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Environmental flow requirements (EFRs) related to preference of phytoplankton in the Yellow River Estuary (YRE) based on an ecohydrodynamic model

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Abstract: The response of ecological processes to hydrological processes is a critical issue in the assessment of environmental flow requirements in estuaries. Considering its representative function of the primary productivity in estuaries, the phytoplankton community was selected as the bioindicator to indicate the variation of ecosystems influenced by hydrological processes in estuaries. Based on the regression analysis, a response relation model was established for describing the relationship between characteristics of phytoplankton communities (chlorophyll a, Fucoxanthin, chlorophyll b, and pyridinin) and indicating factors including salinity, COD, ammonia nitrogen, and dissolved oxygen. The biomass objective of high nutritional level organisms, the biomass of phytoplankton communities, and the concentration of diagnostic pigments were proposed in the Yellow River Estuary according to the principle of nutritional energy flow of ecosystem. An ecohydrodynamic model combined a phytoplankton growth model and a hydrodynamic model was developed in order to simulate relationship between river discharges and preference of phytoplankton in the Yellow River Estuary. Threshold values of environmental flows in the estuary were determined based on objectives of ecosystem and the relationship between ecological processes and hydrological processes in the Yellow River Estuary. It is concluded that the maximum, medium, and minimum annual environmental flows account for 105~111%, 65~68% and 31.7~32.4% of natural runoff in the YRE.

Key words: Phytoplankton community; Diagnostic pigments; Environmental flow; Ecohydrodynamic model; The Yellow River Estuary

1 Introduction

Estuaries are described as places where freshwater from rivers mixes with saltwater from the sea. The salinity and other environmental factors (such as COD, Do, total nitrogen, et al.) gradients are significant for migrated species in estuarine ecosystems. However, estuarine ecosystems are also sensitive to variation of hydrological processes affected by the upstream utilization of freshwater flows. The response of ecological processes to hydrological processes is a critical issue in the assessment of environmental flow requirements in estuaries. Phytoplankton community is the physical and energy foundation of the estuary ecosystem, and also used to be taken as the indicator species for ecosystem healthy. In order to establish relationship between ecological processes and hydrological processes, ecohydrodynamic models were developed based on a combination of different types of phytoplankton growth models and hydrodynamic models (Spillman, 2007; Håkanson, 2007; Skarðhamar, 2007; Lessin and Raudsepp, 2007; Lopes et al, 2009). Due to the complexity and mobility of phytoplankton bio-process, the parameters in phytoplankton model were usually determined by the empirical formula and the experimental measured data.

In this paper, environmental flow requirements (EFRs for short) were determined by considering requirements of phytoplankton community objectives, which represented by diagnostic pigments. Different levels of the FIRs are proposed and the critical periods of protecting the freshwater inflows are identified. Finally, suggestions for water resource management of the YRE are presented.

2 Ecohydrodynamic model

2.1 Phytoplankton bio-progress model

Phytoplankton communities were selected as the bioindicator of ecosystem health of the estuary. The temporal and special distribution of phytoplankton communities were analyzed in the YRE based on an on-field monitoring. The diagnostic pigments including Fucoxanthin, chlorophyll b, pyridinin, and chlorophyll a, were identified to represent characteristics of phytoplankton communities in YRE. The abundances of each community were variability in different seasons, the abundance of diatom in autumn occupied higher percentage than that in spring, but the abundances of green algae and blue algae in autumn occupied lower percentages than in spring.

By using the method of quantitative ecology (canonical correspondence analysis, CCA), the relation between the different environmental factors and the variation of phytoplankton communities was determined. It is found that the most important environmental factors that influence variation of diagnostic pigments include salinity, COD, ammonia nitrogen, and dissolved oxygen.

The relationship between phytoplankton communities and critical factors of environmental flows was proposed in the YRE in different seasons. After conducting a regression analysis, a response relation model describing this relationship was derived.

Theoretically, there is the exponential relationship between the diagnostic pigments concentration and critical factors for EFRs.

$$y = ae^{bx} \quad (1)$$

$$\ln y = \ln a + bx_i \quad (2)$$

$$Y_i = a_{ij} + b_{ij}x_j \quad (3)$$

where x_j is the j^{th} critical factors; Y_i is logarithm value of the i^{th} diagnostic pigments; a_{ij} is the constant value; b_{ij} is the coefficient.

According to the experimental data of diagnostic pigments and critical factors, the linear regression diagnostic pigments formulas are determined. The coefficient values are shown in Table 1.

Table 1 Coefficient values in the linear regression formulas

Diagnostic pigments	Critical factors for EFRs			
	salinity	COD	ammonia nitrogen	dissolved oxygen
chlorophyll a	0.032	0.636	0.058	0.447
Fucoxanthin	-0.139	0.492	-0.043	-0.331
chlorophyll b	-0.012	0.041	-0.004	0.028
pyridinin	-0.053	0.188	-0.016	0.126

The results of t test for the linear regression formulas are shown in Table 2. Based on the corresponding t value, the P value is lower than a (significance level), therefore, there is a significant linear relationship between critical factors and diagnostic pigments.

The average errors between the simulation results and the experimental data are shown in Table 2, which are range from -20% to 20%. It is concluded that these linear regression models can be applied in calculating the diagnostic pigments concentrations based on the concentration of critical factors of EFRs values.

Table 2 Errors between simulation results and experimental data (%)

	chla	fuco	chlb	perid
Spring	16.2%	18.4%	-20.7%	18.5%
Autumn	13.3%	17.9%	-16.1%	-15.9%

2.2 Hydrodynamic and water quality model

The depth-intergrated equations for conservation of motion and water are the same to the model described by Zhao et al (2009). In addition, the two-dimensional convection-diffusion equation integrated along depth is described by Zhao et al (2009). The water quality parameters in this model contains BOD, COD, ON(organic nitrogen, AMN(ammonia nitrogen) and DO(dissolved oxygen). The model was validated using hydrographic data for two tidal cycles (from 21 - 26 August, 2003) obtained several measurement stations in terms of tidal heights, current velocity and water quality parameters.

3 EFRs in the YRE

3.1 Ecological objectives for the EFRs

According to the higher nutrition level of organisms' biomass, the primary nutrition level organisms' biomass (phytoplankton i.e.) is calculated by the energy flows formula, which is written as:

$$A_p \cdot t^{r-1} = A_r \quad (4)$$

$$A_p = A_r / t^{r-1} \quad (5)$$

where A_p is the biomass of phytoplankton communities; t is the transferring rate between two nutrition levels(10%-20%); A_r is the biomass on the r^{th} nutrition level.

The annual fish catches were 258 kg/ha, 117 kg/ha, 77.5 kg/ha, and 8.5kg/ha in 1959, 1982, 1992, 1998, which decreased sharply in these 50 years. The nutrition level of fish in YRE decreased from 4.1 to 3.4 (Zhang, 2005). According to fish catches in different decades and different transferring rates of 10%, 15%, and 20%, the phytoplankton community biomasses can be determined (Table 3).

Table 3 Ecological objectives in critical periods in the YRE (logarithm values)

Diagnostic pigments	Spring			Autumn		
	Maximum	Medium	Minimum	Maximum	Medium	Minimum
chlorophyll a	2.51~0.26	-0.26~-1.97	-1.64~-3.37	0.87~-1.15	-0.16~-1.93	-0.46~-2.19
Fucoxanthin	1.83~0.19	-0.19~-1.43	-1.19~-2.45	0.71~-0.94	-0.13~-1.58	-0.38~-1.79
chlorophyll b	0.15~0.02	-0.02~-0.12	-0.10~-0.20	0.11~-0.14	-0.02~-0.24	-0.06~-0.27
pyridinin	0.699~0.07	-0.073~-0.55	-0.456~-0.94	0.151~-0.20	-0.028~-0.34	-0.081~-0.38

Based on the diagnostic pigments objectives in Table 3, and the ecohydrodynamic model combined the response relation model in critical habitats, environmental flows can be

determined during critical periods in the Yellow River Estuary. The required monthly environmental flows can then be derived based on the objectives for temporal variation in the water inflows (Sun et al, 2009).

4. Results and Discussions

Considering objectives of diagnostic pigments, the threshold value of environmental flows can be determined at critical habitats (Fig. 1 and Fig. 2).

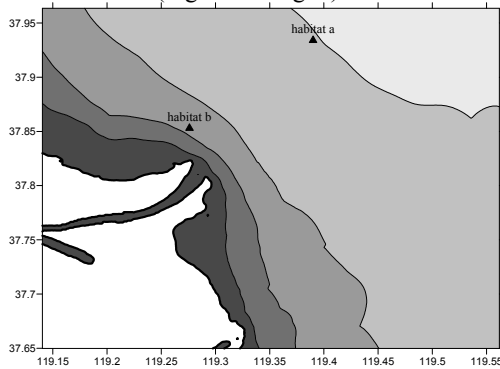


Fig. 1 Two critical habitats in the YRE

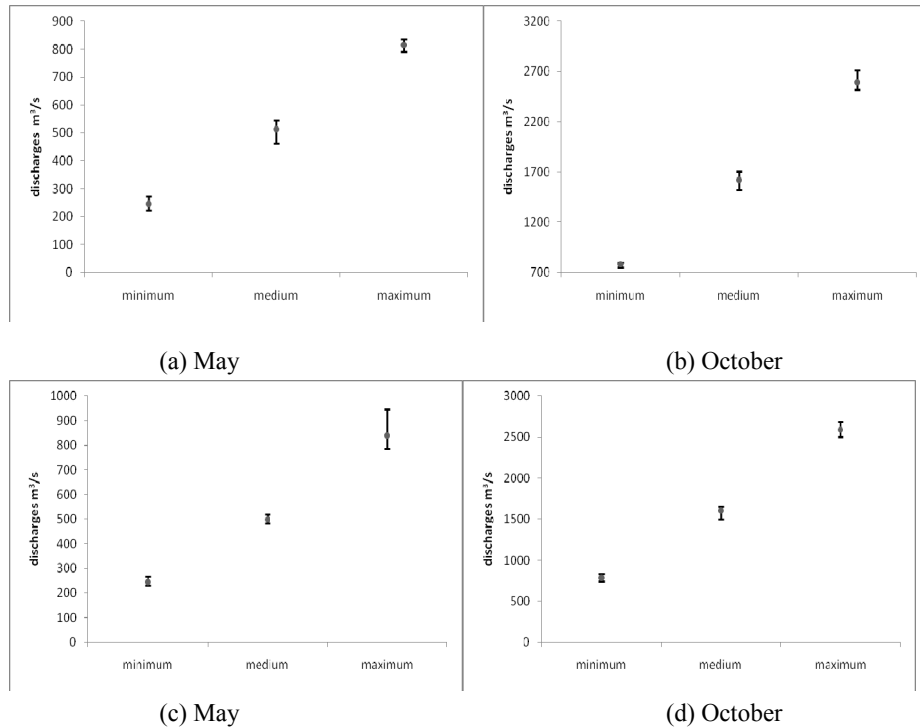


Fig. 2 EFRs for critical habitat in the YRE . (a) and (b) is the EFRs for the critical habitat a; (c) and (d) is for the critical habitat b.

The maximum, medium and minimum annual environmental flows of critical habitats are $452.4\sim 476.9\times 10^8\text{m}^3$, $280.2\sim 291.4\times 10^8\text{m}^3$, and $136.4\sim 139.4\times 10^8\text{m}^3$ respectively, which account for 105~111%, 65~68%, and 31.7~32.4% of natural runoff. The actual river discharge can meet requirements of the minimum environmental flows except April. However, it cannot satisfy both the medium and maximum water requirements of habitats. Notable changes have occurred on the flow regime of the YRE(Fig. 3). Since 1990, the status of ecosystem health were worse than that before in the Yellow River Estuary.

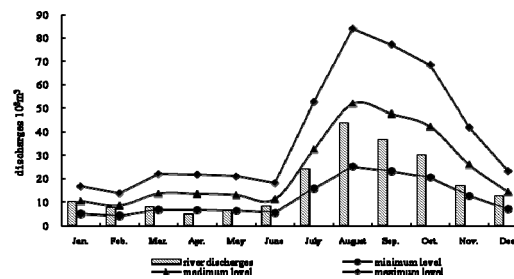


Fig. 3 the EFRs for the critical habitat and the actual river discharges (after 1980)

5. Conclusions

Salinity, COD, ammonia nitrogen, and dissolved oxygen were identified as the most important influencing factors on variations of diagnostic pigments including Chlorophyll a, Fucoxanthin, chlorophyll b, and pyridinin. Based on a response relation model describing the relationship between phytoplankton communities and indicating factors of environmental flows, an ecohydrodynamic model was used to describe the relationship between river discharges and preference of phytoplankton in the Yellow River Estuary. The maximum, medium and minimum annual environmental flows of critical habitats are $452.4\sim 476.9\times 10^8\text{m}^3$, $280.2\sim 291.4\times 10^8\text{m}^3$, and $136.4\sim 139.4\times 10^8\text{m}^3$ respectively, which account for 105~111%, 65~68%, and 31.7~32.4% of natural runoff.

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