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Prediction and setup of phytoplankton statistical model of Qiandaohu Lake*

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Abstract: This research considers the mathematical relationship between concentration of Chla and seven environmental factors, i.e. Lake water temperature (*T*), Secci-depth (SD), pH, DO, COD_{Mn}, Total Nitrogen (TN), Total Phosphorus (TP). Stepwise linear regression of 1997 to 1999 monitoring data at each sampling point of Qiandaohu Lake yielded the multivariate regression models presented in this paper. The concentration of Chla as simulation for the year 2000 by the regression model was similar to the observed value. The suggested mathematical relationship could be used to predict changes in the lakewater environment at any point in time. The results showed that SD, TP and pH were the most significant factors affecting Chla concentration.

Key words: Qiandaohu Lake, Stepwise linear regression, Statistical model, Chla
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INTRODUCTION

Uncontrolled propagation of phytoplankton is one of the main characteristics of lake eutrophication. Qiandaohu Lake is situated in the western part of Zhejiang Province, near the source of the Qiantang River at the border with Anhui Province. It is an artificial lake formed as a result of the 1959 construction of the Xin'anjiang dam for generation of electricity, flood control, and as a source of water for domestic and industrial use, aquaculture, shipping and tourism. The 34 m deep Qiandaohu Lake is famous for its clean water. But evidence of accelerated eutrophication began emerging in the Lake and by 1998 as shown by the rapid increase of algae that proliferated on the Lake's surface during the spring season. As a result of the algae bloom, the lakewater and fish products have a characteristic bad ordour. Controlling of eutrophication and protection of the lake's water quality has since then been considered as a priority by the local, provincial and national Environmental Protection Agency and has led to a series of related investigations and researches (Yan *et al*., 2002).

Many models for predicting lake algae have been presented at home and aboard. The most notable models are PAGGACP (that can predict population growth and productivity) and PROTECH-2 that emphasizes the relation between phytoplankton and environmental factors (Chen *et al*., 2001; Quan *et al*., 2001). These models were all statistical models and easy to manipulate, and yield accurate forecast (Kang *et al*., 1998; Somlyody 1998). Here we present the establishment of statis-

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tical models suitable for predicting the growth of algae in Qiandaohu Lake. The models use data acquired from continuous 1997 to 1999 lake monitoring. Stepwise linear regression was applied to establish multivariate regression equations between Chla and the seven selected environmental factors: water temperature, pH, TN, TP, SD, DO, COD_{Mn}. In this way it was possible to predict lake algae population dynamics.

MATERIALS AND METHODS

Monitoring data generation

We chose seven environmental factors: water temperature (*T*), Secci-depth (SD), pH, DO, COD_{Mn}, TN, TP and a biological factor–Chla concentration during the middle ten days of every month from January 1997 to December 1999. The choice and monitor methods adopted the surface water inspection criterion of the National Environmental Protection Agency. The maximum, minimum and average value of each item in 1999 and 2000 are shown in Table 1.

There were 13 sampling points: Jiekou, 12# Hangbiao, Songcunmatou, Xiaojinshan, Zilaishuichang, Hangtoudao, Daba, Laoshanchukou, Mishan, Santandao, Maotoujian, Jilingkou and Di'ershuichang (Fig.1).

Study method

The models were set up with the use of the stepwise linear regression and the aid of SPSS statistical software package.

Table 1 The maximum, minimum and average value of each item in 1999 and 2000

Index	Maximum	Minimum	Average
T (°C)	30.33	11.95	20.49
COD_{Mn} (mg/L)	1.81	1.19	1.36
DO (mg/L)	10.46	6.67	8.52
pH	9.13	7.53	8.08
SD (m)	6.59	3.67	4.53
TP (mg/L)	0.037	0.008	0.017
TN (mg/L)	0.87	0.33	0.59
Chla (mg/m^3)	10.17	1.77	4.72

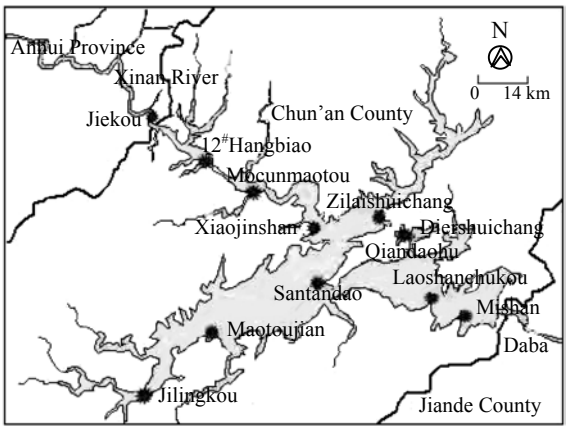

Fig.1 Location of Qiandaohu Lake and sampling points

RESULTS AND DISCUSSIONS

Correlation among monitored factors

Abundant research results indicated correlation between all factors of water quality and biology. Coefficients of correlation between the monitored factors and biological factor chla are shown in Table 2.

Table 2 shows that the correlation of Chla with water temperature (*T*) and pH has positive relationship, with correlation coefficients being 0.60 and 0.70, respectively. The correlation of Chla with TN and TP also shows positive tendency with much weaker regression coefficients of 0.04 and 0.39, respectively. It can be concluded, however, that P, rather than N, is more likely to emerge as a limiting factor to nutrient salts in the lake. Increase in TP could enhance the Chla content. There was significant negative relationship (correlation coefficient

Table 2 The coefficients of the correlation between water quality elements and biological factor Chla

	TN	*TP*	*DO*	COD_{Mn}	*SD*	pH	*T*	*Chla*
TN	1.00							
TP	0.08	1.00						
DO	–0.38	0.75	1.00					
COD_{Mn}	–0.06	0.04	0.04	1.00				
SD	–0.47	0.14	–0.01	0.12	1.00			
pH	–0.21	0.19	0.03	0.16	–0.58	1.00		
T	–0.54	–0.09	–0.40	–0.03	–0.33	0.71	1.00	
Chla	0.04	0.39	0.34	0.04	–0.57	0.70	0.60	1.00

of −0.57) between Secci-depth (SD) and Chla. The correlation between temperature and Chla showed positive relationship. The results showed that the concentration of Chla changed with seasons. TP concentration had linear relationship with Chla, i.e. an increase in the concentration of one led to an increase in the other. It was also demonstrated that Qiandaohu Lake responded distinctly to changes in the different factors.

Regression models of phytoplankton in Qiandaohu Lake

With the seven environmental factors taken as independent variables and algae Chla as the dependent variable, data were input into SPSS's stepwise linear regression program, which produced respective correlation equations between the entire lake sampling points, Chla and environmental factors. Use of the stepwise linear regression equation yielded the multiple correlation coefficients shown in Table 3.

The results indicated that the related environmental factors' effect on Chla were different at each sampling spot. Environmental factors had no significant effect on Chla at the Jilingkou and Di'ershuichang sampling points. Of the eleven equations, SD was the most applied variable because it was used six times (Table 2). This indicated that the status of pollution in Qiandaohu Lake could simply be estimated by its water transparency. TP and pH were each applied three times in the equations. Water temperature (*T*) was used twice whereas DO and TN were each applied only once. These results confirmed the earlier mentioned results that indicated a positive correlation between Chla with SD and pH. The results also supported the earlier conclusion that TP rather than TN was more likely to be a limiting factor for the growth of phytoplankton in the lake. It was also concluded that SD, pH and TP were the most correlated factors with the population concentration of Chla phytoplankton. These three variables were the most applied of all the eleven regression models shown in Table 2 and consequently the veracity of the models can easily be validated.

Model forecast

From the water quality monitoring data acquired in 2000, the concentration of Chla was simulated by use of eleven statistic models at each sampling spot. The observed data were compared with the simulated result as shown in Figs.2−12.

The forecasts of eleven regression statistic models can basically reflect seasonal change of Chla at each sampling point, except for the simulated values of some months in model 3. The results indicated the statistic model of the whole lake could forecast the trend of the algae growth and propagation. But there were some differences between the observed data and the simulated values during excessive growth of algae in spring and summer. The primary reason was that the statistical models could not reflect algae movement caused by current and storm in summer.

Table 3 Models of stepwise regression between algae chlorophylla and environmental factors

Sampling points	Variable	Stepwise linear regression equation	Multiple correlation coefficients	General *F*
Jiekou	*T*	$Chla=-3.773+0.523\times T$	0.695	11.218
12# Hangbiao	*SD*	$Chla=20.135-3.926\times SD$	0.666	9.547
Songcunmatou	*TP*, *T*	$Chla=-14.067+518.24\times TP-0.566\times T$	0.793	10.140
Xiaojinshan	*COD*	$Chla=-18.932+18.319\times COD$	0.694	12
Zilaishuichang	*T*, *SD*	$Chla=7.982+299.375\times TP-1.804\times SD$	0.966	70.828
Hangtoudao	*TN*, pH	$Chla=-30.541+12.902\times TN+3.397\times$pH	0.519	10.183
Santandao	*SD*, pH	$Chla=21.837-1.397\times SD-1.819\times$pH	0.846	13.885
Laoshanchukou	*DO*	$Chla=6.598-0.513\times DO$	0.59	6.411
Mishan	*SD*	$Chla=7.833-0.93\times SD$	0.692	10.122
Daba	*SD*	$Chla=6.491-0.751\times SD$	0.662	10.169
The entire lake	*SD*, *TP*, pH	$Chla=-5.468-1.433\times SD+1.885\times$pH $+57.584\times TP$	0.649	42.23

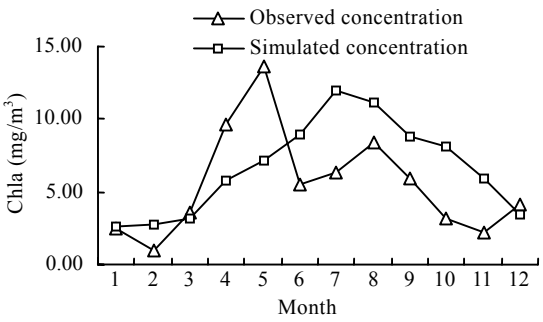

Fig.2 Observed and simulated concentration of Chla in Jiekou in 1999

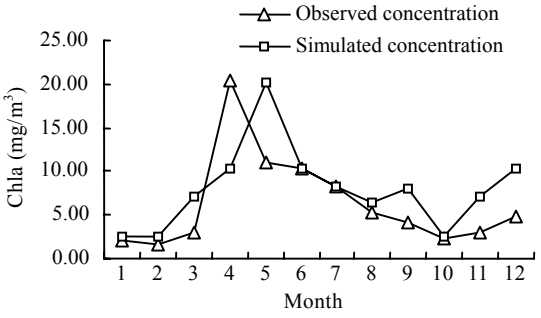

Fig.3 Observed and simulated concentration of Chla in 12# Hangbao in 1999

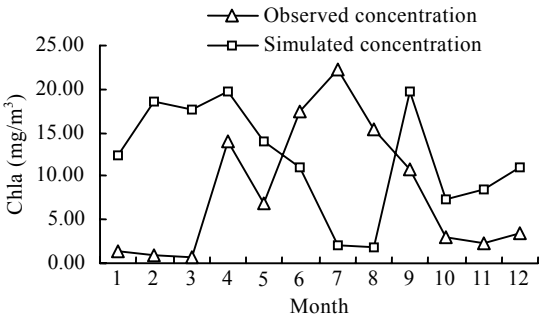

Fig.4 Observed and simulated concentration of Chla in Songchenmatou in 1999

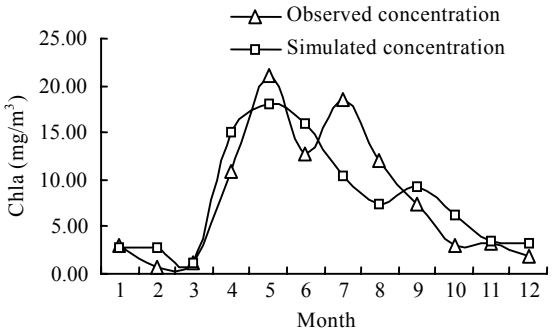

Fig.5 Observed and simulated concentration of Chla in Xiaojingsan in 1999

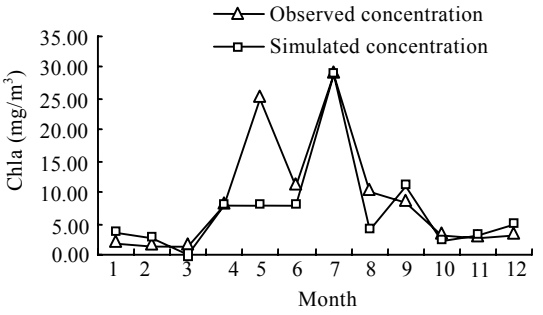

Fig.6 Observed and simulated concentration of Chla in Pailingshuichang in 1999

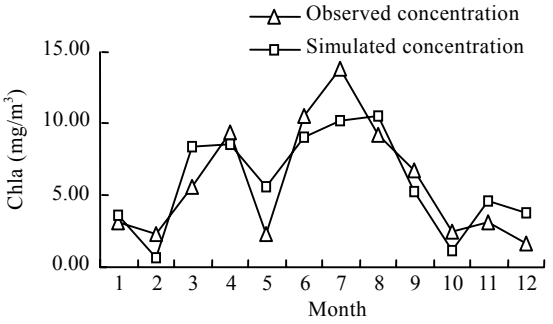

Fig.7 Observed and simulated concentration of Chla in Hangtoudao in 1999

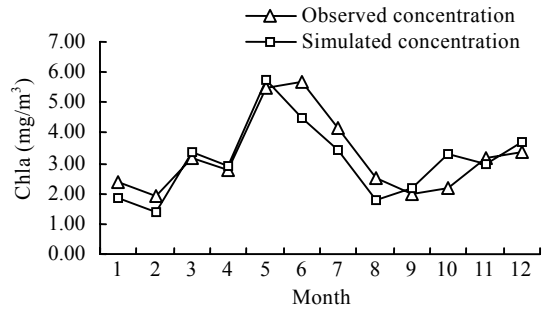

Fig.8 Observed and simulated concentration of Chla in Santandao in 1999

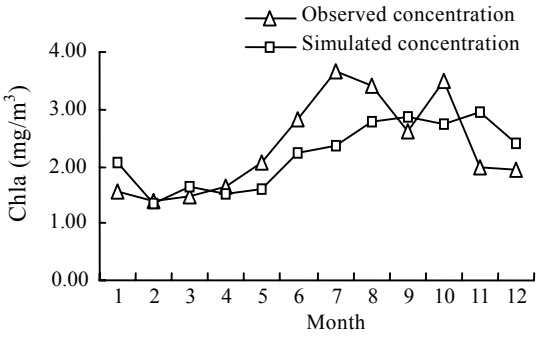

Fig.9 Observed and simulated concentration of Chla in Laosanqukou in 1999

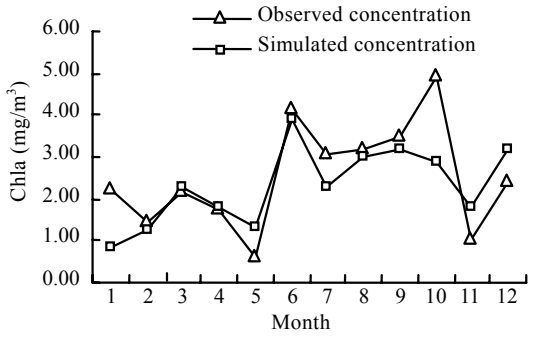

Fig.10 Observed and simulated concentration of Chla in Misan in 1999

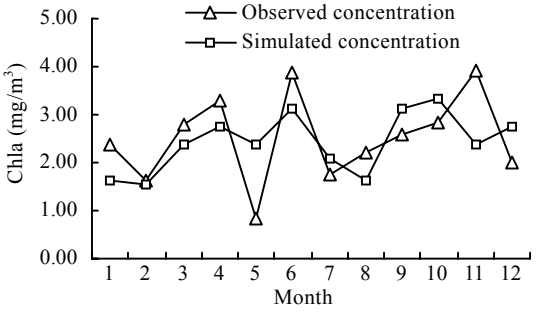

Fig.11 Observed and simulated concentration of Chla in Daba in 1999

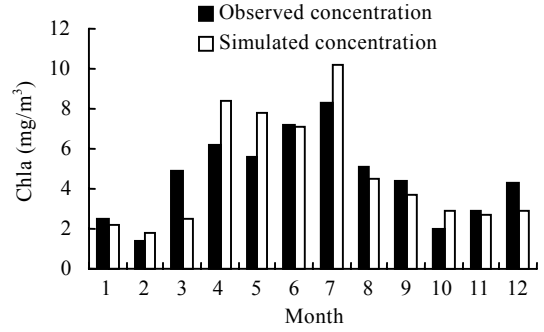

Fig.12 Observed and simulated concentration of Chla in the whole lake in 1999

SUMMARY

In summary, we present following conclusions:

1. Correlation analysis between the environmental factors indicated that water temperature (*T*) obviously affected the growth and propagation of phytoplankton. Phytoplankton growth significantly varied according to seasons. The concentration of chla had significant effect on water transparency and showed an obviously negative relationship. TP is likely to become the limiting factor of phytoplankton growth.

2. SD, pH and TP were the most applied variables in eleven regression models and the three variables were the most significantly related to concentration of Chla. The regression model of the entire lake was:

$$Chla=-5.468-1.433\times SD+1.885\times \mathrm{pH}+57.584\times TP$$

3. In the forecast of eleven regression statistic models, the simulated values were consistent basically with the observed data and could basically reflect seasonal change of the growth and propagation of phytoplankton. In order to make models to predict accurately, more data should be supplied.

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