# 运用灰关联模型分析大鹏湾叶绿素-b与海水理化因子的关系

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**摘要**: 运用灰色理论的系统分析模型研究叶绿素-b与水温、浮游动物、盐度、溶解氧、酸碱度、磷酸盐、亚硝酸盐、硝酸盐、铁和锰等10个海水理化因子间的关系。所有样品数据采自深圳大鹏湾的盐田海域。灰关联值的计算及其排序结果表明: 硝酸盐、磷酸盐、亚硝酸盐和酸碱度对叶绿素-b的浓度比其他海水理化因子有着较大的影响。本文建立叶绿素-b与这4个海水理化因子的灰模型{GM(1, n)}，结果表明，相关因子与叶绿素-b的浓度变化有着较好的吻合。

**关键词**: 灰模型{GM(1, n)}; 叶绿素-b; 海水理化因子; 大鹏湾
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# THE RELATIONSHIPS BETWEEN CHLOROPHYLL-b CONCENTRATION AND RELATED ENVIRONMENTAL FACTORS OF SEAWATER IN DAPENG BAY BASED ON GREY MODEL RELATIVE ANALYSIS

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**Abstract:** The systematic analytical method of grey theory was used to study the relationships between chlorophyll-b and 10 environmental factors (temperature, plankton biomass, salinity, dissolved oxygen (Do), pH, phosphate, nitrate, nitrite, Fe, and Mn) in seawater. Samples were collected from Dapeng Bay of the South China Sea, near Yan-tian area of the Shenzhen City. The resulting grey relative values and their permutation indicated that nitrate, phosphate, nitrite and pH had more influence on the chlorophyll-b concentration in seawater than any other factors. A grey model {GM (1, n)} was established to relate chlorophyll-b concentration with four factors among the ten.

**Key words:** Grey model {GM (1, n)}; Chlorophyll-b; Environmental factors; Dapeng Bay

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The chlorophyll concentration in the sea, an indicator of algal density, is an important index for primary production produced by phytoplankton. The concentration of these primary producers is closely related to the primary productivity in the sea area, which directly or indirectly influences the magnitude of productivity of other organisms in seawater. The chlorophyll in the cells consists of chlorophyll-a, chlorophyll-b and chlorophyll-c depending on which alga taxa. Generally, chlorophyll (including chlorophyll-b) concentration in the seawater increases with the increase of population density of phytoplankton. Therefore, the chlorophyll-b concentration is closely connected to the density of phytoplankton.

Grey theory has been broadly applied in the last decade since Deng Julong suggested the division of systems information to white, grey and black[1-3]. Studies on the relationship between biomass of *Noctiluca scientillans* Macartney or *Prorocentrum sigmoides* Bohm (two red tide organisms) and various physico-chemical factors of seawater by the method of grey system theory[4-8], as well as studies on the reasons why *N. scientillans* and *P. sigmoides* may produce red tide by using models of time sequence, regression and differential equation and others have been reported[9-15]. These studies indicated that 10 of 29 factors that were measured had the greatest influence on the above two species of algae. The ten most influential factors were plankton, nitrate, phosphate, nitrite, pH, dissolved oxygen, Fe, Mn, temperature and salinity. This paper presents a further study on the relationship between chlorophyll-b concentration in seawater and the related environmental factors by analytical method of grey system theory.

# 1 Method

## 1.1 Sampling

All samples were analyzed of the 7 algae forming red tide (including *Prorocentrum sigmoides, Skeletonema costatum, Pseudo-nitzschia pungens, Noctiluca scientillans, Chaetoceros* ssp., etc.) and 29 environmental factors. Twenty-seven samples were collected from seawater near Yan-tian in Dapeng Bay of the South China Sea at three-day intervals from April 2nd to June 22nd in 1990 at three sites located about 100 m ($S_1$), 500 m ($S_2$), and 1000 m ($S_3$) from the shore, respectively. Two depth levels were chosen in each site. The depth of the upper level at three sites was 0.5 m below sea level, and the depths of lower level were at 3 m, 5 m and 9 m below sea level. The geographical position of the sites investigated is shown in Figure 1.

Plankton were sampled by a vertical drag with qualitative and quantitative methods. The net was 37 cm in diameter, and 130 cm in length with a 70 $\mu$m aperture, according to the Standard of Ocean Survey — State Oceanic Administration (SOA), 1975. This qualitative and quantitative sampling was undertaken by the Institute of Hydrobiology, Jinan University. The samples for the study of physical and chemical factors, including chlorophyll-a, chlorophyll-b and chlorophyll-c, were analyzed according to the Tentative Standard of Sea Pollution Survey (1979), and provided by Marine Environmental Monitoring Center of South China Sea Branch, SOA.

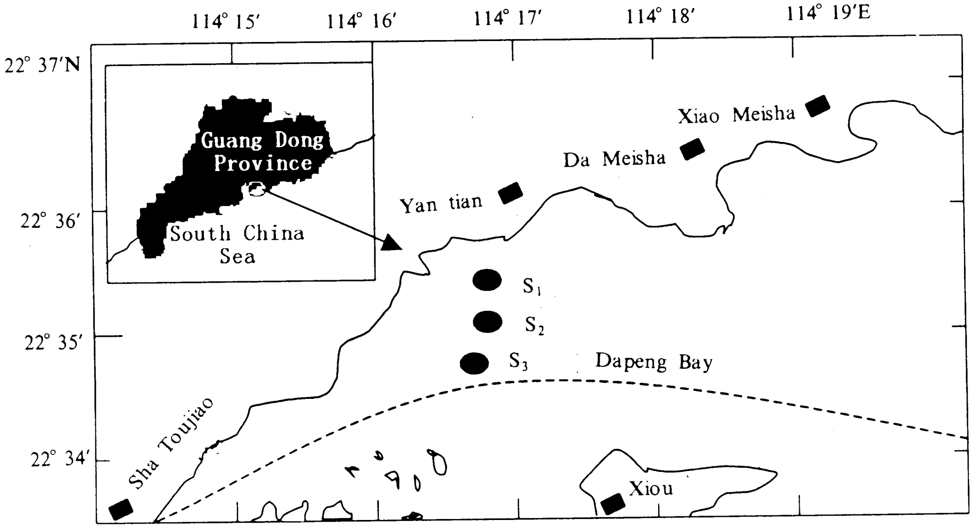


Fig. 1 Sketch map showing the sites investigated

## 1.2 Grey relative analysis

Based on the above investigation, the chlorophyll-b concentration [Chl.b ($\mu$g $L^{-1}$)] of seawater in Dapeng Bay was used as the analyzed sequences $\{X_0(k)|k=1,2,\cdots,N\}$, where sampling number N=27, and 10 factors including biomass of plankton [P (ind $L^{-1}$)], temperature [T(℃)], salinity [S(‰)], dissolved oxygen [DO(mg $L^{-1}$)], pH, phosphate [$PO_4$($\mu$g $L^{-1}$)], nitrite [$NO_2$($\mu$g $L^{-1}$)], nitrate [$NO_3$($\mu$g $L^{-1}$)], Fe($\mu$g $L^{-1}$) and Mn($\mu$g $L^{-1}$) were to be regarded as comparative sequences or sub-sequences $\{X_j(k)|\ k=1,2,\cdots,N\}$ $(j=1,2,\cdots,10)$. The calculation method[16,17] of grey system relative degree is as follows:

All the sequences are initiated for making them comparable. Let the analyzed sequences be:

$$\{Y_0(k)|k=1,2,\cdots,N\}=\{Y_0(1),Y_0(2),\cdots,Y_0(N)\}$$
$$=\left\{\frac{X_0(1)}{M_0},\frac{X_0(2)}{M_0},\cdots,\frac{X_0(N)}{M_0}\right\}$$

where

$$M_0=\frac{1}{N}\sum_{k=1}^{N}X_0(k)$$

So the comparative sequences are:

$\{Y_j(k)|k=1,2,\cdots,N\}=\{X_j(k)/M_j|k=1,2,\cdots,N\}$ $(j=1,2,\cdots,10)$, where

$$M_j=\frac{1}{N}\sum_{k=1}^{N}X_j(k)$$

Let $\zeta_i=\{\zeta_i(k)|k=1,2,\cdots,N\}(i=1,2,\cdots,10)$ be a relative coefficient between the analyzed sequence $\{Y_0(t)\}$ and the comparative sequence $\{Y_j(t)\}$, which is called the grey relative coefficients. Then

$$\zeta_i(k)=\frac{\underset{k}{\text{Min}}\ \Delta_i(k)+\underset{k}{\text{Max}}\ \Delta_i(k)}{\Delta_i(k)+\rho\underset{k}{\text{Max}}\ \Delta_i(k)}\qquad (i=1,2,\cdots,10;\ k=1,2,\cdots,N)$$

where $\Delta_i(k)=|Y_0(k)-Y_i(k)|$ and $\rho\ (0<\rho<1)$ is a distinguished coefficient. Here we take it as $\rho=0.1$. Let

$$\gamma_i=\frac{1}{N}\sum_{k=1}^{N}\zeta_i(k)\qquad (i=1,2,\cdots,10)$$

where $\gamma_i$ is a relative degree between the analyzed sequence $\{Y_0(t)\}$ and the comparative sequence $\{Y_j(t)\}$.

The relative values between the analyzed sequences and subsequences for samples of upper and lower levels of three sites are calculated. The results of relative values are listed in Table 1, and the results of their permutation are in Table 2.

**Table 1 Relative values between chlorophyll-b and ten various factors**

| Site | Depth level | T* | S* | Do* | pH | $PO_4$ | $NO_2$ | $NO_3$ | Fe | Mn | P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_1$ | Upper | 0.731 | 0.699 | 0.777 | 0.794 | 0.797 | 0.803 | 0.799 | 0.761 | 0.771 | 0.728 |
| | Lower | 0.733 | 0.693 | 0.720 | 0.786 | 0.797 | 0.791 | 0.798 | 0.717 | 0.709 | 0.743 |
| $S_2$ | Upper | 0.740 | 0.747 | 0.750 | 0.824 | 0.832 | 0.833 | 0.833 | 0.765 | 0.786 | 0.770 |
| | Lower | 0.777 | 0.741 | 0.781 | 0.846 | 0.863 | 0.855 | 0.867 | 0.802 | 0.790 | 0.794 |
| $S_3$ | Upper | 0.793 | 0.780 | 0.783 | 0.832 | 0.835 | 0.843 | 0.838 | 0.815 | 0.840 | 0.808 |
| | Lower | 0.780 | 0.763 | 0.772 | 0.849 | 0.871 | 0.860 | 0.869 | 0.769 | 0.781 | 0.771 |

*T=Temperature; S=Salinity; Do=Dissolved oxygen

**Table 2 The averages and permutation of the relative values from three sites**

| | T* | S* | Do* | pH | $PO_4$ | $NO_2$ | $NO_3$ | Fe | Mn | P |
|---|---|---|---|---|---|---|---|---|---|---|
| Average | 0.759 | 0.737 | 0.764 | 0.822 | 0.833 | 0.831 | 0.834 | 0.772 | 0.780 | 0.769 |
| Permutation | 9 | 10 | 8 | 4 | 2 | 3 | 1 | 6 | 5 | 7 |

*See Table 1.

### 1.3 Construction of grey model

Based on the above grey relative analyses, th: first four factors, i.e. nitrite, phosphate, nitrate and pH, are chosen to bulid the grey model $\{GM(1, n)\}$ of chlorophyll-b concentration as follows:

Let $\{X_i^{(0)}(k)|\ k=1,2,\cdots,N\}\ (i=1,2,\cdots,n)$ be the primal sequences of chlorophyll-b, nitrite, phosphate, nitrate and pH separately, where $N=27$ is the number of samples and $n=5$ is the number of variables in the grey model.

To provide medial information for building the model, the randomness of the primal sequences is weakened by a m multi-accumulated generating operation (m-AGO) to the primal sequences as follows:

$$X_i^{(m)}(k)=\sum_{t=1}^{n} X_i^{(m-1)}(t) \qquad (k=1,2,\cdots,N;\ i=1,2,\cdots,n;\ m=3)$$

Furthermore, the grey model is built as

$$\frac{dX_1}{dt}+aX_1=\sum_{i=2}^{n} b_{i-1}X_i$$

Then $\hat{a}=[a,b_1,b_2,\cdots,b_{n-1}]^T=(B^TB)^{-1}B^TY_N$

where $Y_N=[X_1(2),\ X_1(3),\ \cdots,\ X_1(N)]^T$

$$B=\begin{bmatrix} -\frac{1}{2}(X_l(2)+X_1(1), & X_2(2) & \Lambda & X_n(2) \\ -\frac{1}{2}(X_1(3)+X_1(2), & X_2(3) & \Lambda & X_n(3) \\ M & M & O & M \\ -\frac{1}{2}(X_1(N)+X_1(N-1), & X_2(N) & \Lambda & X_n(N) \end{bmatrix}$$

The method of regression was used to calculate the parameter â for samples at upper and lower levels of the three sites ($S_1$, $S_2$ and $S_3$). The values of â are listed in Table 3. By means of a 2-time Inverse Accumulated Generation Operation (2-IAGO), the GM model values $X_1(k)$ of chlorophyll-b are reverted to corresponding values of the model, i.e.

$$X_1^{(m-1)}(k)=X_1^{(m)}(k)-X_1^{(m)}(k-1)$$

**Table 3 Parameter values of the model for samples from upper and lower levels of three sites in Dapeng Bay**

| Site | Depth level | a | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|---|---|
| $S_1$ | Upper ($S_{11}$) | -0.4647 | -1.6224 | 1.7196 | -0.3596 | -1.2451 |
| | Lower ($S_{12}$) | 0.0947 | 0.5428 | 0.3049 | -0.4539 | -0.2801 |
| $S_1$ | Upper ($S_{21}$) | -0.2953 | -0.9191 | -0.2402 | -0.1388 | 0.9431 |
| | Lower ($S_{22}$) | 0.1896 | -0.7338 | -0.5682 | 0.1542 | 1.4493 |
| $S_3$ | Upper ($S_{31}$) | 0.3831 | -0.3799 | 0.5084 | -0.7879 | 1.0469 |
| | Lower ($S_{32}$) | -0.6016 | -0.9194 | 0.1444 | -0.1336 | 1.5324 |

And then, the figures of comparison of the corresponding values in GM model with samples of chlorophyll-b are constructed in Figure 2 where the vertical coordinate is chlorophyll-b concentration ($50^{-1}$ $\mu g\ L^{-1}$) and the abscissa is days.

## 2 Results

According to the Tables 1 and 2, four factors influence chlorophyll-b concentration more than other environmental factors of seawater. These are, in descending order of importance, nitrate, phosphate, nitrite and pH. The result is consistent with the work of the papers listed in References. It is shown that the phytoplankton absorbs nitrate, nitrite and phosphate as nutritious salt, so the biomass of phytoplankton increases, and chlorophyll-b concentration

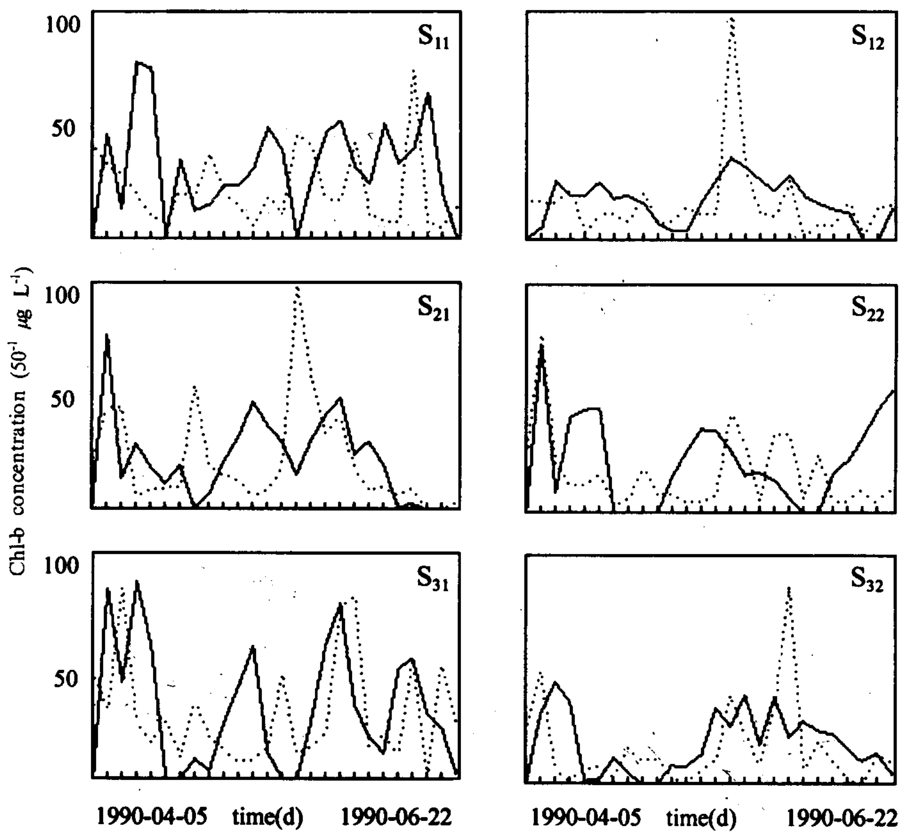


Fig. 2 Comparison of calculated (——) and measured values (·····) of chlorophyll-b concentration at upper and lower levels of three sites in Dapeng Bay

also increases at the same time. Thus, it also indicates that chlorophyll-b concentration is affected directly by these four environmental factors of seawater.

On the other hand, according to the values in Figure 2, it can be seen that the model corresponding values (calculated values) on the upper and lower levels of the three sites coincide with the sampled values (measured values) at least at peak values. It means that this grey relative model is suitable to identify chlorophyll-b concentration, and the model can be used to analyze the biomass of chlorophyll-b as well.

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