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Application of Gray Metabolic GM (1,1) Model in Prediction of Annual Total Yields of Chinese Aquatic Products

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Abstract To predict the annual total yields of Chinese aquatic products in future five years (2011 – 2015), based on the theory and method of gray system, this paper firstly establishes a conventional GM (1,1) model and a gray metabolic GM (1,1) model respectively to predict the annual total yields of Chinese aquatic products in 2006 – 2009 and compare the prediction accuracy between these two models. Then, it selects the model with higher accuracy to predict the annual total yields of Chinese aquatic products in future five years. The comparison indicates that gray metabolic GM (1,1) model has higher prediction accuracy and smaller error, thus it is more suitable for prediction of annual total yields of aquatic products. Therefore, it adopts the gray metabolic GM (1,1) model to predict annual total yields of Chinese aquatic products in 2011 – 2015. The prediction results of annual total yields are 55.32, 57.46, 59.72, 62.02 and 64.43 million tons respectively in future five years with annual average increase rate of about 3.7%, much higher than the objective of 2.2% specified in the *Twelfth Five-Year Plan of the National Fishery Development* (2011 to 2015). The results of this research show that the gray metabolic GM (1,1) model is suitable for prediction of yields of aquatic products and the total yields of Chinese aquatic products in 2011 – 2015 will totally be able to realize the objective of the Twelfth Five-Year Plan.

Key words Gray system, Metabolic GM (1,1) model, Aquatic products, Prediction of yields

1 Introduction

In recent years, the position of aquatic products in Chinese food composition and import and export trade is becoming more and more important. The change in annual total yields of aquatic products can not only reflect the development situations of Chinese fishery, but also influence people's life and GDP national development, even the competitive power and international status of the whole country[1–3]. Therefore, the research and prediction for the change in annual total yields of Chinese aquatic products have an important significance.

For prediction of yields, its research generally adopts traditional methods such as Linear Regression Model[4], Expert System[5], Neural Network Model[6], Productivity Model[7], Factor Analysis Model[8]. However, the fishery system is a complicated and multi-factor system, which will be greatly influenced by factors such as economy, resource and society, *etc*. The prediction for yields of aquatic products with conventional methods is confronted with problems such as insufficient samples, great realization difficulties, high requirements, *etc*., therefore, such methods are not suitable for the prediction and research for yields of aquatic products.

Gray system is a new method for effectively handling the problems of small sample, poor information and uncertainty proposed by Deng Julong[9] in the 1980s. Gray prediction is a prediction method based on the theory of gray system. Its basic idea is to generate a series showing an exponential growth law from irregular historical data with randomness and uncertainty through accumulation, thus establishing a prediction model of gray differential equation[10–14]. Gray prediction has been widely used in many aspects such as water quality change, grain yield, cotton yield, pig breeding stock, agricultural acreage, China's population urbanization level, *etc*.[15–23] At present, the most common gray prediction model is conventional GM (1,1) model. However, this model has certain deficiencies, because it only considers all past data before current moment $t = n$. For long time prediction, old information will disturb the system with the lapse of time, thus reducing the prediction accuracy and weakening the prediction significance[24]. In view of the deficiencies in conventional GM (1,1) model, a new gray prediction model, *i. e.* gray metabolic GM (1,1) model, is established. The difference between gray metabolic GM (1,1) model and conventional GM (1,1) model is that in the process of prediction, gray metabolic GM (1,1) model does not depend on one model for prediction all the way, but it gradually rejects old data and adds new predicted data during model establishing for the purpose of making prediction one by one and adding data in turn.

2 Gray metabolic GM (1,1) model

Gray metabolic GM (1,1) model is a gray prediction model improved on the basis of conventional GM (1,1) model.

2.1 Theory of conventional gray GM (1,1) model The conventional gray GM (1,1) model is a model formed by a first – order differential equation containing a single variable, which is the basis for gray prediction.

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Assume the existing series data is:

$$x^{(0)} = \{x^{(0)}(1),\ x^{(0)}(2),\ \cdots,\ x^{(0)}(n)\} \quad (1)$$

The series generated through primary accumulation is:

$$x^{(1)} = \{x^{(1)}(1),\ x^{(1)}(2),\ \cdots,\ x^{(1)}(n)\} \quad (2)$$

where,

$$x^{(1)}(k) = \sum_{i=0}^{k} x^{(0)}(i) = x^{(1)}(k-1) + x^{(0)}(k) \quad (3)$$

Define $z^{(1)}$ as the series generated from the mean value of consecutive neighbors of $x^{(1)}$:

$$z^{(1)}(k) = \frac{x^{(1)}(k) + z^{(1)}(k-1)}{2} \quad (4)$$

Establish the following gray differential equation:

$$x^{(0)}(k) + az^{(1)}(k) = b \quad (5)$$

Take $\hat{a} = (a,\ b)^T$, then the least square estimation parameter list of gray differential equation will meet the following equation:

$$\hat{a} = (B^T B)^{-1} B^T Y_n \quad (6)$$

where,

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \quad Y_n = \begin{bmatrix} -x^{(1)}(2) & 1 \\ -x^{(1)}(3) & 1 \\ \vdots & \vdots \\ -x^{(1)}(n) & 1 \end{bmatrix} \quad (7)$$

Call $\frac{dx^{(1)}}{dt} + ax^{(1)} = b$ the whitenization equation of gray differential equation $x^{(0)}(k) + az^{(1)}(k) = b$.

The solution of whitenization equation $\frac{dx^{(1)}}{dt} = b$ is also called time response function:

$$\hat{x}^{(1)}(t) = (x^{(1)}(0) - \frac{b}{a})e^{-at} + \frac{b}{a} \quad (8)$$

Then the time response series of GM(1,1) gray differential equation $x^{(0)}(k) + az^{(1)}(k) = b$ is:

$$\hat{x}^{(1)}(k+1) = (x^{(1)}(0) - \frac{b}{a})e^{-ak} + \frac{b}{a},\ k = 1,\ 2,\ \cdots,\ n \quad (9)$$

Take $x^{(1)}(0) = x^{(0)}(1)$, then:

$$\hat{x}^{(1)}(k+1) = (x^{(0)}(1) - \frac{b}{a})e^{-ak} + \frac{b}{a},\ k = 1,\ 2,\ \cdots,\ n \quad (10)$$

Reduce the value, and get:

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) = \hat{x}^{(1)}(k) \quad (11)$$

The above equation is the prediction equation.

2.2 Gray metabolic GM (1,1) prediction model After getting the nearest information data $\hat{x}^{(0)}(n+1)$ from gray prediction, add this information data to the original data series and reject the oldest information $\hat{x}^{(0)}(1)$ from the series. Utilize the new series $\{x^{(0)}(2),\ x^{(0)}(3),\ \cdots,\ x^{(0)}(n+1)\}$ as the original series $x^{(0)}$ to repeat the above steps described in 1.1 and establish GM (1,1) model. Repeat this and add the data in turn until the prediction target is completed, *i.e.* gray metabolic prediction model.

2.3 Accuracy inspection Use the most common inspection indexes of relative error and posterior error ratio C to inspect the model.

Its basic inspection process is as follows: $x^{(0)}$ is the original series, $\hat{x}^{(0)}$ is the simulative series of GM model, and is the residual series, where, $\varepsilon(k) = x^{(0)}(k) - \hat{x}^{(0)}(k)$. The relative error series is $\Delta = (\Delta_1,\ \Delta_2,\ \cdots,\ \Delta_n)$, where, $\Delta_\varepsilon = \left|\frac{\varepsilon(k)}{x^{(0)}(k)}\right|$. Δ_k is the simulative relative error at k point. $\bar{\Delta} = \frac{1}{n}\sum_{k=1}^{n}\Delta_k$ is the mean relative error, and $p = 1 - \Delta$ is defined as the prediction accuracy. The prediction value (*i.e.* P value) is expressed in percentage.

$$S_1 = \frac{\sqrt{\sum(\varepsilon_i - \bar{\varepsilon})^2}}{n-1},\ \bar{\varepsilon} = \frac{\sum \varepsilon_i}{n} \quad (12)$$

$$S_2 = \frac{\sqrt{\sum(x^{(0)}(k) - \bar{x}^{(0)})}}{n-1},\ \bar{x} = \frac{\sum x^{(0)}(k)}{n} \quad (13)$$

$$C = \frac{S_1}{S_2} \quad (14)$$

where S_1 is residual mean square error, S_2 is mean square error of original series, and C is posterior error ratio.

The model accuracy classification standard is as shown in the accuracy class reference list. See Table 1.

Table 1 Inspection class reference list for prediction accuracy of gray model

Model accuracy	Relative error//%	Mean relative accuracy (p, %)	C value
Class 1 (excellent)	1	≥95	≤0.35
Class 2 (qualified)	5	$80 \leq p < 95$	$0.35 < C \leq 0.5$
Class 3 (grudgingly qualified)	10	$70 \leq p < 80$	$0.5 < C \leq 0.65$
Class 4 (unqualified)	20	<70	>0.65

3 Feasibility analysis of gray metabolic GM (1,1) model for predicting the annual total yields of Chinese aquatic products

3.1 Data source The statistical data for annual total yields of Chinese aquatic products in 1996 – 2009 comes from *China Statistical Yearbook* 2010[25]. In 1996 – 2009, the annual total yields of Chinese aquatic products roughly showed an ascending trend year by year. See Fig. 1.

3.2 Establishing the conventional GM (1,1) prediction model Firstly, establish the conventional GM (1,1) model. The data for annual total yields of aquatic products in 1996 – 2005 is used for establishing the model, and the data for annual total yields of aquatic products in 1996 – 2005 is used for inspecting the accuracy of model. Through the programming and calculation in MATLAB software environment, get the equation of conventional GM (1,1) prediction model as follows:

$$\hat{x}^{(1)}(k+1) = 80483.468e^{0.0394149k} - 77195.378 \quad (15)$$

Use this conventional GM (1,1) model to predict the annual total yields of Chinese aquatic products in 2006 – 2009 respectively. For the results, see Table 2 for details.

It can be known from Table 2 that the prediction effect of conventional GM (1,1) model on annual total yield of Chinese aquatic products in 2006 (with the prediction accuracy of 99.352%) is obviously superior to that in 2007 – 2009. With the lapse of time, the prediction accuracy of conventional GM (1,1) model roughly shows a descending trend gradually.

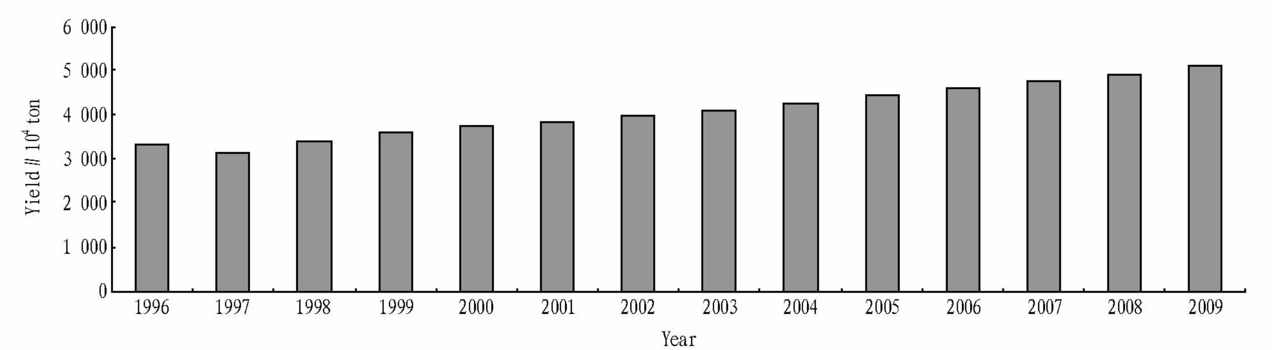

Fig. 1 Diagram for annual total yields of Chinese aquatic products in recent years (1996 – 2009)

Table 2 Analysis of prediction result and prediction accuracy of conventional GM (1,1) prediction model

Year	Actual value 10^4 t	Prediction value // 10^4 t	Residual error // 10^4 t	Relative error // %	Prediction accuracy // %
2006	4 583.60	4 613.31	−29.71	0.648	99.352
2007	4 747.52	4 798.78	−51.26	1.080	98.920
2008	4 895.60	4 991.70	−96.10	1.963	98.037
2009	5 116.40	5 192.38	−75.97	1.485	98.515

3.3 Establishing the gray metabolic GM (1,1) prediction model The accuracy of conventional GM (1,1) model is gradually descended for long time prediction. This research attempts to establish the metabolic prediction model for prediction and analysis of annual total yields of Chinese aquatic products. Reject the statistical data for annual total yield of aquatic products in 1996, and add the statistical data for annual total yield of aquatic products in 2006 to the original series of model. That is, use the statistical data for annual total yields of aquatic products in 1997 – 2006 to establish the gray GM (1,1) model for prediction of annual total yields of Chinese aquatic products in 2007 – 2009. Through calculation, get the equation of gray metabolic GM (1,1) prediction model 1 as follows:

$$\hat{x}^{(1)}(k+1) = 91\,464.504e^{0.036\,642\,6k} - 88\,345.914 \quad (16)$$

Use this model to predict the annual total yields of Chinese aquatic products in 2007 – 2009. For the results, see Table 3 for details.

Table 3 Analysis of prediction result and prediction accuracy of gray metabolic GM (1,1) prediction model 1

Year	Actual value 10^4 t	Prediction value // 10^4 t	Residual error // 10^4 t	Relative error // %	Prediction accuracy // %
2007	4 747.52	4 747.263	0.26	0.005	99.995
2008	4 895.6	4 924.441	−28.84	0.589	99.411
2009	5 116.4	5 108.232	8.17	0.16	99.84

It can be known from Table 3 that the prediction result of model 1 for annual total yield of aquatic products in 2007 is 47.47 million tons with a prediction accuracy of 99.995%, which is considerably higher than that of conventional GM (1,1) model. Meanwhile, the prediction accuracy of model 1 for annual total yields of aquatic products in 2008 – 2009 is also higher than that of conventional model. However, with the lapse of time, the prediction accuracy begins to descend. Therefore, continue to establish the gray metabolic GM (1,1) prediction model 2. Use the statistical data for annual total yields of Chinese aquatic products in 1998 – 2007 to establish the gray GM (1,1) prediction model for prediction of annual total yields of aquatic products in 2008 – 2009. Through calculation, get the equation of gray prediction model 2 as follows:

$$\hat{x}^{(1)}(k+1) = 96\,786.196e^{0.036\,050\,8k} - 93\,403.536 \quad (17)$$

Use this model to predict the annual total yields of Chinese aquatic products in 2008 – 2009. For the results, see Table 4 for details.

Table 4 Analysis of prediction result and prediction accuracy of gray metabolic GM (1,1) prediction model 2

Year	Actual value 10^4 t	Prediction value // 10^4 t	Residual error // 10^4 t	Relative error // %	Prediction accuracy // %
2008	4 895.6	4 914.616	−19.02	0.388	99.612
2009	5 116.4	5 095.024	21.38	0.418	99.582

It can be known from Table 4 that the prediction result of model 2 for annual total yield of Chinese aquatic products in 2008 is 49.14 million tons with prediction accuracy of 99.612%. The prediction accuracy of model 2 for annual total yields of Chinese aquatic products in 2008 – 2009 is higher than that of conventional GM (1,1) model. Continue to establish the gray metabolic GM (1,1) prediction model 3. Use the statistical data for annual total yields of Chinese aquatic products in 1999 – 2008 to establish the gray GM (1,1) prediction model for prediction of annual total yield of aquatic products in 2009. Through calculation, get the equation of gray prediction model 3 as follows:

$$\hat{x}^{(1)}(k+1) = 100\,287.735e^{0.036\,050\,8k} - 96\,717.585 \quad (18)$$

Use this model to predict the annual total yield of Chinese aquatic products in 2009.

The prediction result of model 3 for annual total yield of Chinese aquatic products in 2009 is 50.897 6 million tons with a prediction accuracy higher than that of conventional GM (1,1) model.

3.4 Comparison of accuracy between conventional GM (1,1) prediction model and gray metabolic GM (1,1) prediction model For the comparison of prediction accuracy for annual total yields of Chinese aquatic products between conventional model and metabolic model, see Table 5 for details.

From Table 5, it can be known that conventional GM(1,1) model has the largest average relative error for the known series data fitting, the metabolic model has small error for known series data fitting, and posterior error ratio C of metabolic model is obviously lower than that of conventional model.

Table 5 Analysis of prediction accuracy of conventional model and three metabolic models

Model	Mean relative error//%	C value
Conventional model	0.978	0.087 2
Metabolic model 1	0.412	0.027 1
Metabolic model 2	0.323	0.020 2
Metabolic model 3	0.305	0.019 9

Using the conventional model and metabolic model to predict total yields of Chinese aquatic products from 2006 to 2009, the average accuracy is 98.706% and 99.611% respectively, indicating that the prediction ability of gray metabolic model is better than conventional model.

4 Application of gray metabolic GM (1,1) model in predicting the annual total yields of Chinese aquatic products

4.1 Preferential selection of different-dimensional GM(1,1) -based model From *Twelfth Five-Year Plan of the National Fishery Development* (2011 *to* 2015), it is known that the total yield of Chinese aquatic products in 2010 is 53.73 million tons. With this data as reference data, and we incorporated it into the prediction of annual total yields of Chinese aquatic products in future five years (2011 to 2015). On the basis of statistic data of annual total yields of Chinese aquatic products from 2010 to 2015, we established the gray metabolic GM(1,1) model to predict the yields of Chinese aquatic products in future. The gray metabolic GM(1,1) model was established on the basis of the conventional model. According to statistic data of annual total yields of Chinese aquatic products from 1996 to 2010, we separately established 15-dimensional, 13-dimensional and 11-dimensional GM(1,1) model for 1996 to 2010, 1998 to 2010 and 2000 to 2010, and obtained the simulated results and relative error of prediction models, which are listed in Table 6, and the prediction comparison of three basic models is listed in Table 7.

Table 6 Simulated value and relative error of three different-dimensional GM(1,1) basic models

Year	Actual	15-dimensional		13-dimensional		11-dimensional	
	value//10^4 t	Simulated value//10^4 t	Relative error//%	Simulated value//10^4 t	Relative error//%	Simulated value//10^4 t	Relative error//%
1996	3 288.09	3 288.09	–	–	–	–	–
1997	3 118.59	3 248.458	4.164	–	–	–	–
1998	3 382.66	3 374.907	0.229	3 382.66	–	–	–
1999	3 570.15	3 506.278	1.789	3 540.361	0.834	–	–
2000	3 706.23	3 642.762	1.712	3 673.539	0.882	3 706.23	–
2001	3 795.92	3 784.56	0.299	3 811.727	0.416	3 790.736	0.137
2002	3 954.86	3 931.876	0.581	3 955.113	0.006	3 936.788	0.457
2003	4 077.02	4 084.928	0.194	4 103.893	0.659	4 088.467	0.281
2004	4 246.57	4 243.936	0.062	4 258.27	0.276	4 245.99	0.014
2005	4 419.86	4 409.135	0.243	4 418.454	0.032	4 409.582	0.233
2006	4 583.60	4 580.764	0.062	4 584.664	0.023	4 579.478	0.090
2007	4 747.52	4 759.073	0.243	4 757.126	0.202	4 755.919	0.177
2008	4 895.60	4 944.324	0.995	4 936.075	0.827	4 939.158	0.890
2009	5 116.40	5 136.785	0.398	5 121.756	0.105	5 129.457	0.255
2010	5 373.00	5 336.739	0.675	5 314.422	1.090	5 327.088	0.854

Table 7 Prediction analysis of three different dimensional GM(1,1) basic models

Model	Mean relative error//%	C value
15-dimensional basic model	0.777	0.050 6
13-dimensional basic model	0.412	0.029 6
11-dimensional basic model	0.308	0.028 9

From Table 7, it can be seen that the mean relative error and posterior error ratio C of three different dimensional GM(1,1) basic model to original data fitting drop with reduction of number of dimensions. The 11-dimensional model of 2000 to 2010 has the minimum prediction error (only 0.308%) and the highest prediction accuracy.

4.2 Prediction of annual total yields of Chinese aquatic products in future five years Using the annual total yields of Chinese aquatic products from 2000 to 2010, we established the 11-dimensional basic GM(1,1) model. On the basis of this, we built the gray metabolic model to predict annual total yields of Chinese aquatic products from 2011 to 2015, it predicts that the total yields of Chinese aquatic products are 55.323, 57.463, 59.726, 62.027, 64.438 million tons respectively in 2011, 2012, 2013, 2014 and 2015. The prediction results indicate that the annual total yield of Chinese aquatic products will rise year by year during the period of the Twelfth Five-Year Plan period. It is predicted that by 2014, the total yield of Chinese aquatic products will exceed 60 million tons and realize the objective of Twelfth Five-Year Plan ahead of time.

5 Conclusions and discussion

In the study, the conventional GM(1,1) model and gray metabolic GM (1,1) model are used to predict annual total yields of Chinese aquatic products from 2006 to 2009. Following conclusions are reached. (1) The gray metabolic GM(1,1) model can timely and effectively incorporate new information in the prediction process, eliminate old information that loses meaning with lapse of time, reduce disturbance against model, and be more closer to reality than conventional GM(1,1) model. (2) The essence of gray metabolic GM (1,1) model is still a conventional GM(1,1) prediction model. This model features simple calculation, easy understanding and high applicability. It has neither problem of low prediction accuracy in linear prediction model, nor problem of high difficulty in realization due to no expert system. Thus, it is of great realistic significance to prediction of yield of aquatic products.

In the course of researching changes in annual total yields of Chinese aquatic products in future five years (2011 to 2015), the gray metabolic GM(1,1) model is introduced to make prediction of total yield of Chinese aquatic products. The prediction results show that the annual total yield of Chinese aquatic products will reach 55.32, 57.46, 59.72, 62.02, and 64.43 million tons, with annual increase of 3.7%, far higher than the 2.2% objective specified in *Twelfth Five-Year Plan of the National Fishery Development* (2011 *to* 2015). This indicates that Chinese aquatic products can completely realize the set objective at existing development speed.

The model established in this study is helpful for effective prediction of annual total yields of Chinese aquatic products and comprehensive understanding development situation of China's fishery industry. The prediction results can provide reference for structural regulation of fishery industry, so as to realize reasonable development and utilization of aquatic products.

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