Study of global illegal wildlife trade volume based on social network analysis and ARIMA model

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Abstract. The illegal trade in wildlife and its products has become a global problem, and reducing the trade in illegal wildlife trade worldwide is important for the protection of biodiversity, social public safety and wildlife welfare. To explore ways to reduce illegal wildlife trade, the amount of wildlife trade needs to be integrated and predicted. Using CITES datasets and collected data, multiple linear regression was used to integrate the historical data of illegal wildlife trade, identify important factors, combine social network analysis and ARIMA time series analysis, build AR (2) model to fit the historical data, and forecast global trade records for the next five years. The results show that, the IWT will continue to rise globally over the next five years. At the same time, according to the influencing factors obtained by data integration, it provides the following suggestions and countermeasures to reduce illegal trade: strengthening legal effect, promoting national cooperation, etc.

Keywords: Illegal wildlife trade, TRAFFIC, Linear regression, social network analysis, ARIMA time series prediction.

1. Introduction

The illegal wildlife trade (IMT) is a global problem, which is diverse and global. Global trafficking in wild species is expanding and gradually moving online [1], expanding the extinction of many species, threatening global security and public health, and has become the third largest crime in the world after arms and drugs. Wildlife illegal trade will bring different degrees of harm to nature, ecology and economy; first of all, it leads to mass hunting of wildlife and destruction of wildlife habitat, breaking the balance of the ecosystem [2], seriously affecting biodiversity; Secondly, the illegal wildlife trade has become a syndicated and networked trend [3-4], partly linked to local armed forces or terrorists, resulting in loss of national tax revenue, increased corruption, increasing poverty of local people, and reduced natural assets. In addition, the lifestyle of consuming wild animals and their products established through illegal trade seriously ignores the emotions and perceptions of animals, damages animal welfare [5], and breaks the way of harmonious coexistence between human beings and nature [6-8].

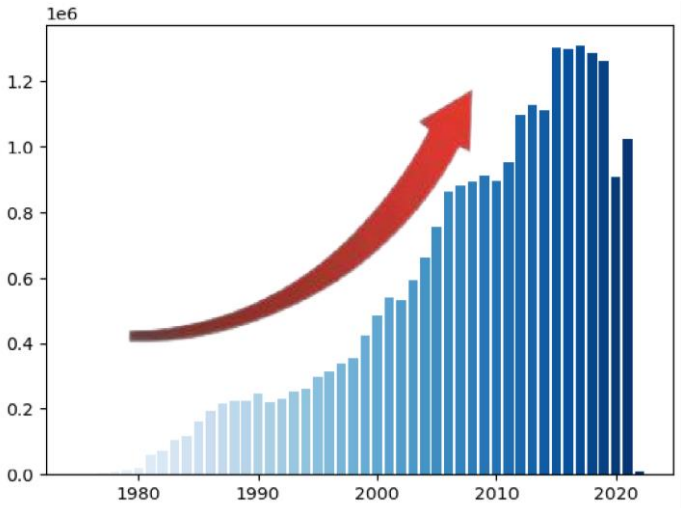

Figure 1. The number of IMT occurrences from 1975 to 2022 worldwide

However, the proportion of trade seizures was very small, and the number of IWTs in the world still has a certain upward trend[9]. In view of the above problems, this paper, based on various algorithms and mathematical analysis, establishes models to fit and predict the global wildlife trade volume, and formulates countermeasures and suggestions by predicting the data, aiming to significantly reduce the illegal wildlife trade.

2. Historical data integration and prediction of the illegal wildlife trade

2.1. Data description

The main data for this paper are from the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Trade Database (by shipment) Guide, compiled by the World Conservation Monitoring Centre of the United Nations Environment Programme (Cambridge, United Kingdom) for the Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora in Geneva, Switzerland. The database currently contains records of international trade in more than 25 million CITES listed species [10]. The database records the illegal trade data of endangered wild animals and plants (mostly animals) up to May 10, 2023, and the animal data in it has been screened to a certain extent, and the remaining data sources are shown in the following table 1:

Table 1. Data and Data Websites

Data Names	Data Websites
MIT records	www.cites.org.eng
Wildlife seizures	https://wildlifedashboard.c4ads.org/
GDP	www.cites.org.eng

2.2. Analysis of the influencing factors of IWT

2.2.1. Construct linear regression models

Based on the data of the last three years (2020-2022) in CITES data set, the top 16 countries are selected according to the source of trade, which are: Norway, the United States, Singapore, Russia, Japan, the Netherlands, China, the United Arab Emirates, Turkey, Italy, France, the United Kingdom, Indonesia, Germany, Ecuador and Switzerland. Taking these countries as the unit, we collected relevant data, constructed indicators, and conducted linear regression analysis to find out the influencing factors of IWT.

2.2.2. Analytical procedure

In the linear regression model, the number of IWT occurrence of a country in the past three years is selected as the dependent variable, and the independent variable of x1-7 is constructed. Among them, x1, x5 and x6 are obtained by three experts by integrating the modernization development process of each country, wildlife protection laws and regulations, and the strictest degree of regulations prohibiting IWT. y and x3 and x4 are calculated from cites datasets, x2 is collected from third-party economic statistics websites, and x7 is the last three years of data from the C4ADS Wildlife Seizures Dashboard, which shows global wildlife seizure trends from 2013 to present. As of today, the C4ADS Wildlife Seizures Dashboard includes data from 7,136 seizures in 118 jurisdictions across five frequently trafficked wildlife categories: ivory, leopards, pangolins, rhino horn, and tigers, and it's important to note that changes in seizures recorded on the dashboard do not necessarily indicate an increase or decrease in wildlife trafficking. It could be the result of changes in investigative capabilities, reporting, or other factors, and could therefore be representative of the extent to which IWT enforcement is prohibited in the area.

The variables and their explanations are shown in the following table 2:

Table 2. The variables and their explanations

Variable encoding	Variable interpretation	Numerical type	data sources
y	IWT occurrence in the past three years	continuation	Cites data set
x1	National modernization level	Discrete [1-5]	Expert comprehensive score
x2	Annual annual GDP in the past three years	continuation	Third-party website search
x3	Import number of IWT trade cases in the past three years	continuation	Cites data set
x4	Export number of IWT trade cases in the past three years	continuation	Cites data set
x5	Score of the wildlife conservation level	Discrete [1-5]	Expert comprehensive score
x6	The Prohibition of IWT regulatory scoring	Discrete [1-3]	Expert comprehensive score
x7	The Prohibition of IWT law enforcement	continuation	C4ADS Wildlife Seizure Dashboard

The results of constructing the Multiple linear regression model for the dependent and independent variables are as table 3 follows:

Table 3. Results of the linear regression analysis

	Non-standardized coefficients		Standardization coefficient	t	p	collinearity diagnostics	
	B	standard error	Beta			VIF	tolerance
constant	43273.410	36170.998	-	1.196	0.266	-	-
x1	3093.342	15633.039	0.033	0.198	0.848	4.759	0.210
x2	1.550	0.158	1.135	9.839	0.000**	2.242	0.446
x3	-0.095	0.117	-0.084	-0.817	0.438	1.765	0.567
x4	0.052	0.060	0.079	0.861	0.414	1.428	0.700
x5	1728.312	10736.428	0.017	0.161	0.876	1.867	0.536
x6	-27678.142	15640.912	-0.223	-1.770	0.115	2.685	0.372
x7	-1269.674	245.977	-0.566	-5.162	0.001**	2.026	0.494
R2	0.953						
adjust R2	0.911						
F	F (7, 8) =22.946, p =0.000						
D-W price	1.659						
dependent variable:y							
* p <0.05 ** p <0.01							

We can see that using x1, x2, x3, x4, x5, x6, x7 as independent variables and y as the dependent variable for linear regression analysis, which can be seen from the above table, and the model formula is:

$$y = 43273.410 + 3093.342 \times x1 + 1.550 \times x2 - 0.095 \times x3 + 0.052 \times x4 + 1728.312 \times x5 - 27678.142 \times x6 - 1269.674 \times x7 \quad (1)$$

The model's R square value of 0.953, means that x1, x2, x3, x4, x5, x6, and x7 can explain 95.3% of the change in y. The F test of the model found that the model passed the F test (F=22.946, p=0.000 <0.05), which means that at least one of x1, x2, x3, x4, x5, x6, and x7 will affect y. In addition, the multiple collinearity of the model found that all VIF values in the model are less than 5, which means there is no collinearity problem; and the D-W value is near the number 2, thus indicating that the model has no autocorrelation between the sample data, and the model is good.We can more clearly observe the effect of x1-x7 on y from Figure 2:

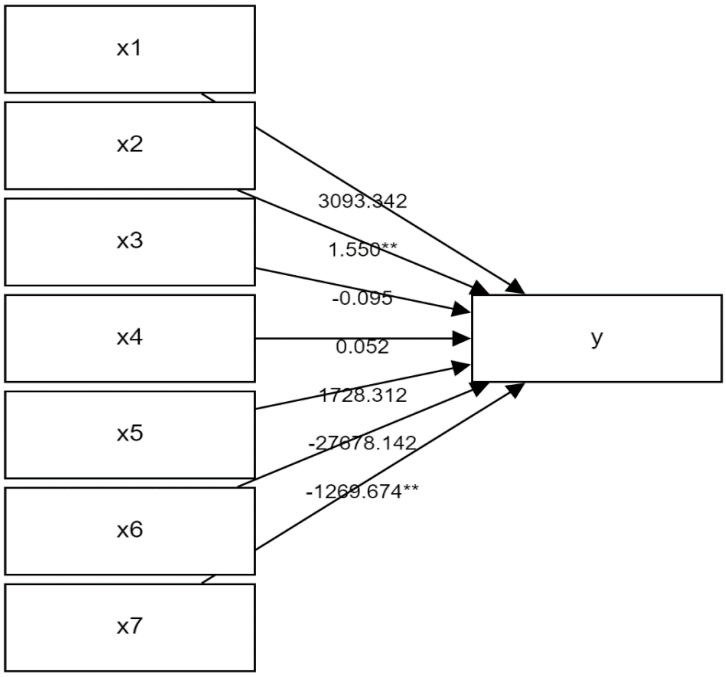

Figure 2. Structural diagram of the graph regression model construction

From the significance analysis of the individual coefficient values: x2 has a significant positive effect on y. And that x7 has a significant negative effect on y. But x1, x3, x4, x5, x6 do not have a relationship on y.

2.3. IWT key point identification

2.3.1. Conduct the social network analysis

Social network analysis method is a research method of quantitative analysis. It is based on mathematical principles, algorithm analysis, visualization methods, matrix analysis and so on. The concept of "social network" was put forward in the analysis of the famous British sociologist Brown when studying the structure of human social structure. The method is based on the following assumptions: the importance of the corresponding node is equivalent to the node and other nodes connecting segment, segment more prove more closely, also means that the point is more important, and alone to the analysis of the node or node connection state of the whole network can remain the same and index survey will not destroy the state of the network.

2.3.2. analytical procedure

A typical social network graph is included in the following two sets of information: as shown in equations (2) and equations (3):

$$V(G) = \{N1, N2, \dots, Nn\} \tag{2}$$

V (G) represents the set of the number of nodes, Nn is the number of nodes, and formula (3) expresses the information of the nodes in the IWT import and export trade country recorded in the cites data set in this study;

$$E(G) = \{L1, L2, \dots, Ln\} \tag{3}$$

It represents the set of directed edges, Ln is the number of directed edges, and equation (3) expresses the information of the opposite edges, indicating the flow direction of IWT trade.

Collect data from the import and export trade countries involved in IWT in the CITES data set, in which the weight of the side is the number of IWT records, according to the a pair of countries (importer-exporter), and the social network relationship diagram is drawn,as shown in Figure 3:

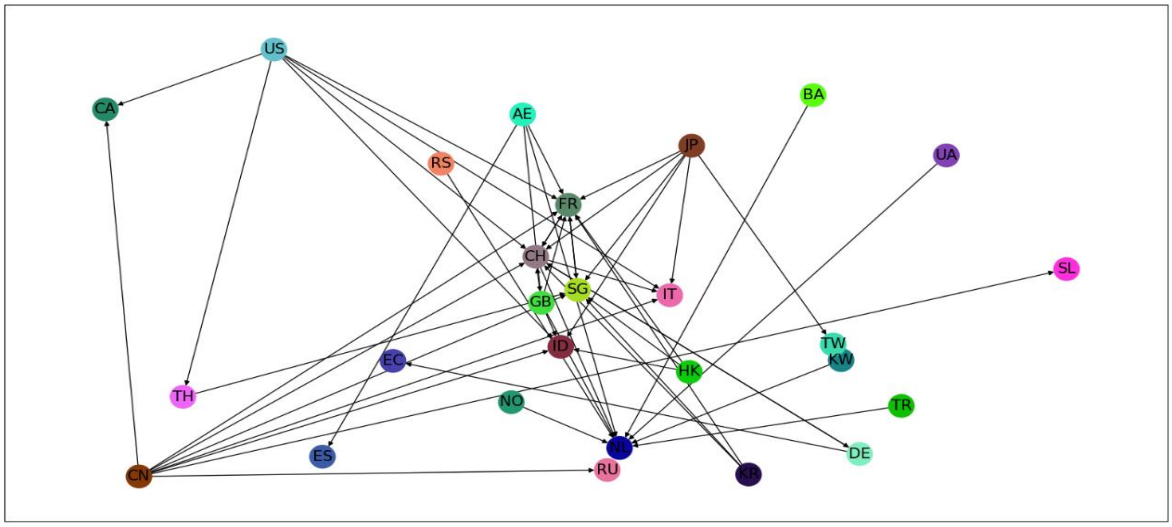

Figure 3. Social network map

In social network analysis methods, degree is commonly used to measure the importance of nodes. There are mainly two evaluation indexes: intermediary centrality and degree center, as (4) follows:

$$\text{Degree centrality} = \frac{N_{\text{degree}}}{\text{n}-1} \tag{4}$$

Where n represents the number of nodes and the degree of nodes. N_{degree} Degree centrality is used to measure how much a node in the network is connected to all other nodes.

$$\text{Betweenness centrality} = \sum_{j,k=1}^{g} sd(j,i,k), (j \neq k) \tag{5}$$

$sd(j,i,k)$ Where the shortest path representing nodes j to k goes through i, Betweenness centrality is used to measure the number of shortest paths where a vertex appears between any two other pairs of vertices, so as to characterize the node importance. Intermediation centrality measures the extent to which a node can become a "mediator", or to what extent it controls others. If a node is between multiple nodes, it can be considered to play an important "intermediary" role, and the country in this position in the IWT trade network can control the transmission of information and affect the entire trade network.

2.4. IWT predictions for the next 5 years

2.4.1. Construct the ARIMA(2) models

We use the A RIMA to predict the number of IWT cases in the next five years,and the data selected were the IWT reocrds from 1975 to 2022.First, we need to test the stability of the time series, and the results of the ADF test are shown in table 4:

Table 4. The ADF test results for IMT records

Differential order	t	p	critical value		
			1%	5%	10%
0	-3.451	0.009	-3.601	-2.935	-2.606

As can be seen from the above table, the t-statistic of the ADF test of the time series data is-3.451, the p-value is 0.009, and the critical values of 1%, 5% and 10% are-3.601, -2.935 and-2.606 respectively. The P = 0.009 <0.01, so this time sequence is stable.

Then we carried out partial autocorrelation analysis, As shown in Figures 4 and 5:

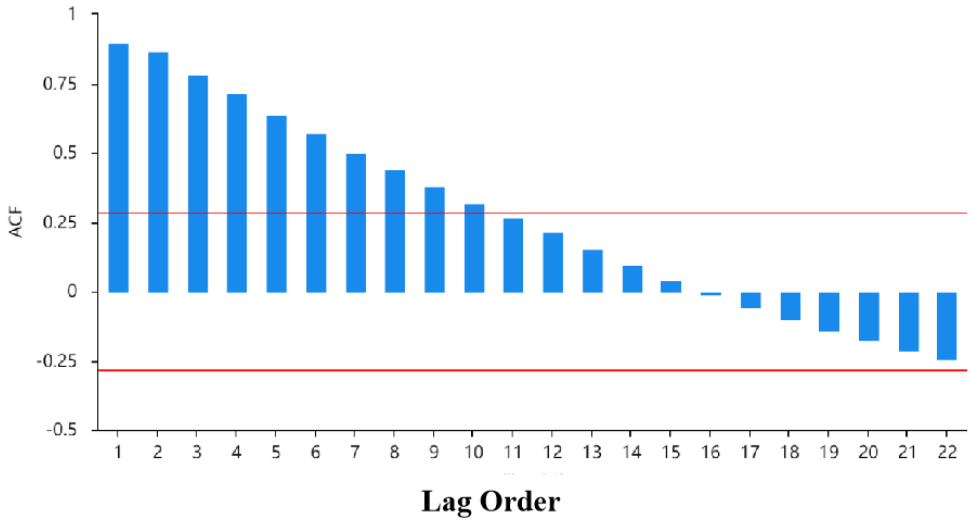

Figure 4. ACF graph

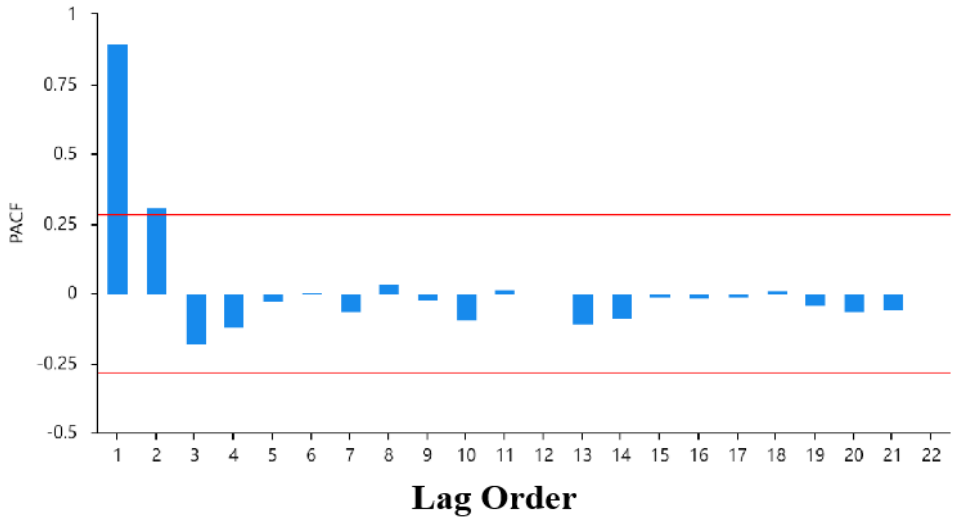

Figure 5. PACF graph

Thus, combining the ACF and PACF plots ultimately suggests an autoregressive order p-value of 2 and a moving mean order q-value of 0. Therefore, A RIMA (2) was selected for the time-series analysis and prediction.

2.4.2. Prediction procedure

First list the AR (2) model parameter table, according to write the model formula of the parameters, the parameter table is shown in table 5:

Table 5. AR (2) Model parameter table

Item	symbol	coefficient	standard error	z price	p value	95% CI
constant term	c	48910.752	41030.709	1.192	0.233	-31507.960 ~ 129329.463
AR parameter	α1	0.620	0.327	1.899	0.058	-0.020 ~ 1.260
	α2	0.283	0.377	0.751	0.453	-0.456 ~ 1.022
AIC value: 1297.542						
BIC value: 1305.027						

According to the AR (2) model parameter table, the model formula is:

$$y(t) = 48910.752 + 0.620 \times y(t-1) + 0.283 \times y(t-2) \quad (6)$$

In addition, the AR (2) model is also Q-tested. According to the Q statistic results, The residual difference of the model is white noise, and the model basically meets the requirements.

To evaluate the effect of ARIMA prediction, where the comparison between the true and predicted values is as figure 6 shows:

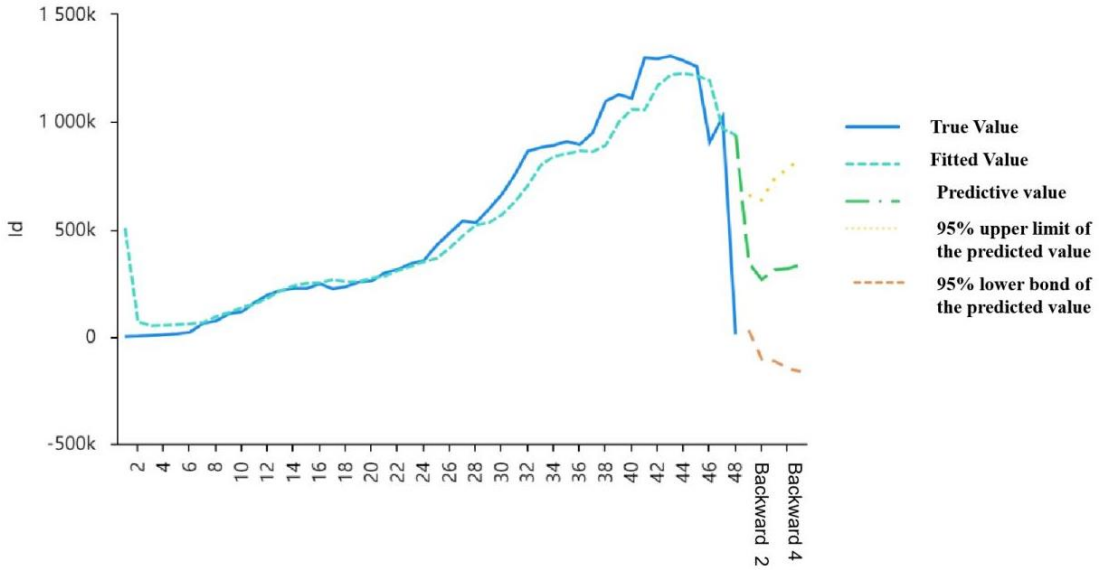

Figure 6. the comparison true and predicted value

According to the figure, the fit based on the ARIMA time series model works well.

3. Experimental results and analysis

3.1. Linear regression analysis of the factors affecting the IWT

Based on the linear regression analysis, it can be concluded that GDP reflects the country's economic development level, the number of IWT records and a country's economic development level present significant positive relationship, tend to occur in the economic development level is higher, x7 represents the prohibition of IWT enforcement, it is concluded that the stronger the enforcement, the lower the number of IWT cases. In addition, the correlation between the variables was also analyzed, as shown in the table 6 below:

Table 6. Test of Pearson's correlation result

	x7	x1	x2	x3	x4	x5	x6
x7	1						
x 1	-0.155	1					
x2	0.524*	0.176	1				
x3	0.301	0.415	0.492	1			
x4	-0.116	0.233	-0.245	-0.227	1		
x5	-0.148	0.648**	0.170	0.295	-0.032	1	
x6	0.045	0.702**	-0.034	0.289	0.115	0.412	1
* p <0.05 ** p <0.01							

The correlation coefficient value between x7 and x2 is 0.524 and showed 0.05 significance, thus indicating a significant positive correlation between x7 and x2. That is to say, the law enforcement level of IWT in a country is related to the GDP of the country, and the higher the economic level of the country, the higher the law enforcement level of IWT in the country. Therefore, from the national level we can consider developing the economy to improve the law enforcement level of IWT.

3.2. Social network analysis identifies the key points of IWT

According to the social network analysis method,Betweenness centrality, degree centrality of top5 nodes are calculated to evaluate the importance of each node.As the table 7 shows:

Table 7. Betweenness centrality, degree centrality of top5 Countries

Country	Betweenness centrality	Country	degree centrality
CH	0.060	CH	0.423
FR	0.033	FR	0.423
DE	0.017	NL	0.346
SG	0.009	CN	0.308
GB	0.005	SG	0.269

The table 7 shows that should focus on the import of IWT trade in CH (Switzerland), FR (France), NL (Netherlands), IT (Italy), and the export of IWT trade in US(US), JP (Japan), CN (China), and KR (South Korea). In the process of trade transit, special attention should be paid to the role of CH(Switzerland), FR (France) and DE (Germany) as intermediary points on the operation of the entire trade network.

We Also draw a thermal map, and from figure 7, we should pay special attention to the countries of China, the United States, and the ports of these countries along the Atlantic coast, the Mediterranean Sea, Malacca, and the waters of China, because these are the places where IWT trade occurs frequently.

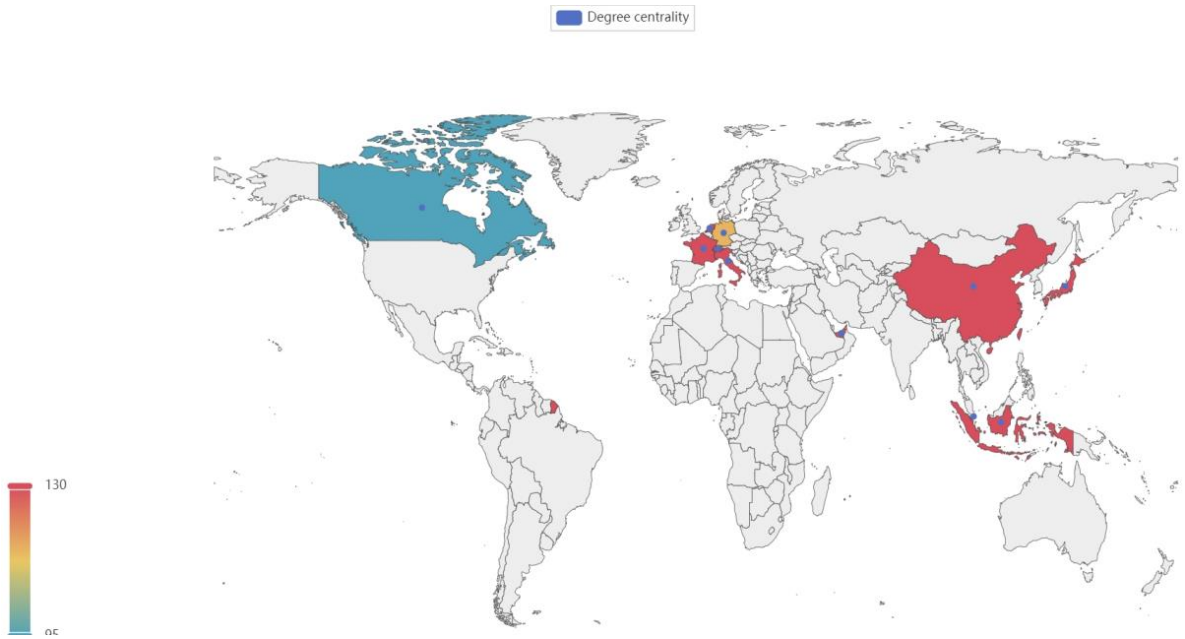

Figure 7. Global degree centrality map

3.3. The prediction results and analysis were performed by using the AR (2) models

According to the AR(2) models, the results for the next five years are as table 8 follows:

Table 8. next five years predicted value

calculate	Back phase 1	Backward phase 2	Back phase 3	Back phase 4	Back phase 5
value	344278.454	265198.591	310820.004	316748.227	333332.248

The forecast results of the next five years show that the number of IWT records still increases worldwide.

4. Conclusion

In view of the global problem of illegal wildlife trade, this paper uses mathematical methods to analyze the trade records, and combines various algorithms and models to fit and predict the data. In the process of data fitting and prediction, the biggest advantage of the method adopted in this paper is the analysis from many aspects. In order to find out the influencing factors of IWT, this paper conducts various analysis and exploration. According to the analysis results, this paper can provide some suggestions and countermeasures to reduce the illegal wildlife trade, which can reduce the illegal wildlife trade by strengthening the legislation and policy formulation to ensure that the law has sufficient deterrent effect. It could also be done by enhancing law enforcement agencies, and the results of the regression analysis showed a significant reduction in IWT trade records in countries with greater enforcement capacity, suggesting that increased enforcement may rapidly reduce illegal trade. International exchanges and cooperation can also be strengthened, and through international cooperation, global resources can be focused on combating illegal trade and promoting the importance of wildlife conservation. Finally, the public awareness of animal protection can also be improved. The existence of the wildlife trade market is the root cause of IWT, and this market comes from the demand of the public. Strengthening the awareness of wildlife protection can effectively reduce the wildlife trade.

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