
Global Sentinel: Disrupting illegal Wildlife Trade Networks**Summary**

The global illegal wildlife trade presents substantial environmental and societal challenges, underscoring the critical need for intervention. This paper proposes a project aimed at dismantling the illegal wildlife trade and improving the global biodiversity.

For Model I, we construct a global illegal wildlife trade network. By calculating the **Flow betweenness** and **Fragmentation index** of each country within the network, we identify five key countries: **China, United States, Germany, Philippines and Kenya**. Effective measures against these key countries can result in the cessation of more than **82.5%** of the global illegal wildlife trade volumes. In order to better implement the measures, our team choose **Traffic** as the ideal client for the "Destroying Illegal Wildlife Trade Networks (**DIWTN**)" project since Traffic dedicates to fighting the illegal trade of wildlife. Besides, Traffic will help us oversee the implementation of our project.

For Model II, we first improve the **Data Envelopment Analysis** to evaluate the efficiency of national project implementations via the **Malmquist productivity index**. Then, in view of the differences in the efficiency of project implementation in different countries, the Seizure to Occurrence Ratio (SOR) is introduced as a metric to evaluate the impact of the project. We utilized **differential equations** to predict the SOR, the results show that SOR will reach **0.971** in 2028. Further, we examine the project's effects on the global illegal trade volumes, indicating a notable decrease among key countries. Finally, we analyze fluctuations in project implementation efficiency (between 10-20%) in different countries to explore the impact of these fluctuations on our expected project outcomes. The findings indicate that key countries exhibit initial stability, succeeded by a significant influence in subsequent years. This leads to a recommendation for Traffic to enhance supervision during the crucial two-year period.

For Model III, given the current state of global biodiversity, which is under significant threat from climate change and other anthropogenic factors, our project aims to effectively improve this critical situation. Firstly, the **Entropy Weight Method, Analytic Hierarchy Process and an optimization model** are applied to determine weights. Then, Utilizing **TOPSIS method**, we calculate each country's biodiversity index, illustrated in Figure 10. Subsequently, we employ **Hierarchical clustering** to categorize 53 countries into four tiers based on their biodiversity index. According to the clustering results, we calculate Global Biodiversity Index (**GBI**) for the period 2000-2020. In addition, considering the interaction of illegal wildlife trade with other secondary indicators, we develop regression models. Finally, based on the results of Model II, we recalculate the GBI and forecast its value in 2028 using **ARIMA**, predicting a rise to **0.8** five years post-implementation.

Keywords: global illegal wildlife trade network, Fragmentation index, Flow betweenness, Malmquist productivity index, global biodiversity

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1 Introduction

1.1 Background

The global illegal wildlife trade presents substantial environmental and social challenges. It not only endangers species of paramount ecological importance but also inflicts deleterious effects on biodiversity, thereby impacting the vitality and stability of ecosystems. In light of these conditions, the imperative for developing a project dedicated to fighting illegal trade in wildlife and plants is underscored.

1.2 Restatement

Given the background information and constraints outlined in the problem statement, the subsequent tasks must be completed:

- **Task 1:** To fight illegal wildlife trade, the first step is to select a capable client for implementation.
- **Task 2:** Demonstrate the project's rationale and effectiveness through data analysis and relevant research findings.
- **Task 3:** Analyze the additional rights and resources required by the client for project implementation.
- **Task 4:** Examine the impact of project implementation on illegal wildlife trade and indicate what analyses were done.
- **Task 5:** Assess the likelihood of achieving the project's intended goals and its implications for project implementation.

1.3 Our Work

Initially, we calculate flow betweenness to identify the trade center and calculate fragmentation index to identify the key participants. Based on the results of calculations, we select five key countries within the illegal wildlife trade network and choose our client, Traffic.

Then, we analyze the economic conditions, education levels, and the completeness of the legal systems of the key countries we selected, considering these factors as characteristics of their roles in the trade network. Next, based on the characteristics of the key countries within the trade network, we develop projects from various dimensions. Finally, we assess the impact of implementing these projects using the Malmquist productivity index and SOR trends.

Subsequently, we develop a global biodiversity evaluate model to quantify national biodiversity levels. The model includes five key indicators and eleven secondary indicators. We use a combination of EWM, AHP, and CV methods to determine the indicator weights, and modified key indicators weights through an optimization algorithm. Then, the biodiversity index (BI) of each country was evaluated using the TOPSIS method. For a holistic evaluation of global biodi-

versity, 53 countries were categorized into four groups using hierarchical clustering, leading to the calculation of the global biodiversity index (GBI). To evaluate the project's impact on biodiversity, we conducted correlation and regression analyses on the model's indicators and illegal wildlife trade (IWT), among other related factors. We used an ARIMA model to predict changes in GBI five years after project implementation. Comparative analysis of GBI and BI in key countries show significant enhancements, affirming the project's beneficial effect on GBI.

Finally, we write a memo to provide Traffic with the process and key points of the “DIWTN” project. It also explains why the project is right for them.

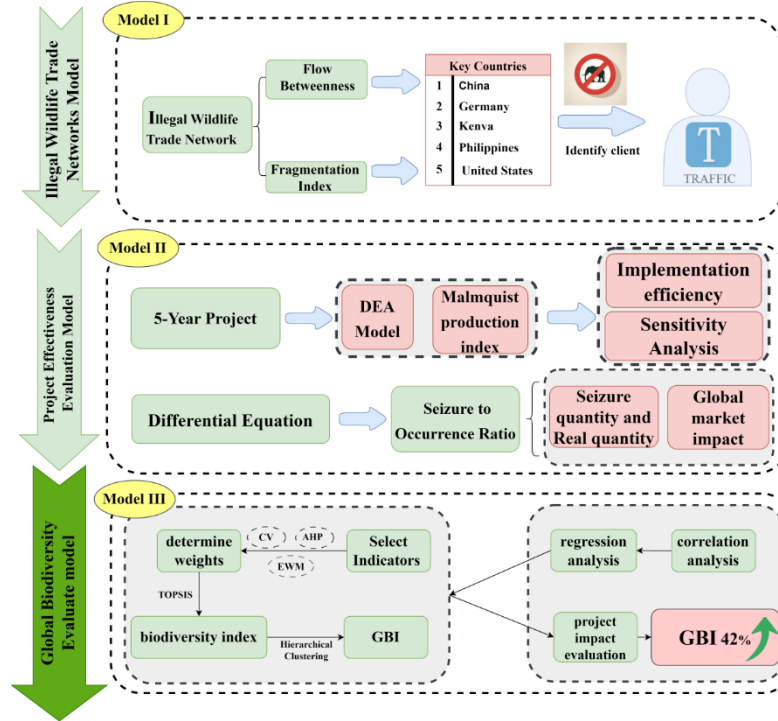


Figure 1 Our work

2 Model Preparation

2.1 Assumptions and Justifications

To streamline our approach, we adopt the following assumptions, each rigorously justified:

Assumption 1: The statistical data sourced from various websites is deemed credible and reliable.

◆ **Justification:** Our dataset includes contributions from international organizations and national statistical bureaus across multiple countries, ensuring the data's authenticity and dependability.

Assumption 2: The production possibility sets of countries conform to the standards of constant returns to scale, triviality, convexity, conicity, inefficiency, and minimality.

◆ **Justification:** This assumption simplifies the complexities of real scenarios, allowing

for the study of sustainability across different countries within a unified framework.

Assumption 3: The selected countries for our analysis are characterized by stable political, social, and economic frameworks, minimizing the likelihood of significant natural catastrophes or human-induced crises, such as wars, economic downturns, and terrorist activities.

- ◆ **Justification:** Our model simplifies by excluding the effects of various uncontrollable elements, including major natural and human-induced disruptions.

Assumption 4: Our client can establish good partnerships with various countries and oversee the implementation of projects.

- ◆ **Justification:** The client's supervision of project implementation ensures that the project progresses smoothly towards its intended goals.

2.2 Notations

The primary notations used in this paper are listed in Table 1.

Table 1 Notations

Symbol	Description
Fb	Flow between
FI	Fragmentation index
SOR	Seizure to Occurrence Ratio
Se	Seizure quantity
Re	Real quantity
Efficiency	Project efficiency
Sg	Seizure quantity's global share
Rg	Real quantity's global share
BI	Biodiversity index
GBI	Global Biodiversity index

2.3 Data Pre-processing

Due to the limitations of our data sources, the data we collect exhibits missing values to varying extents. To mitigate this, we employ methods to impute missing data:

- In instances where data points preceding and succeeding a missing value are available, we interpolate using the average of these adjacent values.
- For data exhibiting a stable trend, we employ cubic spline interpolation for filling in the values.
- In instances where a country's dataset is incomplete for all years, the missing values are imputed using the mean values from the entire dataset, taking into account relevant indicators and the specific context of the country with missing information.

3 Model I: Illegal wildlife trade networks

Illegal wildlife trade is an industry that sees thousands of wild animals and related products

transported globally every day, including food, pets, medicines, clothing, hunting souvenirs, and religious talismans. The intricate network structure of illegal wildlife trade often involves crucial intermediary hubs used for bulk or split shipments, changing modes of transportation, and manufacturing wildlife byproducts.

Based on relevant data from Routes ^[6,7], we analyze the wildlife trade network from 2009 to 2021. In section 3.1, we calculate flow betweenness to identify the trade center. In section 3.2, we calculate fragmentation index ^[3] to identify the key participants. Based on the results of sections 3.1 and 3.2, we select five key countries within the illegal wildlife trade network and choose our client, Traffic.

3.1 Flow betweenness

We have constructed a wildlife trade network based on trade routes and seizure frequencies. In this network, countries are represented as a set of nodes, denoted as $X = \{x_1, x_2, \dots, x_n\}$, and the number of seizures between countries is used as the weight, denoted as w . The trade routes, denoted as S_{ij} , represent a country i using its j -th route as a transit country. For example, in May 2015, Kenya seized 12 kilograms of ivory, and the trade route was Kenya-Dubai-China. Based on this, we increase the node weight for the Kenya to Dubai route and the Dubai to China route by 1 each. The formula for calculating Flow Betweenness centrality is as follows:

$$Fb_i = \sum_{j=1}^{|S_i|} \min w_{S_{ij}} \quad (1)$$

$w_{S_{ij}}$ represents the collection of weights for country i on its j th route, and $|S_j|$ represents the number of routes for country j .

We have listed the top 5 countries ranked by Flow betweenness, which often serve as transit countries for illegal wildlife trade. The results are shown in Table 2.

Table 2 Flow betweenness

Country	Philippines	Indonesia	China	United States	Kenya
Fb	183	177	152	103	96

3.2 Fragmentation index

Flow betweenness prioritizes the identification of intermediary countries as pivotal nodes. However, the origins of illegal wildlife trade often exhibit diversity, encompassing smuggling cases of specific species, such as seahorses, that may originate from multiple countries. Conversely, the number of destination countries is typically more restricted. To improve the determination of crucial destinations, we calculate the fragmentation index. The fragmentation index quantifies the proportion of the network that becomes isolated upon the exclusion of key participants. To refine the identification of these key participants, we formulate an optimization model aimed at maximizing the network's isolation proportion upon the removal of K participants.

$$\max FI_K = 1 - \sum_{i>j} \frac{1}{d_{ij}} \frac{2}{n(n-1)} \quad (2)$$

FI_k represents the fragmentation index when removing K countries, d_{ij} represents the minimum number of edges from country i to country j , and n represents the number of remaining countries after removing K countries.

We find that if we remove four countries (China, Germany, Philippines, United States) from the global illegal wildlife trade, over 80% of the trade network becomes isolated.

Table 3 Fragmentation index

K	Country	FI
1	Philippines	0.745
2	China, United States	0.771
3	China, Germany, United States	0.799
4	China, Germany, Philippines, United States	0.825

3.3 Select the client

Considering the Flow Betweenness and the corresponding Fragmentation Index for each country, we have identified Kenya, China, Germany, the Philippines, and the United States as key countries in the effort to fight illegal wildlife trade. **Figure 2** illustrates the trade networks involving these key countries, emphasizing their significant involvement in a substantial volume of trade activities. We have selected Traffic as our client, which is a leading non-governmental organization dedicated to ensuring the legal and sustainable trade of wildlife species for the benefit of the Earth and humanity. Traffic's work and collaborations have had a significant impact on reducing illegal wildlife trafficking and promoting the legal and sustainable trade of wildlife species, ultimately benefiting the Earth and humans. In the following section, we will introduce the project we have developed for Traffic, present the project's vision, and assess the project's implementation outcomes.

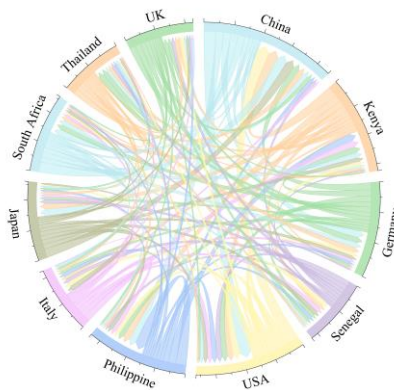


Figure 2 Key Countries illegal wildlife trade network

4 Model II: Project Effectiveness Evaluation Model

In this section, we first analyze the economic conditions, education levels, and the completeness of the legal systems of the key countries we select, considering these factors as characteristics in the trade network. Next, according to the characteristics of pivotal countries in the trade network, we propose a project entitled "Disrupting Illegal Wildlife Trade Networks." Finally, we evaluate the project's impact on Seizure to Occurrence Ratio (SOR) and the global illegal wildlife trade.

4.1 Characteristics of the Trade Network in Key Countries

Illegal wildlife trade mainly encompasses mammals, birds, reptiles, ivory, and marine species.^[10] In order to provide our client with feasible and rational projects, we first consider the primary illegal wildlife trade categories in key countries and then conduct individual analyses for each country.

We have calculated the proportion of global illegal wildlife trade for each category in key countries from 2009 to 2021, and the specific results are as follows:

Table 4 Percentage of each category in global

Category	Birds	Ivory	Mammals	Marine Species	Reptiles
Percentage of global	0.11	0.81	0.18	0.17	0.46

The selected key countries primarily engage in the trade of ivory and reptiles, which comprises a significant portion of global trade. Our projects will primarily focus on analyzing these two categories. Below is a specific analysis for each country:

Philippines: Philippines plays a significant role in illegal wildlife trade, with an estimated annual trade value of approximately \$1 billion, encompassing market values of wildlife and their resources, ecological impacts, habitat destruction caused by poaching, and potential losses in ecotourism revenue^[9]. From June 2003 to September 2021, the Sulu-Celebes Seas region seized over 25,000 live animals and more than 120,000 tons of wildlife from illegal trade^[8]. Based on the analysis in section 3.1, we will study the Philippines as an intermediary country in illegal wildlife trade.

China: Between 2003 and 2021, China was responsible for **70%** of the global ivory trade, with **96%** of imports, and 42% of the global reptile trade, representing **84%** among key countries with **97%** of imports, making it a typical demand country for illegal wildlife trade. Locations where illegal wildlife trade has been seized include Hong Kong, Quanzhou, Macau, Guangzhou, and Xiamen.^[7] Transport methods include air freight, checked luggage, and mail. Besides, China serves as an intermediary country in illegal wildlife trade, particularly through Hong Kong and Taiwan.

Germany: Germany has been actively committed to fighting illegal wildlife trade. Germany has organized forums addressing the impact of illegal wildlife trade on sustainability many

times ^[11]. These forums emphasize cross-sectoral law enforcement cooperation within Africa, between Africa and China, including the implementation of anti-poaching measures through monitoring technology in Serengeti National Park. ^[16] However, due to its central European location and developed logistics and transportation networks, Germany serves as a hub for illegal wildlife trade.

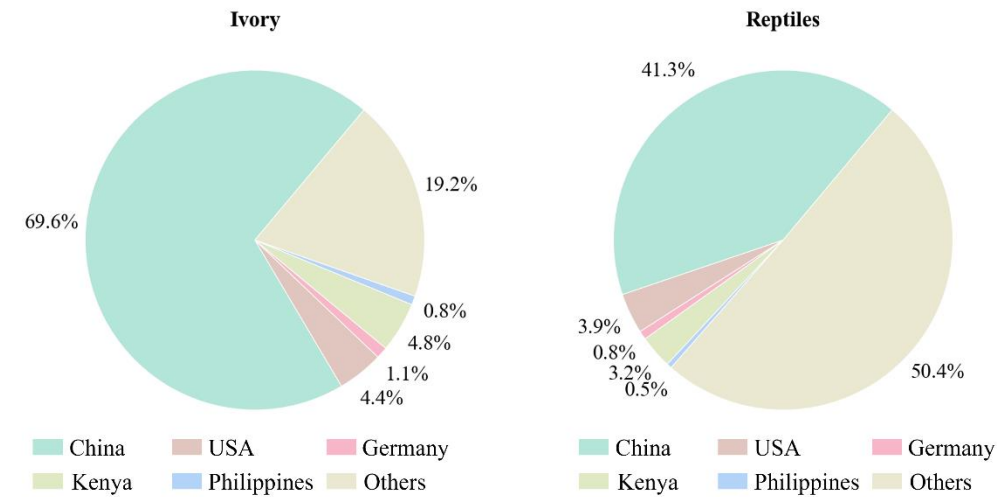


Figure 3 Ivory&Reptiles

United States: As one of the world's largest wildlife markets, the United States meticulously records all declared wildlife trade, including species not listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The number of non-CITES species imported into the United States is 11 times that of the listed species, totaling 8.84 million individuals, with over a quarter facing conservation risks ^[14]. Specifically, the import of Asian water dragons, a vulnerable species, has exceeded 575,000 individuals over the past decade from Vietnam to the United States, highlighting the significant threat posed to species conservation due to global trade regulation deficiencies ^[12].

Kenya: Kenya is known for its rich wildlife resources, particularly African elephants and endangered black rhinos. However, between 2007 and 2017, Kenya ranked third globally in ivory seizures, trailing only China and the United States, making it the most ivory seizures in Africa. ^[13] Kenya's strategic geographic location, bordering the Indian Ocean and multiple neighboring countries involved in wildlife trafficking activities, makes it an significant transit point for illegal wildlife products.

4.2 Destroying Illegal wildlife trade networks

We propose a project titled "Destroying Illegal Wildlife Trade Networks (DIWTN)" which develops strategies to the specific characteristics and current state of illegal wildlife trade within targeted nations.

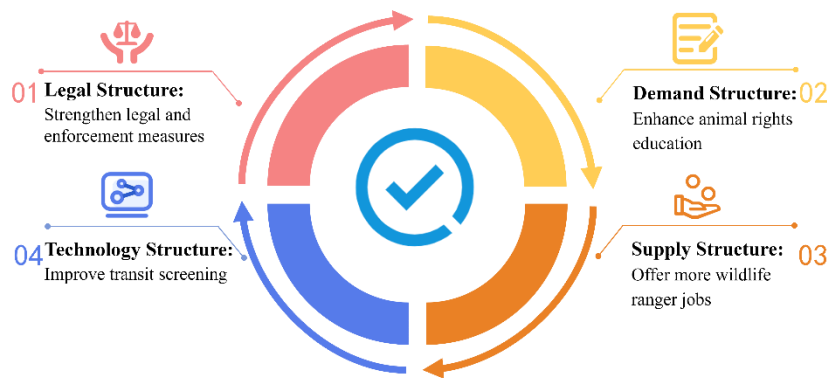


Figure 4 the framework of DIWTN

1. Illegal wildlife trade not only threatens the survival of many endangered species but also disrupts natural ecosystems, posing significant challenges to the legal protection and sustainable use of wildlife. By making stricter laws and increasing penalties for illegal activities, we can effectively deter those individuals considering or participating in illegal wildlife trade. This includes not only imposing higher fines and longer prison sentences but also strengthening international cooperation to combat transboundary illegal trade networks. relevant laws and policies.
2. By conducting extensive education, we can raise public awareness of ecological ethics. Emphasizing the interdependence and symbiotic relationship between humans and the natural world, as well as the destructive impact of the illegal trade in exotic wildlife on ecological balance. Through collaboration with the Central Buddhist Association of Vietnam, Traffic has successfully altered the perceptions of 60% of the population through 12 Buddhist lectures, achieving significant results. China and the United States can strengthen wildlife rights education to reduce demand for wildlife products. Germany can host more forums on the impact of illegal wildlife trade on sustainable development and support educational activities in Kenya, Ethiopia, South Africa, and Mozambique. To effectively advance the implementation of the project, Traffic can be responsible for creating promotional posters and arranging professional speaking teams.
3. Many African and poor countries rely on illegal wildlife trade for their livelihoods. Providing suitable employment opportunities can significantly reduce their involvement in illegal wildlife hunting. Serving as wildlife rangers can not only prevent new poachers from joining but also help with wildlife protection, reducing the supply of endangered wildlife. In order to maintain transparency and efficiency in the project, and to prevent any corrupt practices from interfering with project progress, Traffic retains the right to strictly supervise the allocation of funds. This is also in line with promoting Kenya's 2030 Vision Plan.
4. Most customs and law enforcement officials currently have limited screening capabilities during transit, largely shifting the responsibility for detection to the origin and destination locations. In addition, short dwell times limit the effective screening of transit passengers,

baggage, air cargo, and mail. Kenya, which relies partly on sniffer dog teams, can intercept smuggled wildlife during transit, reducing screening times and enhancing efficiency. Increasing screening efforts in transit countries along trade routes, particularly in the Philippines and China, and introducing machine learning algorithms such as image recognition, can further improve screening efficiency.^[4] To ensure the effective operation of technical equipment, Traffic has the authority to conduct regular maintenance and inspections, ensuring the smooth implementation of the project.

We outline our goals and measures for each stage of the project, as depicted in Figure 5.

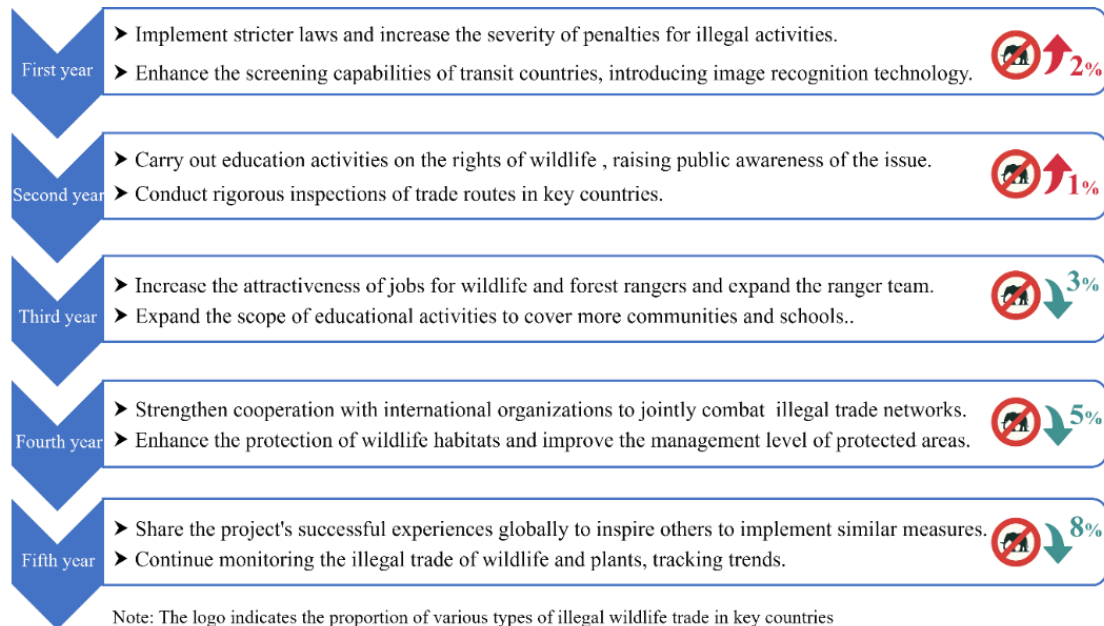


Figure 5 Ideal Vision for project

4.3 Evaluation of the project efficiency

We have improved the traditional DEA (Data Envelopment Analysis) model to calculate the Malmquist productivity index, thereby assessing the impact of projects on the sustainability of various countries.

Subsequently, Section 3.1 will introduce the traditional DEA (Data Envelopment Analysis) model. Section 3.2 will detail the computation of the Malmquist Productivity Index, as outlined in subsection 4.3.2. In Section 3.3, we will evaluate the efficiency of project implementation in key countries based on the results calculated in Section 3.2.

4.3.1 DEA model

Data Envelopment Analysis (DEA) is a non-parametric approach in operations research, employed for assessing the production efficiency of Decision-Making Units (DMUs) with similar configurations. The DEA model is predominantly utilized for estimating efficiency in scenarios involving multiple inputs and outputs, in comparison to a cohort of analogous units. The CCR model represents a quintessential example within DEA.

$$\begin{aligned} \max \theta_i &= \frac{\sum_{m=1}^r b_{im} u_m}{\sum_{n=1}^s a_{in} v_n} \\ \text{s.t.} \quad &\begin{cases} \frac{\sum_{m=1}^r b_{im} u_m}{\sum_{n=1}^s a_{in} v_n} \leq 1, j = 1, 2, \dots, N \\ u_m, v_n \geq 0, m = 1, 2, \dots, r, n = 1, 2, \dots, s \end{cases} \end{aligned} \quad (3)$$

where a_{in} represents the n -th input of the i -th evaluation object, b_{im} represents the m -th output of the i -th evaluation object, u_m represents the weight of the m -th output, v_n represents the weight of the n -th input. θ_i represents the efficiency of the i -th evaluation object.

4.3.2 Malmquist Productivity Index

The CCR model primarily serves static efficiency analysis, assessing the efficiency of DMUs at a single time point. However, our objective is to evaluate a nation's level of sustainable development, which necessitates a dynamic assessment. Since the CCR model primarily focuses on efficiency under a given technological level, we have introduced the Malmquist Productivity Index.^[2] This index allows us to measure productivity changes over time, offering a dynamic efficiency assessment that distinguishes between technological and efficiency changes. Consequently, it provides a more comprehensive analysis of sustainability.

Output-Oriented Distance Function

$$D^t(a_i^t, b_i^t) = \frac{1}{\theta_i^t} \quad (4)$$

$D^t(a_i^t, b_i^t)$ represents the distance function at time t for (a_i^t, b_i^t) , where a_{it} , b_{it} denote the inputs and outputs of the i -th evaluation object at time t , θ_{it} represents the efficiency of the i -th evaluation object at time t .

The change in efficiency from time t to time $t+1$ at the t -time level

$$M_i^t = \frac{D^t(a_i^{t+1}, b_i^{t+1})}{D^t(a_i^t, b_i^t)} \quad (5)$$

Malmquist Index

$$MI(a_i^t, b_i^t, a_i^{t+1}, b_i^{t+1}) = (M_i^t \times M_i^{t+1})^{1/2} \quad (6)$$

Note: If $MI > 1$, efficiency improves; if $MI = 1$, efficiency remains unchanged; if $MI < 1$, efficiency declines.

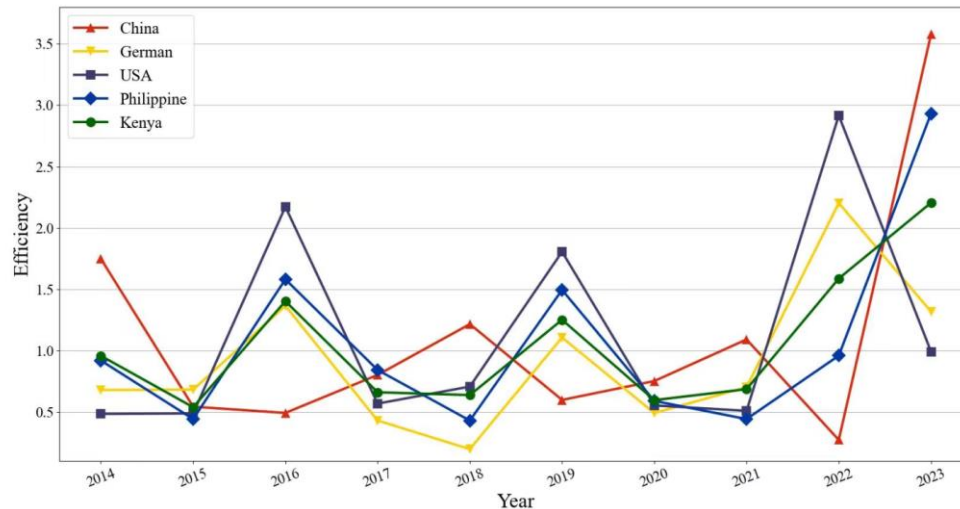
4.3.3 Results of efficiency

First, let's define inputs and outputs, and then calculate the efficiency of each key country. Inputs and outputs are shown in Table 5.

Table 5 Input and Output

Type	Symbol	Description
Input	SPI	Species Protection Index ¹
	CT	Conservation target (percent area)
Output	RTO	Reduction of Trafficking Origin number
	RTD	Reduction of Trafficking Destination number

We calculate the Malmquist Productivity Index of key countries from 2014 to 2023, as shown in Figure 6.

**Figure 6 Malmquist Productivity Index of key countries**

Nations typically implement projects on a regular basis. As illustrated in Figure 6, the efficiency of project implementation across countries exhibits a cyclical trend. Therefore, we utilized data from the past five years to assess the efficiency of project implementation in various countries over a five-year period. The detailed outcomes are presented in Table 6.

Table 6 Efficiency of project

Countries	2024	2025	2026	2027	2028
China	0.597	0.751	1.09	0.271	3.578
German	1.106	0.49	0.701	2.202	1.317
USA	1.805	0.552	0.508	2.916	0.991
Philippine	1.494	0.589	0.441	0.958	2.932
Kenya	1.2505	0.5955	0.685	1.58675	2.2045

4.4 Impact of project implementation

In this section, we utilize differential equations to assess the impact of project implementation on the Seizure to Occurrence Ratio (SOR). Subsequently, we examine the influence of the project on the global market share of ivory trade between China and Kenya, as well as the share

¹ Species Protection Index reflects how effectively protected areas safeguard habitats and support the health and survival of species and their populations.^[19]

of reptile trade between China and the United States. Finally, we conduct a sensitivity analysis to explore the effects of external events and uncertain factors on policy implementation.

4.4.1 the impact of project implementation on SOR

The data utilized by the Routes initiative is derived from official reports provided by governmental agencies, international organizations, collaboration with partner networks, and media coverage. Our data spanning from January 2005 to July 2017 reveals that media reports significantly underrepresent the number of seizures, with 78% of seizures not reported.^[5] The discrepancy in the actual number of illegal wildlife trade incidents, which remain largely undetected, can be attributed to several factors, including inadequate customs enforcement and corruption issues. To quantify the ratio of the number of seizures to the actual number of illegal transactions, we define a metric termed the Seizure to Occurrence Ratio (SOR), calculated as follows:

$$SOR = \frac{Se}{Re} \quad (7)$$

Se represents Seizure quantity, Re represents Real quantity.

Anupam Mukherjee et al. used mixed logistic regression for the prediction of crime data analysis^[15]. To investigate the impact of our project on the SOR, we have developed a differential equation model:

$$\begin{cases} \frac{d(SOR)}{dt} = r(SOR) \times SOR \\ SOR(0) = SOR_0 \end{cases} \quad (8)$$

In the initial stages of the project, aimed at enhancing enforcement requirements and efficiency, the success rate (SOR) is relatively low, but the growth rate is rapid. However, as the project progresses over time, there is a significant increase in the SOR, and the growth rate begins to slow down gradually.

$$r(SOR) = r_0 - a \times SOR \quad (9)$$

r_0 represents the initial growth rate. If $SOR = 1$, $r(SOR) = 0$.

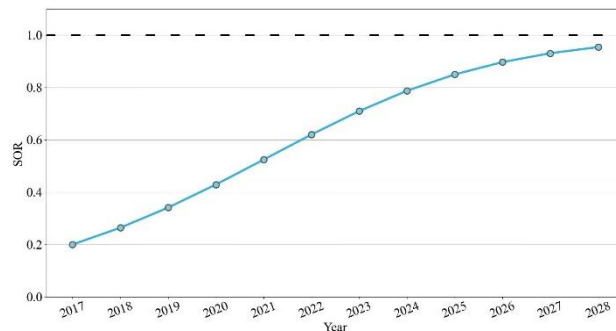


Figure 7 SOR

The results show that by 2028, the SOR will approach 1. Our project has the potential to significantly enhance enforcement standards and efficiency, thereby effectively reducing regulatory gaps in the illegal wildlife trade.

4.4.2 the impact of project implementation on the global market

Section 4.1 presents our analysis of the illegal wildlife trade in key countries. In Section 5.1, we calculate the efficiency of the project's implementation across various countries. In this subsection, to explore the global impact post-implementation of the project, we focus on the trade of Ivory and Reptiles. We aim to predict the proportion of Ivory and Reptiles trade volume from key countries in relation to the global total. This approach is used to assess the harm key countries pose to the global environment and the impact of our project's implementation on a global scale.

$$Sg_{t+1} = Sg_t \times (1 + S_t \times E_t)$$

$$Rg = \frac{Sg}{SOR} \quad (10)$$

Sg represents Seizure quantity's global share, Rg signifies Real quantity's global share, S denotes the project's impact and E represents the efficiency.

We calculate the annual proportion of Seizure quantity and Real quantity to the global total, as a result of project implementation. The outcomes are illustrated in Figure 8.

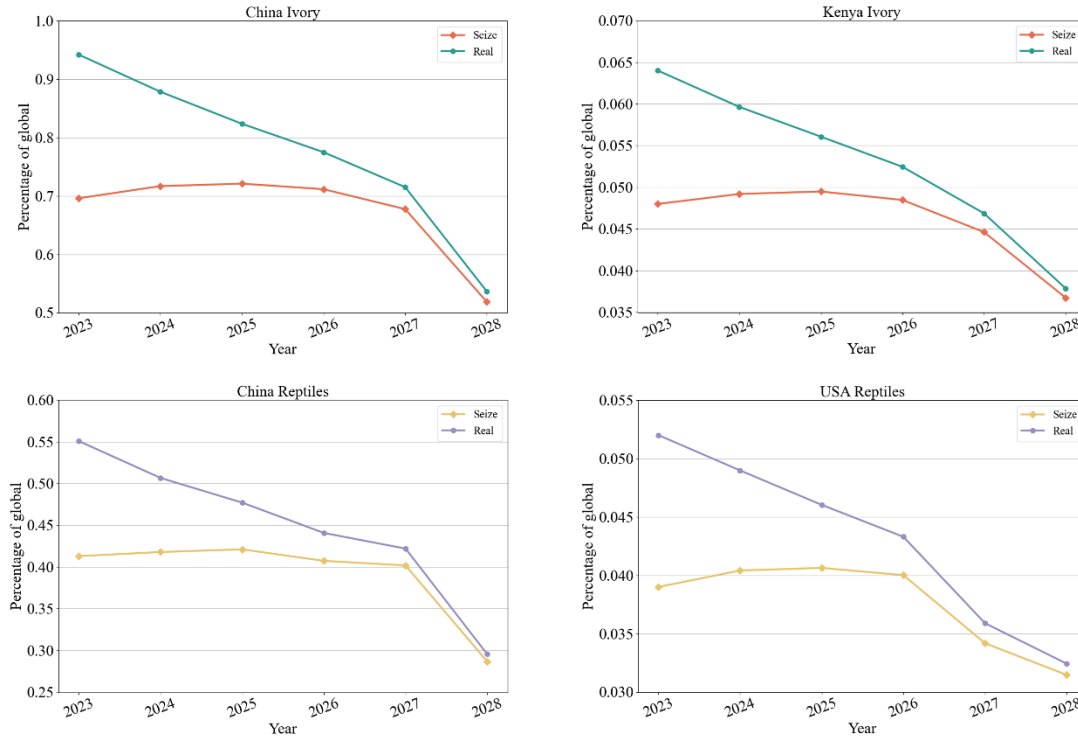


Figure 8 project implementation on the global market

In the initial stages of the project, there will be an improvement in customs enforcement ef-

efficiency and seizure rates, yet the overall trade volume will remain relatively stable. Consequently, over the past two years, there has been a slight increase in the seizure of ivory and reptiles in China, ivory in Kenya, and reptiles in the USA. As the project continues, the frequency of education and awareness campaigns increase, leading to more individuals involve in illegal wildlife trade gradually joining wildlife conservation ranger teams, thereby significantly reducing the quantity of illegal wildlife trade.

The impact level in each country annually is also closely related to the efficiency of project implementation. In 2027, the USA and Kenya demonstrate extremely high project execution efficiency, resulting in a substantial reduction in illegal wildlife trade. Similarly, in 2028, China's project execution efficiency will be also high, leading to a significant reduction in illegal wildlife trade. Despite the substantial reduction in illegal wildlife trade volumes across these countries, the overall decrease is relatively modest. Extending the duration of the project will potentially yield better outcomes.

4.4.3 Sensitivity Analysis

To evaluate the stability of our project implementation, we investigate the fluctuations in project execution efficiency across countries and their impact on the reduction of illegal wildlife trade. We conduct an analysis of efficiency fluctuations at $\pm 10\%$ and $\pm 20\%$ to study their effect on the annual proportion of significant illegal wildlife trades by key countries on a global scale.

The trade of ivory in China will have no impact on illegal wildlife trade from 2024 to 2027, but significant changes will be observed in 2028, as detailed in the figure below. The trade of reptiles in the USA will have a noticeable impact in 2027, while the trade of ivory in Kenya and the trade of reptiles in China also show significant changes in 2028. The Traffic organization can implement stricter management measures in these key years for the relevant countries to ensure the rigorous execution of the project and enhance the efficiency of its implementation.

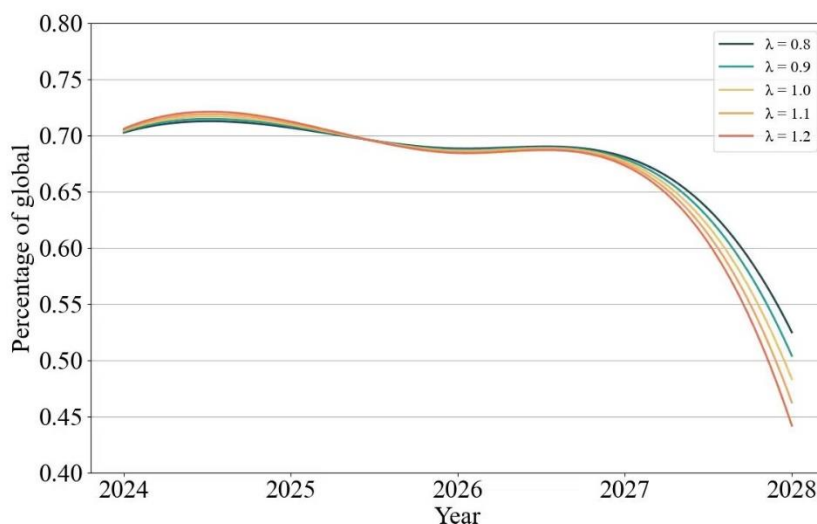


Figure 9 Sensitivity Analysis of China Ivory Trade

5 Model III: Global Biodiversity Model

5.1 Indicators and data normalization

Based on World Bank ^[17] and Our World ^[18] data and relevant literature, we have selected five key indicators to reflect the biodiversity index across different dimensions.

For each primary indicator, we have selected several secondary indicators. The specific details are shown in the table below.

Table 7 Indicators of global climate model

Level 1	Level 2	Description	Type
Pressure (Pr)	CO2	CO2 emissions as kt	−
	PM	PM2.5 air pollution (micrograms per cubic meter)	−
	IWT	illegal wildlife trade seizure quantity	−
Ecology (Ec)	FA	Forest area (% of land area)	+
	MDCI	Mountain Green Cover Index	+
Species (Sp)	AS	Animal species (kingdom Animalia) by country	+
	PS	Plant species (kingdom Plantae) by country	+
Response (Rs)	SHI	Species Habitat Index	+
	SPI	Species Protection Index	+
Protect (Pt)	CT	Conservation target (percent area) ²	+
	MB	Protected area coverage of marine key biodiversity areas	+

To enhance the accuracy of our dataset, we employ a normalization procedure across various dimensions to ensure uniformity in their respective scales. This process is executed as follows:

•Maximum normalization method

This method is used to normalize the benefit-type indicators, like Species Protection Index. The way to normalize the indicators is:

$$\tilde{x}_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)} \quad (11)$$

•Minimum normalization method

It is used to normalize the cost-type indicators, such as CO2 emissions as kt. The way to normalize the indicators is:

$$\tilde{x}_{ij} = \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)} \quad (12)$$

5.2 Calculation of the Weights for Indicators

Numerous methods exist for determining the weights of indicators. To improve the accuracy of our model, we have opted for a combined weighting approach to calculate the weights of all indicators. This method integrates the subjective Analytic Hierarchy Process (AHP) with the objective Entropy Weight Method (EWM) and the Coefficient of Variation Method (CVM). Given that AHP is more subjective and prone to the influence of decision-makers, and considering the high sensitivity of data which can lead to errors, we employ a hybrid approach. For primary indicators, we combine AHP with CVM, while secondary indicators utilize EWM to ascertain their weights, thereby increasing accuracy.

• Analytic Hierarchy Process

- Establish a hierarchy
- Construct the judgment matrix for primary indicators

$$A = (a_{ij})_{n \times n} \quad (13)$$

where A is judgment matrix; a_{ij} is the importance of x_i to x_j ; n is the number of primary indicators.

- Calculate weights and conduct consistency testing

• Entropy Weight Method

After normalization, we obtain new data. Then, we use the entropy-weight method to calculate the weights of the secondary indicators.

- Calculate the probability matrix P_{ij}
- Calculate the information entropy for each inferior indicator E_i

$$E_i = -\ln(n)^{-1} \sum_{j=1}^n P_{ij} \ln(P_{ij}) \quad (14)$$

- Calculate weights based on information entropy

$$w_i = \frac{1 - E_i}{\sum_{i=1}^k (1 - E_i)} \quad (15)$$

• Coefficient of Variation Method

The Coefficient of Variation Method leverages information from diverse indicators and determines the weight of each superior indicator through calculations, demonstrating its objectivity in weight assignment.

To mitigate the impact of differing units of measurement among various evaluation indicators, it is essential to measure the degree of variation in the values of these indicators using their respective coefficients of variation. The formula for the coefficient of variation of each indicator is as follows:

$$V_j = \frac{\sigma_j}{\bar{x}_j} \quad j=1,2,\dots,m \quad (16)$$

where V_i is the coefficient of variation of the superior indicators i , σ_i means the standard deviation of the superior indicators. Then the weight of each superior indicators comes to us:

$$W_j = \frac{V_j}{\sum_{j=1}^n V_j} \quad j=1,2,\dots,m \quad (17)$$

•Weight combination

Given the plethora of secondary indicators, the construction of the judgment matrix in the Analytic Hierarchy Process (AHP) encounters challenges. The entropy weight method, grounded in information entropy theory, serves as an effective tool for quantifying dispersion among indicators, leading to more accurate results. Consequently, this study opts for the entropy weight method to determine the weights for second-level indicators. Regarding first-level indicators, weights obtained from the Analytic Hierarchy Process are denoted as W_1 , while those derived from the coefficient of variation method are denoted as W_2 . We have established an optimization model aimed at minimizing the disparity among combined weights across various indicators, to prevent certain indicators from exerting excessive influence on the final outcome.

$$\begin{aligned} & \min \quad \frac{\sigma}{\bar{W}} \\ & s.t. \quad \begin{cases} W = \lambda W_1 + (1-\lambda)W_2 \\ W > 0 \\ \sigma = \sqrt{\frac{\sum (W - \bar{W})^2}{m}} \\ \lambda \in (0,1) \end{cases} \end{aligned} \quad (18)$$

We get the preference coefficient $\lambda = 0.56$.

Table 8 The Indicators' Weights

Level 1	weight	Level 2	weight
Pr	0.27	CO2	0.14
		PM	0.38
		IWT	0.48
Ec	0.18	FA	0.57
		MDCI	0.43
Sp	0.26	AS	0.65
		PS	0.35
Rs	0.14	SHI	0.78
		SPI	0.22
Pt	0.15	CT	0.57
		MB	0.43

5.3 Calculate the global biodiversity index

We select 53 countries, spanning various continents and at different stages of development, for our study to compute a biodiversity index (BI). Employing the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), we assess these countries, generating a biodiversity score for each. A higher score indicates better ecosystem diversity within the nation.

Firstly, we calculate the proximity of each indicator to the optimal and worst scenarios

$$D_i^+ = \sqrt{\sum_{j=1}^m w_j (X_j^+ - \tilde{x}_{ij})^2}, D_i^- = \sqrt{\sum_{j=1}^m w_j (X_j^- - \tilde{x}_{ij})^2} \quad (19)$$

where X^+ represents optimal solution, X^- represents worst solution.

Then, we calculate the biodiversity score for each country

$$BI_i = \frac{D_i^+}{D_i^+ + D_i^-} \quad (20)$$

The disparities in biodiversity indices among countries are illustrated in Figure 10. From the chart, it is evident that there are significant variations in BI across different nations. This underscores the imperative need for global ecosystem diversity.

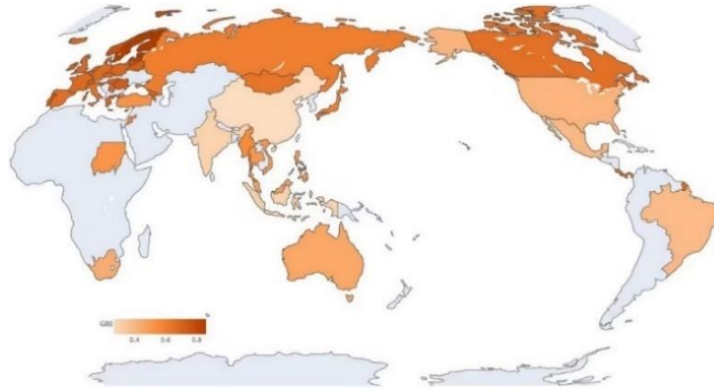


Figure 10 Biodiversity Index Map

Subsequently, we conduct hierarchical clustering on 53 nations, categorizing them into four groups: excellent, good, fair, and poor, as shown in Figure 11.

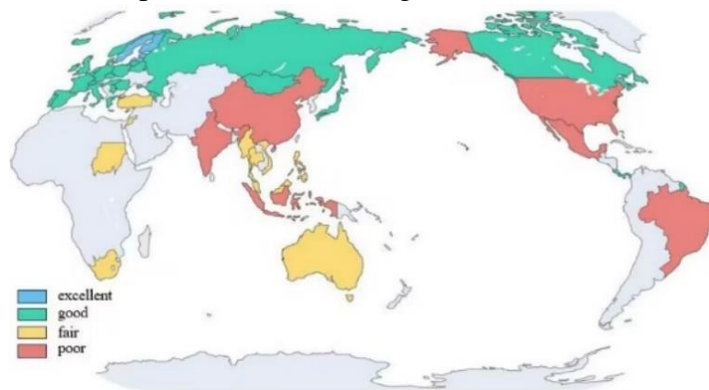


Figure 11 cluster map

Lastly, we define the Global Biodiversity Index. The specific calculation formula as follows:

$$GBI = \frac{BI_1 + BI_4}{2} \quad (21)$$

where GBI represents the global biodiversity index. BI_1 represents the average value of the climate index for countries with excellent biodiversity. BI_4 represents the average value of the biodiversity index for countries with poor biodiversity.

5.4 Impact of project on biodiversity

In Section 4, we investigate the impact of the project on illegal wildlife trade. Next, we will assess the impact of the project on biodiversity. Given that we have quantified the impact of our project on illegal wildlife trade in the previous section, to explore the relationship between illegal wildlife trade and other indicators within the assessment system, we analyze the indicators within the assessment system.

Firstly, given that we select 53 countries, with the sample size being close to 50, we use the Shapiro-Wilk and Kolmogorov-Smirnov tests to conduct a **normality test** on the assessment system indicators. The results of the normality test are as follows:

Table 9 normality test

p	Indicators
$p < 0.05$	FA, MDCl, SHI, CT, MB
$p > 0.05$	CO ₂ , PM, IWT, AS, PS, SPI

Then, we conduct a **correlation analysis**. For indicators that conform to a normal distribution, Pearson correlation coefficients are calculated, while for those that do not meet this criterion, Spearman correlation coefficients are computed. The correlation results for some indicators are illustrated in Figure 12.

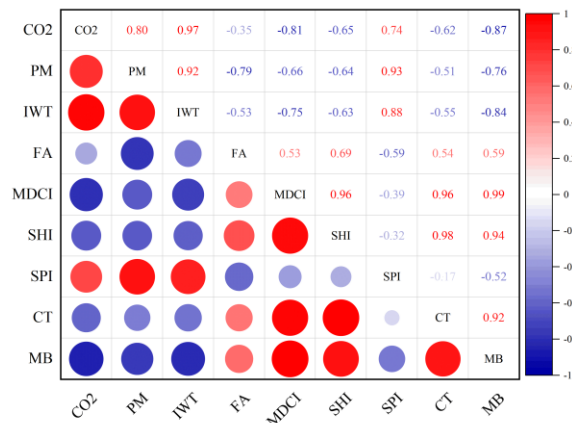


Figure 12 correlation heatmap

Additionally, we attempt regression analysis to explore the relationships among highly correlated indicators more effectively. We treat IWT as independent variables and the other indica-

tors as dependent variables. Table 10 presents the test results of MB, indicating that it passes significance tests. The results of other regression equations are as follows:

Table 10 Parameter tests for regression equations

	<i>t</i>	<i>p</i>
constant	20.322	0.002
LN(MB)	-5.739	0.029

$$\ln(MB) = -0.08IWT + 4.279$$

$$\ln(CO_2) = 0.012IWT + 13.211 \quad (22)$$

$$\ln(SPI) = -0.11IWT + 4.19$$

Finally, we re-enter the updated indicator data into our global biodiversity model to calculate the biodiversity index introduced by project for the period from 2000 to 2020.

The global biodiversity index before and after the project implementation are illustrated in Figure 13, indicating that the project's execution can enhance the global biodiversity index.

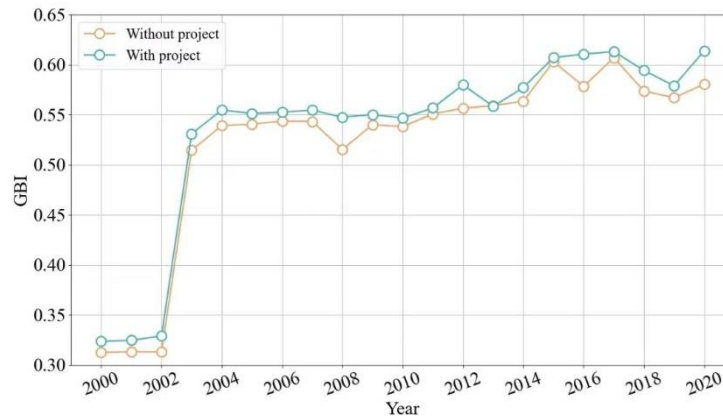


Figure 13 Comparison of global biodiversity index

In 2020, following the implementation of the project, the biodiversity index of key countries will improve. The biodiversity in Kenya and the United States significantly increase, China's biodiversity improves from “poor” to “fair”, and Germany's from “fair” to “good”.

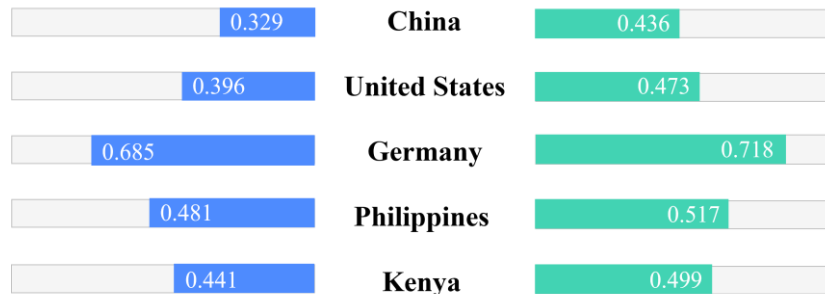


Figure 14 Comparison of biodiversity index in key countries

To further explore the future impact of the project implementation and changes in the global biodiversity index after the five-year plan, we use ARIMA model to predict the global biodiversity index for the upcoming years. The results suggest that after five years of project implementation, the global biodiversity index will reach **0.8**, significantly enhancing global biodiversity.

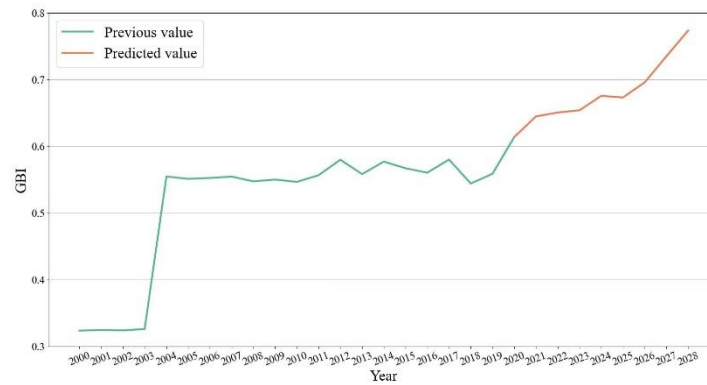


Figure 15 Predicted global biodiversity index

6 Strengths and Weaknesses

6.1 Strengths

1. We not only investigate the influence of our program on the illegal wildlife trade, but also evaluate its impact on ecological diversity.
2. To identify key countries within the illegal wildlife trade network, we employ various methods including Flow betweenness and Fragmentation index.
3. We employ a suite of models including EWM, CV, AHP, DEA, hierarchical clustering, ARIMA and differential equation and ensure comprehensive and accurate analysis,
4. We develop an optimization model to determine the optimal combination of weights for CV and AHP.
5. We assess the efficiency of countries to measure differences in their project implementation rates.

6.2 Weaknesses

1. In our model, unforeseen events, including natural disasters and man-made destructive incidents, are not taken into account.
2. We conduct research exclusively on the major illegal trade species in key countries, without encompassing all species. Nevertheless, our model can be applied to other species.
3. We use the efficiencies of the first five years for each country as the efficiency of program implementation, based on the cyclical trend of the individual efficiencies over the last 10 years.

Memo

To: Traffic

From: Team #2409853

Date: February 5, 2024

Subject: Proposal to Combat Illegal Wildlife Trade

Your organization is dedicated to ensuring the legal and sustainable trade of wild species, thereby benefiting both the planet and humanity. We are honored to present to you our five-year project aimed at combating the illegal trade of wildlife and plants.

Initially, we identify key nations within the illegal wildlife trade networks—China, Germany, Philippines, United States, and Kenya—through the analysis of flow betweenness and fragmentation indices. Subsequently, we develop a five-year plan tailored to the specific conditions of these countries, focusing on the primary illegal trade goods, such as ivory and reptiles. Upon evaluating our project over its duration, we observe that the Seizure to Occurrence Ratio is projected to reach **0.971**. Notably, China's share of the global ivory trade is expected to decrease from 69.6% to 51.8%, and its reptile trade from 41.3% to 29.5%. Kenya's ivory trade is anticipated to drop from 4.8% to 3.6%, and United States' reptile trade from 3.9% to 3.1%. Furthermore, an evaluation of the project's impact on ecosystem diversity revealed significant improvements in the biodiversity of key nations, with a global biodiversity index expected to reach **0.77**.

Our five-year project is as follows:

First Year: Implement stricter laws and regulatory measures, and increase the severity of penalties for illegal activities. Enhance the screening capabilities of transit countries, such as introducing image recognition technology. The proportion of various types of illegal wildlife trade in key countries increases by 2% globally.

Second Year: Carry out education activities on the rights of wildlife and plants, raising public awareness of the issue. Conduct rigorous inspections of trade routes in key countries. The proportion of various types of illegal wildlife trade in key countries increases by 1% globally.

Third Year: Increase the attractiveness of jobs for wildlife and forest rangers to expand the ranger team. Expand the scope of educational activities to cover more communities and schools. The proportion of various types of illegal wildlife trade in key countries **decreases** by 3% globally.

Fourth Year: Strengthen cooperation with international organizations to jointly combat transnational illegal trade networks. Enhance the protection of wildlife habitats and improve the management level of protected areas. The proportion of various types of illegal wildlife trade in key countries decreases by 5% globally.

Fifth Year: Share the project's successful experiences with the international community, encouraging other countries to adopt similar measures. Continue monitoring the illegal trade of wildlife and plants, tracking trends. The proportion of various types of illegal wildlife trade in key countries decreases by 8% globally.

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Report on Use of AI

Our LLM is mainly used for data collection and article embellishment.

OpenAI ChatGPT (Nov 5, 2023 version, ChatGPT-4,)

Query1:

Please provide me with access to relevant illegal wildlife trade data.

Output1:

To access data on illegal wildlife trade, you can explore several key resources:

The World Wildlife Report by the United Nations Office on Drugs and Crime (UNODC) provides a comprehensive overview of the current situation regarding wildlife crime, including the illicit trafficking of protected species. It assesses the nature and extent of the problem globally, offering valuable insights into the patterns and trends of illegal wildlife trade.

The CITES Illegal Trade Database is a rich source of data on individual wildlife seizures worldwide. Managed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), it gathers information on wildlife seizure events, including quantities seized, trafficking routes, taxon information, and modes of transport. This database is available to governmental representatives of CITES Parties and International Consortium on Combating Wildlife Crime (ICWC) partner agencies.

TRAFFIC, the wildlife trade monitoring network, provides in-depth analyses and reports on the state of illegal wildlife trade. It focuses on the impact on species such as elephants, rhinos, tigers, and pangolins, highlighting the scale of poaching and trafficking activities. TRAFFIC's work includes developing strategies for detection, prevention, and prosecution of illegal wildlife trade, aiming to reduce demand and promote sustainable practices.

These resources offer detailed and up-to-date information on the illegal wildlife trade, crucial for understanding and combating this global issue.

Query2:

Main species transported in the illegal wildlife trade and corresponding modes of transport.

Output2:

The illegal wildlife trade involves a variety of species and methods of transportation, depending on the type of species, its value, and the destination. Here are some of the key species involved in illegal wildlife trade and the methods used for their transportation:

Ivory and Rhino Horns: These items are often smuggled into Asian markets, especially China and Vietnam, where they are considered precious. Transportation methods include air luggage, sea containers, and even postal services.

Pangolin Scales: Pangolins are among the most trafficked mammals in the world, with their scales being smuggled into Asian countries for traditional medicine. They are usually hidden in other legal goods and transported via land, sea, or air.

Tiger Bones and Other Large Cat Parts: These are trafficked for use in traditional medicines or as luxury decorations. They are often transported through concealment in the web, disguised, or mixed with other goods.

Birds and Reptiles: Live animals, especially parrots and reptiles, are trafficked for the pet trade. They are often squeezed into small cages or other containers and transported across borders by air or land.

Rare Plants: Rare plants, like orchids and cacti, are also subjects of illegal trade, usually dug up and smuggled to collectors and horticulture enthusiasts. These plants might be transported via mail or carried across borders in hand luggage.

Marine Species: Such as abalones and shark fins, are usually illegally fished and then smuggled into major markets, like China, by sea or air.

To combat this illegal trade, the international community has implemented a range of measures, including strengthening laws, raising public awareness, and international cooperation. CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) is a crucial international agreement aimed at ensuring that international trade does not threaten the survival of wildlife species. Efforts by organizations like TRAFFIC and the World Wildlife Fund (WWF) have raised public awareness about the illegal wildlife trade, emphasizing the importance of combating this global issue.

Query3:

Is TRAFFIC recognized by the United Nations, what has it done, and with which countries has it cooperated?

Output3:

TRAFFIC is a non-governmental organization focused on issues related to wildlife trade, with the goal of ensuring that the trade in wild animals and plants does not threaten species survival. It is a collaborative program between the World Conservation Union (IUCN) and the World Wide Fund for Nature (WWF). Although TRAFFIC is not a United Nations organization, it frequently collaborates with UN-affiliated bodies, such as the United Nations Environment Programme (UNEP) and the United Nations Educational, Scientific and Cultural Organization (UNESCO), on wildlife conservation and sustainable trade initiatives.

TRAFFIC's work focuses on the following areas:

Law and Policy: Supports and facilitates the development and implementation of international and regional wildlife trade regulations, especially the enforcement of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Research and Analysis: Conducts scientific research and analysis to provide information and recommendations on wildlife trade, supporting conservation policies and practices.

Capacity Building: Offers training and resources to enhance the ability of governments and other stakeholders to manage and monitor wildlife trade.

TRAFFIC works globally with governments, international organizations, NGOs, the private sector, and academic institutions, especially in wildlife trade hotspots such as Asia, Africa, Latin America, and Europe. Through these collaborations, TRAFFIC is dedicated to combating illegal wildlife trade and promoting the sustainable trade and conservation of wild animals and plants.

Query4:

The following is a quote from an academic paper. Polish the text to conform to academic style and improve spelling, grammar, clarity, conciseness, and overall readability. Rewrite the entire sentence if necessary.

Next, based on the characteristics of the key countries within the trade network, we develop a project titled "Destroying Illegal wildlife trade networks". Finally, we assessed the impact of project implementation on SOR and global market.

Output4:

Next, drawing upon the characteristics of pivotal countries in the trade network, we devised a project entitled "Disrupting Illegal Wildlife Trade Networks." Subsequently, we evaluated the project's impact on species at risk (SOR) and the global market.