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Research on Reducing Illegal Wildlife Trade Based on Combined Dynamic Mathematical Model and Combined Intervention Model

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Abstract: *Until now illegal wildlife trade has caused great ecological and economic losses. Thus, this study simulates the possible effects of a group's behavior on the reduction of competition in illegal wildlife trade. Firstly, enough data can be found form the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Secondly, a dynamic mathematical model can simulate the dynamic changes caused by different aspects of a group's behavior in simulating illegal wildlife trade. Finally, a combined intervention model can simulate future trends in changes in trade volumes following the intervention of these behaviors. Probabilistic models and sensitivity analyses demonstrate the good stability and robustness of the model. This study helps to better deepen the understanding of different groups in reducing illegal trade in flora and fauna, thus mobilizing more people to participate in the environmental cause.*

Keywords: *Dynamic Mathematical Model, Time Series, Probabilistic Model, Sensitivity Analysis*

1. Introduction

The global cost of illegal wildlife trade competition (illegal hunting, logging, fishing, and wildlife trade) has been estimated to be between $7 billion and $23 billion per year and combating illegal wildlife trade requires supportive efforts at different group levels [1,2]. The aim of this paper is to analyze, through modeling, the impact of a group's behavior on reducing competition in the illegal wildlife trade. First, a large amount of relevant data can be obtained by reviewing the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Then, a dynamic mathematical model is established to simulate the dynamic changes caused by the behaviors of different aspects of a group in the illegal wildlife trade. Through the combined intervention model, the future trend of trade volume after intervention can be predicted. Finally, the sensitivity analysis of the probabilistic model shows that the model has good stability and robustness. This study can help different groups to better combat illegal trade and promote the conservation and sustainable utilization of wildlife to maintain the ecological balance of the earth and the sustainable development of human society [3,4].

2. Data collection and pre-processing

2.1 Data collection and analysis

Preparation before modeling: By reviewing the data of the International Convention on the Trade in Endangered Wild Animals and Plants, cleaning and modeling the proportion of companies and regions with a large illegal trade in wildlife and presenting it in a pie chart. As can be seem in intuitively Figure 1, that Asia has the most illegal trade in the region, and CHN companies have the most illegal trade among the enterprise companies.

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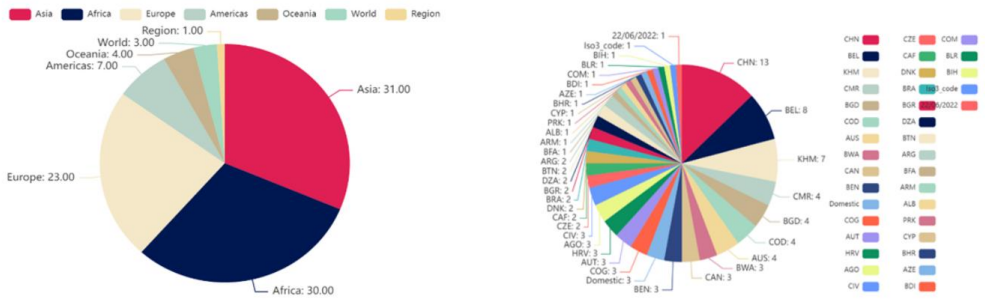

Figure 1: Pie chart of the regional proportion of the illegal animal and plant trade volume and companies

The main groups involved in combating illegal wildlife trade can be divided into four parts: government departments, non-governmental organizations (NGOs), enterprises, and the public. NGOs include the International Union for Conservation of Nature and the World Wide Fund for Nature (WWF). Governments can enhance laws and enforcement; NGOs can raise awareness; enterprises can ensure legal procurement; and the public can be educated to influence consumption choices. The Convention on International Trade in Endangered Species of Wild Fauna and Flora shows that North America, a major global transit hub, is a key area for illegal wildlife trade due to insufficient regulation and high market demand. Effective reduction of this trade requires: governments to legislate and enforce laws; NGOs to have resources for advocacy; companies to ensure ethical supply chains; and the public to be informed about environmental impacts. In conclusion, reducing illegal wildlife trade necessitates joint efforts from all stakeholders, including governments, enterprises, NGOs, and the public [5,6].

According to the factors provided, the following indicators in the related factors should be considered: G1 funding, G2 regulatory enforcement capability, G3 technical support, G4 cooperation (influence), G5 human resources, G6 publicity and education (public awareness).

Table 1: Consensus matrix

	Fund	Ability of supervision and law enforcement	Technical support	Cooperation (influence)	Human resources	Publicity and education
Fund	1	0.7	0.5	0.6	0.4	0.5
Ability of supervision and law enforcement	1.4	1	0.8	0.7	0.5	0.6
Technical support	2	1.25	1	0.7	0.6	0.7
Cooperation (influence)	1.7	1.4	1.4	1	0.6	0.8
Human resources	2.5	2	1.7	1.7	1	0.6
Publicity and education	2	1.7	1.4	1.25	1.7	1

2.2 Hierarchical analysis with decision trees

Each influencing factor should be quantified, and according to the quantitative difficulty of each factor, establish a mixed model of hierarchical analysis and decision tree will be established. According to the search and analysis of the data, various relevant factors are obtained, and the correlation on the influence degree of suitable customers is as Table 1.

These factors are first tested for consistency. Calculate the consistency index:

$$CI = \frac{\lambda_{max-n}}{n-1} \tag{1}$$

Using python code to obtain the weight results of arithmetic average method, geometric average method and eigenvalue method. Because the weight calculated by eigenvalue method is more accurate, the weight of eigenvalue method is adopted. NamG1=0.0928, G2=0.1227, G3=0.1495, G4=0.1700, G5=0.2284 and G5=0.2366. It can be found that the decision passed the consistency test, indicating that the decision or data that passed the consistency test was more credible. A comprehensive value evaluation method can be set as follows: G1 * funds + G2 * regulatory and law enforcement ability + G3 * technical

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support + G4 * cooperation (influence) + G5 * human resources + G6 * publicity and education.

Here we assume a money, regulatory ability, technical support, cooperation (influence), human resources, publicity and education ability of groups called dt.predict can be obtained. The next step in the study will be to examine what factors specifically affect this group's programs to reduce wildlife trade and how these factors are affected.

3. Dynamic mathematical model

3.1 Model construction

In constructing the mathematical model, we believe that the group can be expressed as a decision maker or controller, whose role in the model can regulate and influence various variables, so as to achieve the goal of reducing the illegal wildlife trade. The client has the power, resources and interest in the mathematical model to implement the project we propose.

We use mathematical models to describe the role of groups. Suppose that group actions affect wildlife conservation efforts (P), the level of sustainable alternative promotion (A), the level of international cooperation (I), and public awareness and participation (C). We can express group actions as a vector. Among them, U_P, U_A, U_I and U_C indicate the regulatory role of groups on protection strength, substitute promotion, international cooperation and public participation.

The mathematical model can be expressed as follows:

$$\frac{dT}{dt} = -ki - T + k2.(P + Up) \bullet (A + UA) : (I + UI) - (C + Uc) \tag{2}$$

In this model, U_P, U_A, U_I and U_C are the changes caused by the group's actions, which can be positive or negative numbers, representing the group's actions increasing or reduce the influence of the corresponding factors. By adjusting these parameters, groups can somewhat influence the scale of the illegal wildlife trade (T).

We can simulate the dynamic model of the illegal wildlife trade and combined with some of the role of the group, we set the initial scale of the illegal wildlife trade to 1000, protection intensity, substitution promotion, international cooperation, public awareness to 0.5. Comprehensive consideration, the group influence on protection set to 0.1, the group to substitute promotion effect set to 0.1, the group influence on international cooperation is set to 0.05, the group influence on public awareness set to 0.03, short-term simulation of a 5 years, long-term simulation of a 50 years, we can get the following illegal wild trade dynamic changes.

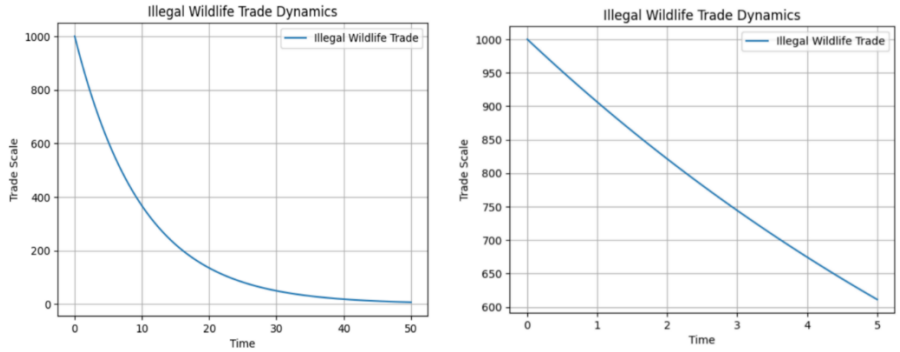

Figure 2: Changes in the scale of illegal animal and plant trade in five years and fifty years

Figure 2 simulates the change of the scale of the illegal wildlife trade over time. The model considers the strength of protection, the degree of alternative promotion, international cooperation and public participation, and considers the regulatory effect of group actions on these factors. The group has implemented our project, and the number of illegal trade has decreased year by year.

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3.2 Model application

Through the establishment and pre-setting of preliminary models, the wildlife trade will be significantly reduced. Through data monitoring and analysis, illegal trade activities can be tracked and combated more accurately, and public awareness of wildlife protection can be raised. With the reduction of illegal trade activities, species diversity increases, and the environment becomes more beautiful, which will bring windfall benefits to the local tourism industry. The project's impacts on illegal wildlife trade include national law enforcement, citizen awareness levels, and regional economic development. In terms of national law enforcement, by combating illegal hunting, smuggling and trafficking activities, it directly reduces the volume of illegal trade, improves the efficiency of capacity building of law enforcement agencies, enhances the efficiency of investigations and crackdowns, reduces the risk of smuggling, and provides stronger legal safeguards by improving laws and regulations. In terms of civic awareness, the successful implementation of the project will have a broad social impact, attracting more people to pay attention to and support wildlife protection, and raising public awareness and understanding of illegal trade through education and publicity activities. In terms of regional economic development, the implementation of the project may help to restore threatened wildlife populations, promote legal and sustainable wildlife trade, reduce the attractiveness of illegal trade, and attract more organizations, enterprises and countries to participate in the cooperation against illegal wildlife trade [7].

The impact and results of the project are shown in Figure 3:

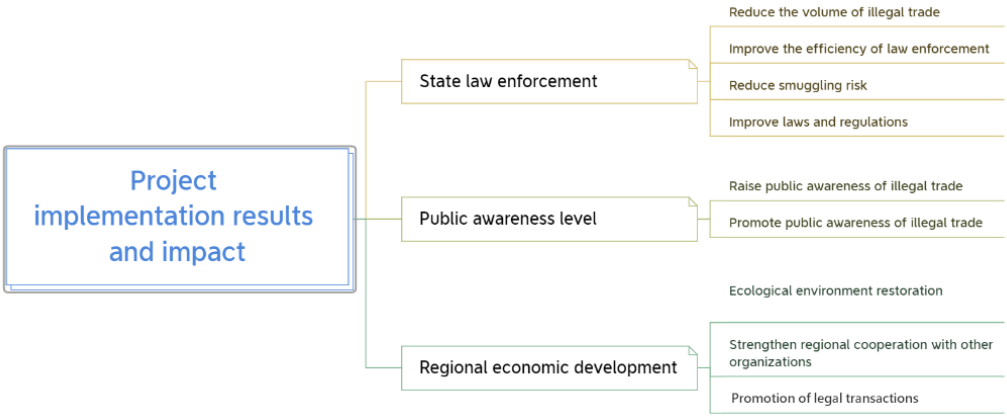

Figure 3: Results and impact of project implementation

4. Combined intervention model

To analyze the measurable impact on the illegal wildlife trade after executing the project, we could adopt a model of time series analysis and intervention analysis. Through time series analysis, we can observe the change trend of illegal wildlife trade over time, while through intervention analysis, we can intuitively see and evaluate the significant change in the trade volume before and after the implementation of the project.

Construction of a time series analysis model: Assuming that we have historical data on the amount of illegal wildlife trade, we can build a time series model to predict the future trend of trade volume. The time series model can be represented by the following autoregressive moving average (ARIMA) model:

$$Z = \varphi_1 Z_{t-1} + \varphi_2 Z_{t-2} + \ldots + \varphi_p Z_{t-p} + a_t - \theta_1 a_{t-1} - \ldots - \theta_q a_{t-q} \quad (3)$$

Where Z is the trade volume of the time point t, $\theta_1, \theta_2, \ldots \theta_q$, is the moving average parameter, and a is the white noise term.

Construction of the intervention model: an intervention model can be added to the time series model to assess the impact of the implementation of the project on the trade in illegal wildlife. The variable is 0 before the implementation of the project and 1 after the implementation. The intervention model can be expressed as follows:

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$$S_t^T = \begin{cases} 0, t < T \\ 1, t \geq T \end{cases} \tag{4}$$

$$Z = \omega_0 + \omega_1 I_t + ARIMA\,Model + \epsilon_t \tag{5}$$

To further determine these effects, we can do the following: we simulate the volume of illegal wildlife trade and visualize the impact of an intervention (possibly policy support, increased law enforcement) on trade volume. np.random. normal can be used to generate a set of random numbers, representing the amount of illegal wildlife trade. The set of random numbers has a mean of 50, a standard deviation of 10, and the same length as the date range. An intervention variable was created with 2024 and later years marked 1 (indicating intervention implementation) and previous years marked 0. For the period with an intervention variable of 1, by multiplying the trade volume by 0.8, the simulated intervention resulted in a 20% decrease in trade volume. As can be seen from the graph, the changes 5 changed after the implementation of the policy, and the trade volume decreased after the implementation of the intervention measures.

In the way of time series prediction, we take time as the horizontal axis and the vertical axis as the amount of illegal wildlife trade, as shown in Figure 4.

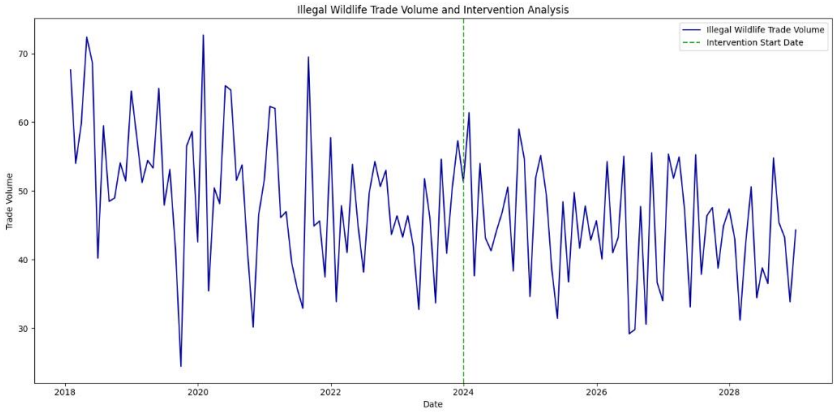

Figure 4: Changes in illegal wildlife trade after interference

We set the random number, and set the forecast time range on January 1,2018 to December 31, 2028, a monthly value, create random trade volume data, set the average and standard deviation, and set an intervention sign from 2024 to implement the intervention with the green dotted line, obviously, 5 years after the implementation of the intervention of the change of illegal trade (blue broken line) with time is gradually declining, from the other hand reflects the project on the illegal wildlife trade. Therefore, with the successful implementation of the project, we can intuitively see the measurable standard of the illegal wildlife trade. This model means that after the successful implementation of the project, the scale of the illegal trade will decrease over time, until it drops to zero.

5. Probabilistic model and sensibility analysis

5.1 Probabilistic model

According to all the previous analyses, the project is highly likely to achieve the expected goals. At the same time, there are also some conditions or events that may affect the project, such as political instability, capital shortage, technical problems, etc. To reduce the risk, we will closely monitor the progress of the project, and adjust and optimize according to the actual situation.

As for the possibility of the project to achieve the expected goal, we can evaluate the relevant mathematical model of the probability analysis. Specifically, we can establish a probability model, consider various uncertainty factors in the project implementation, and quantify the impact of these factors on the expectation of the project and the goal. To this end, we assume a simplified probabilistic model that considers five key factors of project implementation, such as policy support, resource input, implementation capacity enhancement, organization and cooperation, and education and publicity. Next, we can represent the degree to which these factors contribute to project success by the probability

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distribution.

Let P be the probability that the project achieves the expected goal, which can be expressed as:

$$P = P_1 \times P_2 \times P_3 \times \ldots \times P_n \tag{6}$$

Where the contribution probability of the five key factors of policy support, resource input, implementation ability, organization and cooperation, and education and publicity to the success of the project is P_1, P_2, P_3, P_4, P_5.

Next, based on the background sensitivity analysis, we can identify some conditions or events that may cause disproportionate assistance or damage to the project's ability to achieve its goals, which may include political aspects, international cooperation, resource input, public participation, and so on. Suppose we represent these factors as further split into: $F_1, F_2, \ldots F_n$ then the contribution of each factor to the project can be divided:

$$P_i = \frac{favorable\ \ factors}{favorable\ \ factors + unfavorable\ \ factors} \tag{7}$$

Among them, the favorable factors and the unfavorable factors are evaluated and quantified according to the situation. Through such a mathematical model, we can quantitatively evaluate the possibility of the project to achieve the expected goal, and identify which factors play a key role in the success of the project. Further, through a sensitivity analysis, we can identify which factors may cause a disproportionate help or damage to the project's ability to achieve its goals.

We set five factors for policy support, resource input, execution ability, organization and cooperation, education and propaganda, each factor corresponding to the favorable probability of 0.9, 0.9, 0.95, 0.85, 0.95, using python to calculate the probability of the expected goal, and through sensitivity analysis, calculate the contribution of each factor to the success of the project.

We can see that the probability of the project to reach the expected target is about 0.6214, which is a standard value. The project is based on reality and considers the influence of many other factors. On this basis, the feasibility of its implementation is relatively high. Next, further sensitivity analysis, which can help us understand the extent of different factors on project success and identify possible risks and opportunities. We can observe the change in the overall success probability of the project by adjusting the impact probability of each strategy. Let P_{a} as the new probability of success after adjusting a decision, we can say the formula is:

$$P_{\mathrm{a}} = P_1 \times \ldots \times (P_{\mathrm{i}} + \Delta P_i) \times \ldots \times P_n \tag{8}$$

5.2 Sensibility analysis

Using python to achieve data visualization as shown in the figure below. We set the prob-ability adjustment parameter in the sensitivity analysis to 0.05, -0.1, 0.1, 0.1, 0.1, 0.05. This ex-ample can show the strategy factors affect the initial probability of the project through Figure 5. And help us intuitively understand the impact of different strategies and the results of the sensitivity analysis.

In practical application, we also need to adjust the model and parameters according to the specific situation, conduct different analysis of different group situations, and present visual maps to show our project to groups. For example, the impact of the choice and combination of strategies on the project goals can be huge. If a key strategy is replaced or no longer implemented, or a new strategy is introduced, these changes may have a disproportionate impact on the project, and then we go on for further analysis.

In background sensitivity analysis, factors that can significantly influence the achievement of project goals may affect project success or failure in a disproportionate manner. To this end, we can analyze which conditions or events may cause disproportionate help or damage to the project in terms of additional conditions or event requirements, policy combination, and possible external interference.

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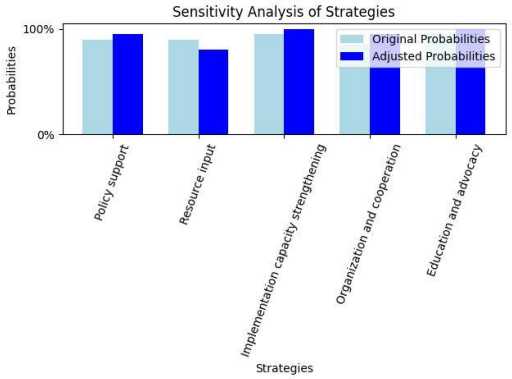

Figure 5: Analysis of factor 1

We can analyze that for additional conditions or event requirements, if the demand for certain resources increases suddenly and greatly, while other resources remain unchanged or decrease, this may cause disproportionately damage to the project, because the lack of resources may limit the progress or success of the project. In actual projects, external factors (such as market changes, policy adjustments, natural disasters) may also have unforeseen and disproportionate effects on the project. For example, changes in policy may affect the effectiveness of resource access or project strategies. In conclusion, factors such as additional conditions or event requirements, adjustment of strategy combinations, external interference, and probabilistic adjustment in sensitivity analysis can all cause disproportionate assistance or damage to a project's ability to achieve its goals. These factors should be carefully considered and strategies developed to mitigate potential risks.

6. Conclusions

Focusing on the impact of different groups' behaviors on illegal wildlife trade, this paper conducts modeling and mathematical analysis. After the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) access to provide numerical information. The predictions and analyses of the results generated after the actions are taken are made through dynamic mathematical modeling and the combined intervention model, respectively. The introduction of probabilistic modeling and sensitivity analysis proved that the model has some stability and robustness. The prediction results of the model show that different groups can significantly reduce the scale of wildlife trade after investing more in key aspects such as policy support, resource input, implementation capacity enhancement, organization and cooperation, and education and publicity. This approach, it helps to understand the interactions between the illegal trade in plants and animals with other areas of influence, offering unlimited possibilities for developing more comprehensive and effective solutions.

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