Temperature, light and nutrient based model on spring primary production for heavily eutrophied subtropical coastal waters (1)

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Noxious algal blooms caused by toxigenic or non-toxigenic phytoplanktonic species during spring has attracted increasing attention worldwide especially since 1980's. Besides neurotoxic, paralytic and diarrhatic shellfish poisoning toxins, sometimes only anoxia has caused mass mortalities of many marine consumers during these toxic and/or nontoxic blooms (STEIDINGER, 1983; WYATT, 1990). In any case, these blooms have constituted a risk factor both as a threat to public health and aquaculture in sub-tropical regions such as eastern coast of Aegean Sea, Izmir Bay (JACQUES and SOURNIA, 1980; KORAY, 1987; MONTRESOR *et al.*, 1990). Although the impact of red-tides on some fish species has been documented since 1950's for the region (NUMANN, 1955; ACARA and NALBANDOGLU; 1960; KORAY, 1984; KORAY and BUYUKISIK, 1988; KORAY, 1990), little is known how the primary and secondary ecological factors influence red-tides and other noxious spring phytoplankton bloomings.

This study was conducted in the inner part of Izmir Bay in which "color-tides" were continuously observed between March and July. Bi-weekly or three weekly visits to the four sampling stations were carried out to provide a detailed time series. The water samples were collected from 0.5, 2.5, 5.0 and 10.0 m. with a Hydro-Bios water sampler (1.5 l^{-1}) and were stored in polyethylene bottles in the dark and cool carrying boxes for chemical analyses. Temperature and light were determined *in situ*. Inorganic nutrigenous nutrients, silica phosphate, pH, salinity, Chl-a and phaeopigment determinations were realized in the laboratory according to the procedures of STRICKLAND and PARSONS (1972).

In this study, an empirical multiple regression model was used to develop a predictive equation between dependent variable Chl-a, and the physico-chemicals that were thought to be independent but potentially important to phytoplankton production during spring bloomings. Standardization of the dependent and independent variables (n=109 for each variable) were required to eliminate the effect of differences in measurement scale, to show the relative standardized strenghts of the effects of independent variables on the Chl-a and stabilize the variance. For prediction equation, $\log_{10}(Y_i+1)$ transformation was preferred to simplify conversation to original measurement units and to normalize the data. The stepwise selection procedure was used to obtain estimate of the regression coefficients and significant relationships. The standardized data were also used for PCA.

The multiple regression equation in standard format with orthophosphate P, temperature, light, Si, ammonium N and nitrate N was highly significant ($F = 17.551$, $p < 0.05$) respectively and explained 52 % of the total variance in the data (Table I). The standard partial regression coefficients indicated that as P, temperature, light and nitrate N increased, Chl-a increased.

Table I: Parameters of multiple regression equation in standard format for dependent variable Chl-a (standardized variables).

Variables	Reg.	Coeff. F	Sig. level
Orthophosphate P	0.499	20.474	0.000
Temperature	0.358	20.241	0.000
Light	0.288	15.656	0.000
Si	-0.217	5.369	0.022
Ammonium N	-0.214	5.306	0.023
Nitrate N	0.152	4.029	0.048

Si and ammonium N are inversely correlated with the Chl-a increases.

This pattern clearly established Si controlled bloom succession. Although P was the most important parameter affecting the equation, it was never limiting because of rapid recycling and continuous inputs from sewage.

For predictive purposes, conventional regression without intercept was obtained as function of the same variables;

$$\log(\text{Chl-a}+1) = 1.445 \log(PO_4^{-3}+1) + 0.676 \log(T+1) + 0.132 \log(L+1) - 0.518 \log(SiO_4+1) - 0.128 \log(NH^+_4+1) + 0.199 \log(NO^-_3+1)$$

The six environmental independent variables described 92 % of the total variance in predictive regression equation, however, effects of ammonium and nitrate were almost negligible in the final predictive regression ($p < 0.46$).

The principal component analyses performed on the standardized nutrients, primary ecological factors, light, primary (Chl-a) and secondary (phaeopigments) production units described 95 % of the total variance within the nine PCs. The first seven PCs which were used to calculate multiple regression equations explained 88 % of the variation in production during blooming season. The eigenvectors were included in Table II. Practically, the first PC can be interpreted as a nutrient concentration and biomass component (P, ammonium N, Si and Chl-a). PC 2 summarized biomass and photosynthetic activity (Chl-a, DO, pH, nitrite N) while the other PCs were generally interpreted as nutrient and primary ecological factor components.

Table II: The component weights of the first seven PCs.

Variables	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
P	0.516	-0.148	0.083	-0.092	-0.049	0.059	-0.016
Ammonium N	0.351	-0.260	-0.319	-0.022	-0.260	-0.210	-0.454
Nitrate N	0.127	0.139	-0.360	-0.038	-0.733	0.118	0.253
Light	0.232	0.279	-0.279	0.309	0.287	-0.397	-0.130
Temp.	0.258	0.289	0.320	-0.495	-0.080	-0.112	0.008
Si	0.384	-0.291	0.239	0.262	0.023	0.015	-0.309
Chl-a	0.338	0.449	0.055	-0.105	-0.053	0.148	0.081
Oxygen	0.055	0.486	0.378	0.113	-0.000	0.126	-0.342
pH	0.007	0.434	-0.414	0.324	0.101	0.044	-0.030
Nitrite N	-0.262	0.037	0.251	0.420	-0.431	0.275	-0.030
Salinity	0.177	-0.041	0.368	0.486	-0.175	-0.409	0.556
Phaeo.pig.	0.331	-0.127	-0.092	0.200	0.272	0.697	0.262

Both multiple regression coefficients and principal components indicated that phytoplankton biomass during blooms increased with increasing P, nitrate N, light and temperature. Species succession was mainly controlled with Si. These informations also suggest that phosphorus controls the amount of phytoplankton biomass in red-tide season, however, phosphorus loading in the system is adequate and never limiting in eutrophied Izmir Bay.

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