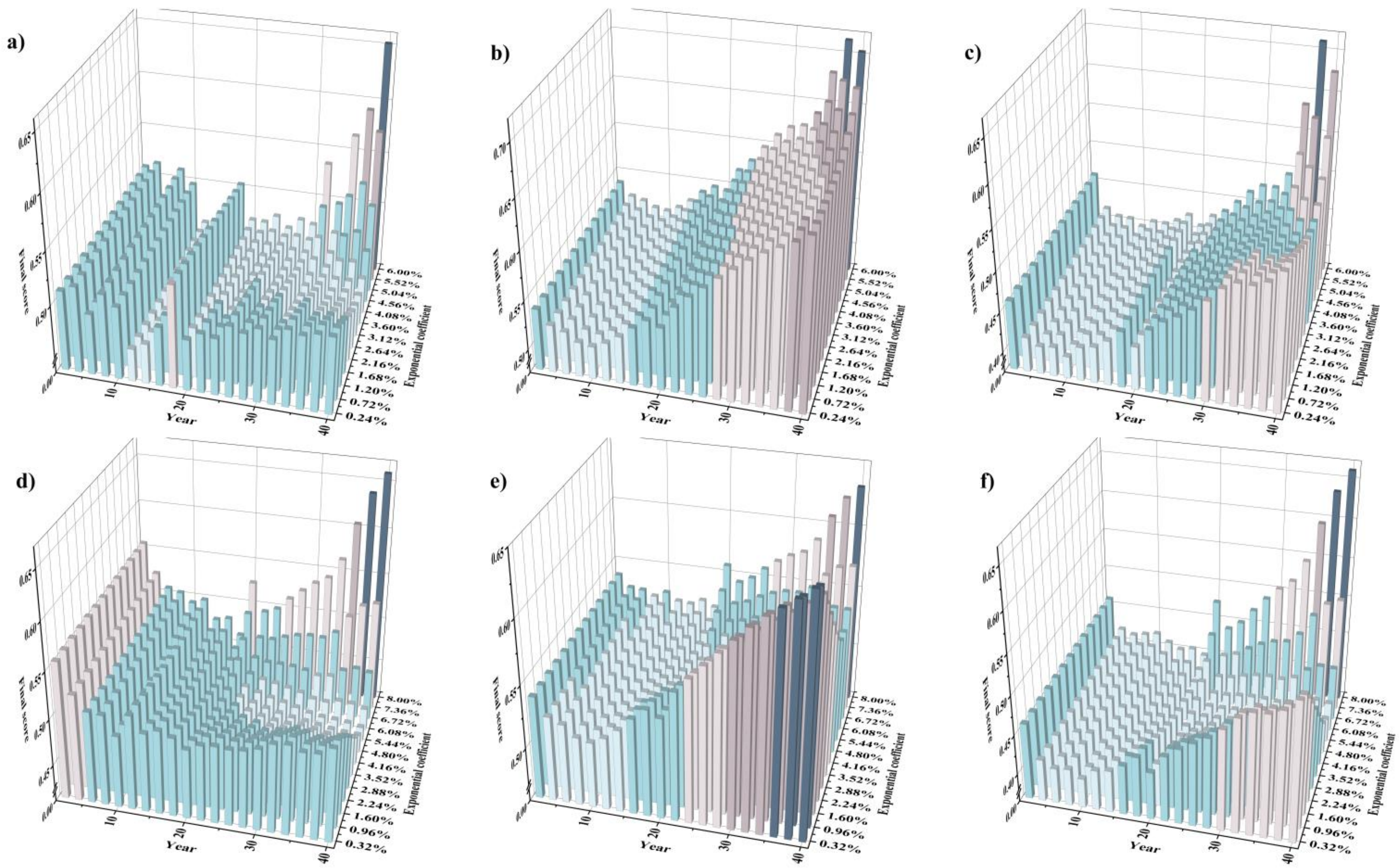

Figure 11. *Sensitivity analysis for livestock and wildlife populations. Figure 11 a-c) represent the sensitivity of livestock populations in the wildlife preservation zone, the human settlement zone and the livestock grazing zone, respectively; Figure 11 d-f) show the sensitivity of wildlife populations in the wildlife preservation zone, the human settlement zone and the livestock grazing zone, respectively. The inward-axis shows the change in the exponential coefficient α. The vertical axis displays the final score under each year and exponential coefficient.*

- Overall, it can be determined that the model is more sensitive to changes in livestock populations.
- The wildlife preservation zone is least sensitive to changes in livestock populations and the livestock grazing zone is least sensitive to changes in wildlife populations. The human settlement zone is the most sensitive area to both factors due its relatively low bio-capacity.

VI. Testing the Model

We test the applications of our model on other wildlife management areas to ensure its stability and certainty. If the model is stable, we can therefore assess the aforementioned policy scenarios in another region. In order to do so, we assume that all data for the alternative preserve are adequate and correct. By substituting the data for another preserve, we need to adjust modelling parameters to befit the region. We use the policy of restricting tourism in the wildlife preservation zone to demonstrate this process and show the stability of our parameters.

We introduce the correcting coefficient to describe the adjusting process. A correcting coefficient is multiplied onto the original parameter of our Maasai Mara model. To better illustrate this, in section 3.2, we expect the policy of restricting tourism to 1. Decrease tourist numbers by 30% 2. Increase wildlife populations by 0.5% annually and 3. Increase the amount of water resources by 5%. When applying the correcting coefficient (CC), we expect the impact of the policy be transformed into

- Decrease tourist numbers by $(1 + CC) \times 30\%$
- Increase wildlife populations by $(1 + CC) \times 0.5\%$ annually
- Increase the amount of water resources by $(1 + CC) \times 5\%$

The value of CC changes when we adopt our model into another wildlife management preserve. In this way we can adjust our parameters so that they describe the conditions of another area. To ensure our model is stable under all conditions, we performed an additional sensitivity analysis on the correcting coefficient CC. We adjusted CC within a whopping range of -3.6% to -90%. The sensitivity of the final score to changes in CC within forty years is shown in the figure below.

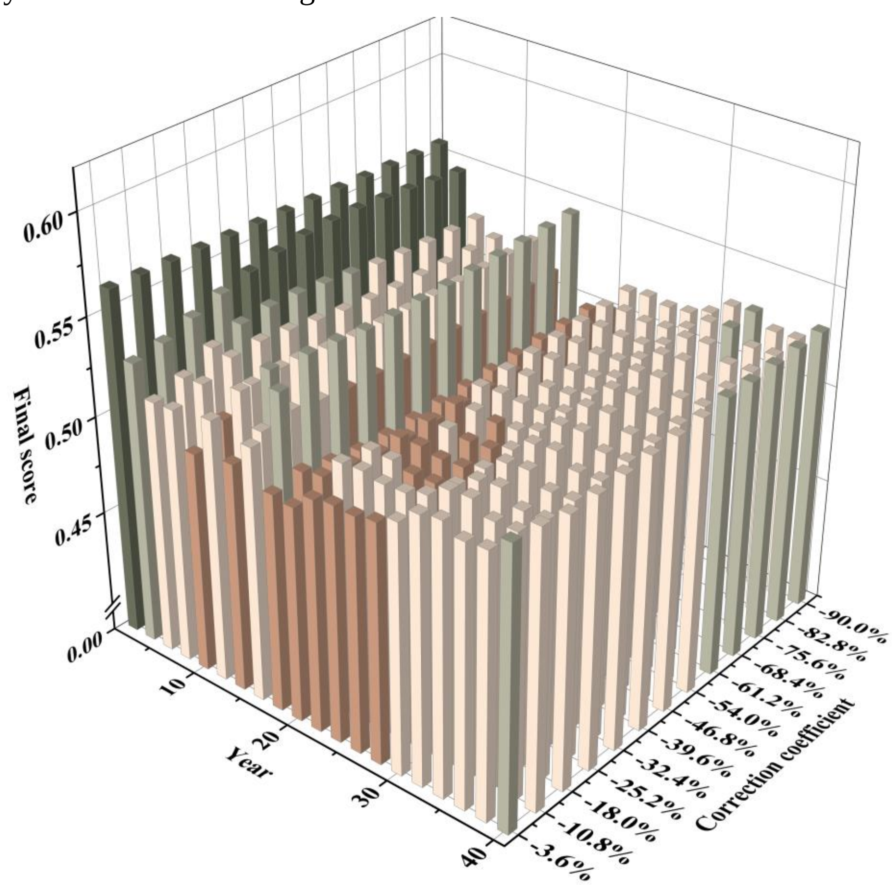

Figure 12. *Sensitivity analysis of the correcting coefficient CC.*

We discover that despite this dramatic change in CC, the final score is relatively unvarying within the range of 0.5 to 0.575. This result indicates that our model is very stable when parameters are adjusted. We can successfully apply this model to another wildlife conservancy and assess the ranking and outcomes of our proposed policies with certainty.

VII. Strengths and Weaknesses

7.1 Strengths

- **Strength 1: The model considers multiple aspects of wildlife conservation.**
  Wildlife preservation is not limited to fencing a human-free haven for wild animals. We consider multiple aspects of human-wildlife interactions, including but not limited to competition for grazing and water, the introduction of invasive species, disease transmission and income generation opportunities. We provide a modelling approach presenting the complexities of community-based wildlife preservation.
- **Strength 2: The classification of three different land types provides a more specific approach.**
  Our model divides the Maasai Mara preservation into a core wildlife preservation zone, a zone for human settlement and a livestock grazing zone. Instead of taking a general and uniform approach, we set up different objective weights and suggested disparate policies for each land type. This allows us to pinpoint the effects of each policy more accurately.
- **Strength 3: The model is dynamic and time-related.**
  We consider time-related factors by estimating future trends of different species of wildlife, livestock, tourists and local residents based on past evidence. We also incorporate the time value of money using a social discount rate to account for risks and uncertainties. Therefore, the model is dynamic and can simulate future shifts in our objectives.
- **Strength 4: We use scores to keep track of the effects of policies.**
  We calculate the scores of the four objectives to determine their state. By summing up the four scores, we determine that the policy scenario with the highest score is the optimal policy. This is a very effective and straight-forward way to analyze the effects of policies, with an easily observable outcome.
- **Strength 5: We use stochastic elements in our model.**
  To simulate future trends with more precision when conducting regression analysis, we apply random residuals in our model to capture unobserved heterogeneity. Rather than risking error through incorrect constants or overlooked variables, we set stochastic elements to randomly generate values that follow a normal distribution.

7.2 Weaknesses

- **Weakness 1: Our model is limited by data precision.**
  Data on wildlife is limited to statistical reports on large mammals that were not conducted annually. We assume that the welfare of selected mammals can indicate the well-being of the entire ecosystem. Additionally, data on local residents were mainly collected through the surveys conducted by previous researchers. The results may be biased according to the group of people selected in a survey.
- **Weakness 2: The model excludes the occurrence of sudden exogenous events.**
  In reality, many unexpected incidents may occur in a time span of twenty years. For example, the COVID-19 pandemic caused tourism income to plummet in 2020, droughts and unexpected plagues such as the now eradicated rinderpest may severely threaten wildlife populations. Policies must quickly adapt to the ever-changing series of events in order to fully achieve the goal of wildlife conservation.
- **Weakness 3: The model assumes that policies can be enacted and implemented without endogenous delays or funding inadequacies.**
  The enforcement of a certain policy is a long and devious process in reality. Delays, budget constraints and government annulments all contribute to the demise of an intended policy. We assume that fundings are adequate and there are no endogenous forces obstructing the full implementation of a policy. In this way, we only focus on the comparisons between the full effects of policies, bringing out the best of each policy.

VIII. Conclusions

To predict future trends for wildlife conservation policies, we construct a net-work based evaluation model with four sections. A scoring system is developed to assess the well-beings of each section. Data is collected through previous researches and government reports. We divide the preservation into three different land types and applied three policies for each land type. Eight scenarios are derived through the combination of the three policies. We ran twenty-four trials on MATLAB to simulate the performances of all policies from 2022-2041. We determine the optimal policy for the wildlife preservation zone is the combination of enforcing hunting quotas, increasing grazing fines and restricting tourism. The optimal policy for the human settlement zone is providing conservation job opportunities. As for the livestock grazing zone, the combination of compensating livestock loss, restricting livestock grazing, controlling invasive species produces the most beneficial results.

Future work should focus on the relaxation of some of our strongest assumptions. For example, considering other natural resources except for grassland pastures and water or taking into account the impact of sudden exogenous events. As a final concluding remark, decentralizing wildlife conservation can face various challenges including institutional barriers, conflict of interests throughout planning processes, and equity issues relating to collective decisions or unequal distribution of benefit. More stress should be placed on the construction of a community-based management structure as we move into the future.

IX. References

[1]The Maasai Mara National Park 2023 https://www.masaimara.com/index.php.
[2]Oduor, A.M.O. 2020. Livelihood impacts and governance processes of community-based wildlife conservation in Maasai Mara ecosystem, Kenya. J Environ Manage 260, 110133.
[3]The Wildlife Conservation and Management Act, R.o.K., Kenya Gazette Supplement No. 181 (Acts No. 47), 2013.
[4]Mackenzie, C.A. 2012. Accruing benefit or loss from a protected area: Location matters. Ecological Economics 76, 119-129.
[5]Spiteri, A. and Nepal, S.K. 2008. Evaluating Local Benefits from Conservation in Nepal's Annapurna Conservation Area. Environmental Management 42(3), 391-401.
[6]Ward, C., Stringer, L.C. and Holmes, G. 2018. Protected area co-management and perceived livelihood impacts. J Environ Manage 228, 1-12.
[7]Brehony, P., Tyrrell, P., Kamanga, J., Waruingi, L. and Kaelo, D. 2020. Incorporating social-ecological complexities into conservation policy. Biol Conserv 248, 108697.
[8]Berkes, F. 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J Environ Manage 90(5), 1692-1702.
[9]Eklund, J. and Cabeza, M. 2017. Quality of governance and effectiveness of protected areas: crucial concepts for conservation planning. Ann N Y Acad Sci 1399(1), 27-41.
[10]Bedelian, C. (2014) Conservation, tourism and pastoral livelihoods: Wildlife conservancies in the Maasai Mara, Kenya, University College London.
[11]Lamprey, R.H. and Reid, R.S. 2004. Expansion of human settlement in Kenya's Maasai Mara: what future for pastoralism and wildlife? Journal of Biogeography 31(6), 997-1032.
[12]KWCA State of Wildlife Conservancies in Kenya 2016.
[13]Ottichilo, W.K., De Leeuw, J., Skidmore, A.K., Prins, H.H.T. and Said, M.Y. 2000. Population trends of large non-migratory wild herbivores and livestock in the Masai Mara ecosystem, Kenya, between 1977 and 1997. African Journal of Ecology 38(3), 202-216.
[14]KWS Kenya Wildlife Service 2021 National Wildlife Census Report, https://kws.go.ke/content/national-wildlife-census-2021-report.
[15]Oindo, B.O., Skidmore, A.K. and de Salvo, P. 2010. Mapping habitat and biological diversity in the Maasai Mara ecosystem. International Journal of Remote Sensing 24(5), 1053-1069.
[16]Stelfox, J.G., Peden, D.G., Mbugua, S.W., Amuyunzu, C.L. and Hudson, R.J. 1980. Populations, stocking rates and distributions of wildlife and livestock on Mara and Loita Plains: December 1978–November 1979. . Technical Report Series 19(KREMU), NAIROBI.
[17]Woodward, S.J.R. and Wake, G.C. 1994. Optimal Grazing of a Multi-paddock System Using a Discrete Time Model. Agricultural Systems 48, 119-139.
[18]Dessu, S.B., Melesse, A.M., Bhat, M.G. and McClain, M.E. 2014. Assessment of water resources availability and demand in the Mara River Basin. Catena 115, 104-114.
[19]Vorosmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth. Science 289(5477), 284-288.
[20]Drupp, M.A., Freeman, M.C., Groom, B. and Nesje, F. 2018. Discounting Disentangled. American Economic Journal: Economic Policy 10(4), 109-134.
[21]Masai Mara Travels https://www.masaimara.travel/calculate-masai-mara-safari-cost.php.
[22]Berger, J. and Cunningham, C. 1998. Behavioural ecology in managed reserves: gender-based asymmetries in interspecific dominance in African elephants and rhinos. Animal Conservation 1(1), 33-38.