The Journal of the Oceanological Society of Korea
Vol. 16, No. 2, p. 43~48, December, 1981

SEAWATER QUALITY AND RED TIDES IN JINHAE BAY: I. RELATIONSHIPS BETWEEN WATER QUALITY PARAMETERS AND RED TIDES

Kwang Woo Lee, Gi-Hoon Hong, Dong-Beom Yang and Soo-Hyung Lee
Chemical Oceanography Laboratory, Korea Ocean Research and Development Institute

ABSTRACT

To carry out baseline studies on monitoring systems for red tides in Jinhae bay, measurements and analyses were made on seawater samples from 15 sampling stations during 15 months from July, 1979.

Water quality parameters studied are temperature, pH, DO, salinity, COD, SS, NO_3, NO_2, PO_4, SiO_2, Ca, Mg, Cd, Cu, Pb, Zn, Chlorophyll *a*, diatoms and dinoflagellates.

Multiple regression analyses were undertaken with chlorophyll *a*, cell numbers of diatoms and dinoflagellates as the dependent variables and water quality parameters as the independent variables. The results showed that biomass, expressed as total cell numbers of diatoms and dinoflagellates, was largely influenced by COD, salinity and nutrients.

INTRODUCTION

The municipal and industrial wastewaters of the Changwon and Masan industrial complexes have been deteriorating at a rapid pace the water quality of Jinhae Bay. One impact of this coastal water pollution is shown by frequent occurrences of red tides, a phenomenon of eutrophication, which causes damages as well as poisoning to aquaculture of fish and shellfish.

Although red tides in Japan have been studied quite extensively and intensively, only a few studies have been reported on red tides in Jinhae Bay since the early 1960's (Park and Kim, 1967; Cho, 1978; Cho, 1979; Yoo and Lee, 1979; Yoo and Lee, 1980).

The objectives of the present study are to investigate relationships among the physicochemical and biological parameters in different zones of Jinhae Bay and to discuss results of multiple regression analyses on cell numbers of diatoms and dinoflagellates with various water quality parameters.

Multiple regression analysis can be used in estimation or prediction of values of one characteristics (red-tide organisms) from knowledge of several other characteristics (water quality parameters).

MATERIALS AND METHODS

The location of 15 sampling stations is shown in Fig. 1. Seawater samples were collected from surface (1 m below) and bottom (2 m above) with a van Dorn sampler (5 *l*) nearly once a month for 15 months from July 1979 to September 1980.

Methods of measurements and analyses for water quality parameters and red-tide organisms are shown elsewhere (Strickland and Parsons, 1972; EPA, 1979; Lee *et al.*, 1980; KORDI, 1980; Lee *et al.*, 1981). Total biomass

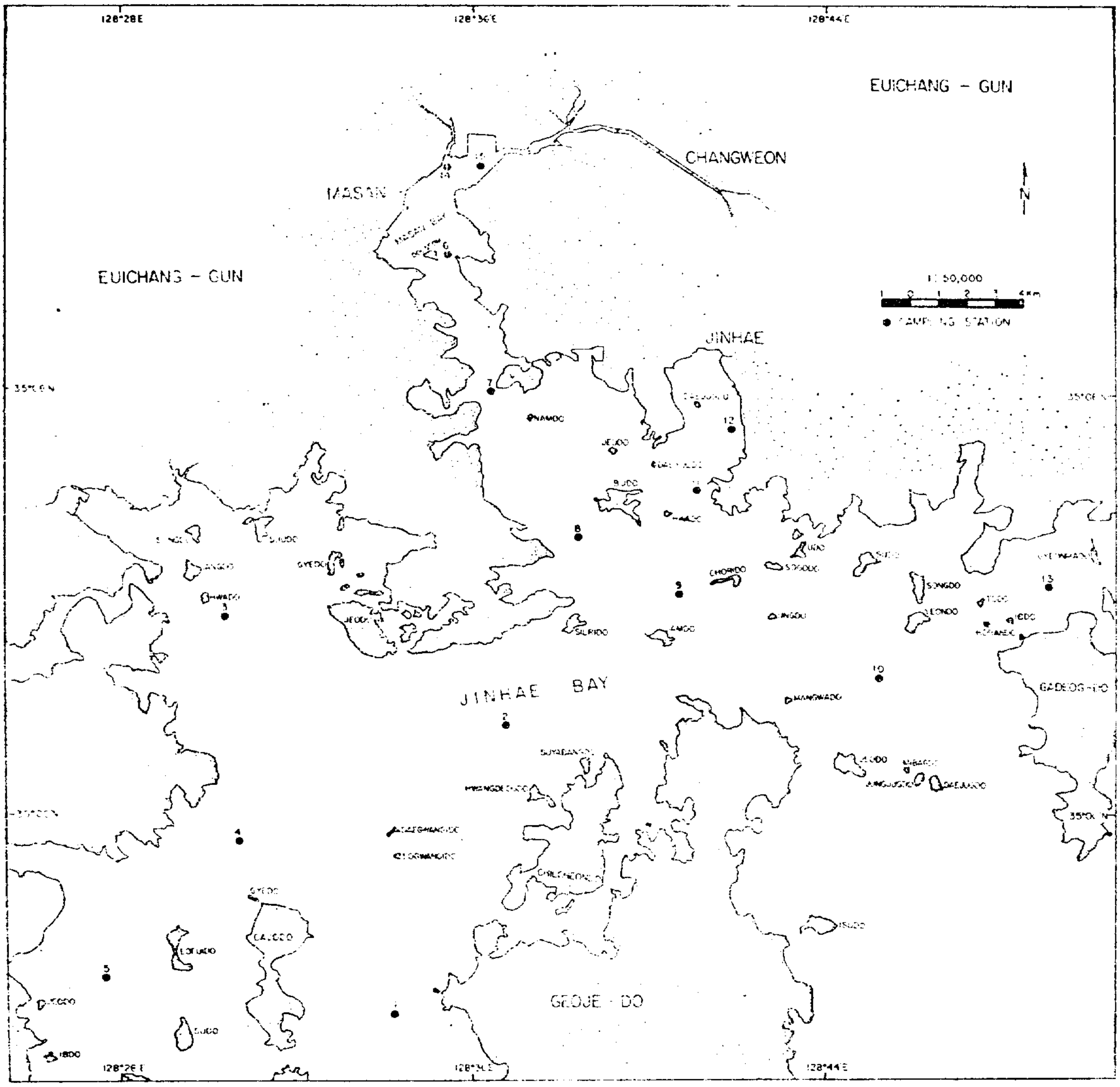

Fig. 1. Location of sampling stations in Jinhae Bay

was expressed as the sum of cell numbers of dinoflagellates and diatoms.

Multiple regression analyses were carried out with cell numbers of diatoms and dinoflagellates as the dependent variable and water quality parameters as independent variables.

Using the stepwise multiple regression package of SAS(Statistical Analysis System), the following equation can be written

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots\cdots + b_kX_k$$

where Y is the dependent variable (cell numbers); b_0, the Y intercept; b_i, partial regression coefficients and X_i, the independent variables (water quality parameters).

RESULTS AND DISCUSSION

Jinhae Bay is subdivided into two zones. The zone I comprises Stations 1 through 5 and is a less polluted area, whereas the Zone II includes Masan Bay and Stations 6, 7 and 8 with apparent severe pollution problems with red tides.

Stepwise regression analyses were undertaken separately with chlorophyll *a*, cell numbers of dinoflagellates and diatoms, and biomass as the dependent variables, and water quality parameters as the independent variables for Zone I and Zone II.

By stepwise addition of the independent variables one by one, the best model was selected on the basis of the largest coefficient of determination and the least error mean-square value of regression analysis of variance.

The coefficient of determination is the portion of variance of the dependent variable which can be explained by the model.

Table 1 shows a regression model with chlorophyll *a* as the dependent variable in the Zone I. The coefficient of determination with this mode was 37%, which was rather small. The major independent variables were nutrients (PO_4, NO_3,NO_2), temperature, pH, and COD. One-variable models showed PO_4(R^2 of 11.9%), pH(9.3%), NO_3 (6.7%) and temperature (6.2%), where R^2 values were relatively small.

Table 1. The best stepwise regression model with chlorophyll *a* as the dependent variable for surface water of the Zone I(R^2=0.370)

	df	SS	MS	F	Prob.>F
Regression	6	247	41.1	4.09	0.0026
Error	41	412	10.0		
Total	47	658			

Variables	B value	F	Prob.>F	R^2 for one var. model
Intercept	−37.5			
PO_4	0.22	12.7	0.0009	0.119
Temperature	0.17	4.69	0.0362	0.062
NO_3	4.92×10^{-3}	3.15	0.0832	0.067
*p*H	4.09	1.61	0.2116	0.093
COD	0.94	1.58	0.2153	0.021
NO_2	0.50	1.28	0.2638	0.032

In case of cell numbers of dinoflagellates as the dependent variable in the Zone I, a six-variable model was shown to be best, as in Table 2, where the coefficient of determination was 55.6% and the variables were AOU (apparent oxygen utilization), COD, Chl. *a*, SiO_2, pH and PO_4. One-variable models were AOU(R^2 of 28.6%), Chl. *a*(26.8%), COD (25.5%) and pH(21.7%). The diffierence between two kinds of models was largely due to interaction among variables.

When cell numbers of diatoms in the Zone I were taken as the dependent variable, as shown in Table 3, a five-variable model with R^2 of 61.3% was best with salinity, SiO_2, AOU, NO_2, NO_3, It is to be noted that the partial regression coefficients for nutrients were negative. The reason for this could be due to the fact that dissolved nutrients in the Zone I were rather limited, especially when diatom blooms were taking place. One-variable models were salinity (R^2 of 22%), and SiO_2 (6.6%).

With biomass (sum of cell numbers of dinoflagellates and diatoms) as the dependent

Table 2. The best stepwise regression model with cell numbers of dinoflagellate as the dependent variable for surface water of the Zone I(R^2=0.556).

	df	SS	MS	F	Prob.>F
Regression	6	8.59×10^{10}	1.43×10^{10}	8.13	0.0001
Error	39	6.86×10^{10}	1.76×10^{9}		
Total	45	1.55×10^{11}			

Variables	B value	F	Prob.>F	R_2 for one var. model
Intercept	-5.12×10^{5}			
AOU	-5.42×10^{2}	5.63	0.0226	0.286
COD	2.46×10^{4}	4.91	0.0326	0.255
Chlorophyll *a*	4.37×10^{3}	4.27	0.0455	0.268
SiO_2	24	1.86	0.1806	0.002
*p*H	5.39×10^{4}	1.50	0.2282	0.217
PO_4	1.05×10^{3}	1.05	0.3112	0.018

Table 3. The best stepwise regression model with cell numbers of diatoms as the dependent variable for surface water of the Zone I($R^2=0.613$).

	df	SS	MS	F	Prob.>F
Regression	5	$1.4. \times 10^{13}$	2.81×10^{12}	13.28	0.0001
Error	42	8.89×10^{12}	2.12×10^{11}		
Total	47	2.29×10^{13}			

Variables	B value	F	Prob.>F	R^2 for one var. model
Intercept	7.25×10^{6}			
Salinity	-1.98×10^{5}	54.83	0.0001	0.220
SiO_2	-8.31×10^{2}	15.19	0.0003	0.066
AOU	8.30×10^{3}	12.41	0.0010	0.001
NO_2	-1.66×10^{5}	6.87	0.0122	0.042
NO_3	-6.68×10^{2}	2.05	0.1595	0.015

variable, an eleven-variable model was shown to be best with R^2 of 68.3% in the Zone I, as in Table 4. Since diatoms were predominant

Table 4. The best stepwise regression model with biomass as the dependent variable for surface water of the Zone I($R^2=0.683$).

	df	SS	MS	F	Prob.>F
Regression	11	1.57×10^{13}	1.43×10^{12}	6.66	0.0001
Error	34	7.30×10^{12}	2.15×10^{11}		
Total	45	2.30×10^{13}			

Variables	B value	F	Prob.>F	R^2 for one var. model
Intercept	-2.72×10^{6}			
SiO_2	-8.40×10^{2}	16.05	0.0003	0.066
Salinity	-1.25×10^{5}	9.36	0.0043	0.230
AOU	8.01×10^{3}	6.86	0.0131	0.004
NO_2	-1.22×10^{5}	2.93	0.0961	0.049
Ca	-2.40×10^{3}	2.84	0.1011	0.161
COD	-2.26×10^{5}	2.82	0.1021	0.001
Chlorophyll *a*	-3.87×10^{4}	2.66	0.1121	0.061
*p*H	9.36×10^{5}	2.44	0.1274	0.169
PO_4	-1.64×10^{4}	1.97	0.1693	0.002
Temperature	3.45×10^{4}	1.54	0.2232	0.061
Mg	3.29×10^{2}	1.12	0.2970	0.006

in the total biomass, the first four variables in this model were the same as that for diatoms. The negative partial regression coefficients were shown with salinity, nutrients, including PO_4, and also COD. One-variable models were salinity(R^2 of 23%), pH(16.9%), Ca(16.1%), Chl. *a* (6.1%) and temperature (6.1%).

In the Zone II, where the water quality is directly influenced by the municipal and industrial wastewaters of Changwon and Masan, multiple regression models were quite different from those in the Zone I.

When Chl. *a* was taken as the dependent variable in the Zone II, as shown in Table 5, a five-variable regression model was most reasonable with R^2 of 56% and COD, NO_3, AOU, Ca and PO_4 as independent variables. One-variable models showed COD(R^2 of 38.4%) AOU(24.5%), NO_3(14.4%) and PO_4(13.4%).

Table 6 shows the multiple regression analysis of a seven variable-model with the cell numbers of dinoflagellates as the dependent variable. The seven variables were COD, Chl. *a*, SiO_2, pH, NO_2, AOU, and salinity. The R^2 values for one-variable models were 54.7%

Table 5. The best stepwise regression model with chlorophyll *a* as the dependent variable for surface water of the Zone II ($R^2=0.560$).

	df	SS	MS	F	Prob.>F
Regression	5	5.44×10^{4}	1.09×10^{4}	11.45	0.0001
Error	45	4.27×10^{4}	9.49×10^{2}		
Total	50	9.71×10^{4}			

varibles	B value	F	Prob.>F	R^2 for one var. model
Intercept	17.0			
COD	6.83	5.07	0.0293	0.384
NO_3	4.43×10^{-2}	3.07	0.0865	0.144
AOU	9.81×10^{-2}	3.01	0.0899	0.245
Ca	−0.11	2.47	0.1228	0.047
PO_4	0.35	2.18	0.1468	0.134

Table 6. The best stepwise regression model with cell numbers of dinoflagellates as the dependent variable for surface water of the Zone II(R^2=0.721).

	df	SS	MS	F	Prob.>F
Regression	7	7.10×10^{13}	1.01×10^{13}	15.15	0.0001
Error	41	2.75×10^{13}	6.70×10^{11}		
Total	48	9.85×10^{13}			

Variables	B value	F	Prob.>F	R^2 for one var. model
Interecpt	-1.13×10^{7}			
COD	3.40×10^{5}	13.04	0.0008	0.547
Chlorophyll *a*	7.05×10^{3}	3.36	0.0741	0.433
SiO_2	5.75×10^{2}	2.42	0.1273	0.071
*p*H	1.12×10^{6}	2.35	0.1326	0.389
NO_2	1.30×10^{4}	2.35	0.1329	0.361
AOU	2.39×10^{3}	2.25	0.1415	0.170
Salinity	3.32×10^{4}	1.55	0.2201	0.047

for COD, 43.3% for Chl. *a*, 38.9% for pH, 36.1% for NO_2 and 7.1% SiO_2.

In Table 7, it shows an eight-variable model with cell numbers of diatoms as the dependent variable and with R^2 of 58.2%. The independent variables were SiO_2, COD, Ca, Mg, NO_2, salinity, AOU and PO_4. One-variable models showed the R^2 values of 25.5% for SiO_2, 17.1% for Ca, 16.2% for salinity and 7.7% for PO_4.

Table 7. The best stepwise regression model with cell numbers of diatoms as tha dependent variable for surface water of the Zone II(R^2=0.582).

	df	SS	MS	F	Prob.>F
Regression	8	1.57×10^{14}	1.96×10^{13}	7.31	0.0001
Error	42	1.13×10^{14}	2.68×10^{12}		
Total	50	2.70×10^{14}			

Variables	B value	F	Prob.>F	R^2 for one var. model
Intercept	4.83×10^{6}			
SiO_2	3.72×10^{3}	17.71	0.0001	0.255
COD	5.48×10^{5}	10.25	0.0026	0.030
Ca	-1.01×10^{4}	7.86	0.0076	0.172
Mg	1.33 10^{3}	7.04	0.0112	0.001
NO_2	-4.97×10^{4}	6.56	0.0141	0.013
Salinity	-1.35×10^{5}	6.31	0.0159	0.162
AOU	4.09×10^{3}	1.71	0.1987	0.002
PO_4	-1.70×10^{4}	0.87	0.3564	0.077

The multiple regression model of the Zone II with biomass as the dependent variables had R^2 of 66.7%, as shown in Table 8. Those variables were COD, SiO_2, NO_2, Ca, Mg, AOU, salinity, and Chl. *a*. One-variable models showed Chl. *a*, (R^2 of 28.7%), SiO_2 (27.6%), COD (23.6%), salinity (18.3%), NO_2 (14.5%) and Ca (12.3%).

Table 8. The best stepwise regrssion model with biomass as the dependent variable for surface water of the Zone II

	df	SS	MS	F	Prob.>F
Regression	8	2.89×10^{14}	3.61×10^{13}	10.02	0.0001
Error	40	1.44×10^{14}	3.60×10^{12}		
Total	48	4.33×10^{14}			

Variables	B value	F	Prob.>F	R^2 for one var model
Intercept	2.17×10^{6}			
COD	9.40×10^{5}	19.72	0.0001	0.236
SiO_2	3.77×10^{3}	17.25	0.0002	0.276
NO_2	-4.44×10^{4}	5.23	0.0276	0.145
Ca	-9.21×10^{8}	4.68	0.0366	0.123
Mg	1.14×10^{3}	3.16	0.0831	0.012
AOU	6.10×10^{3}	2.57	0.1169	0.050
Salinity	-9.10×10^{4}	2.11	0.1538	0.183
Chlorophyll *a*	9.18×10^{3}	1.02	0.3177	0.287

CONCLUSION

The results of multiple regression analyses of biomass indicated that characteristics of two Zones in Jinhae Bay were quite distinctive from each other. In the Zone II with severe red tide problems, biomass can be best estimated and predicted with COD, various nutrients, salinity and chlorophyll *a*. The order of importance of independent variables in the biomass regression model was influenced more by that for diatoms than for dinoflagellates.

Although multiple regression analyses can be useful for prediction or estimation of the dependent variable, it can not describe complicated relationships between changes in the independent variables and response in the dependent one. More systematic studies are needed for elucidation of mechamism and establishment of monitoring systems for red tides in Jinhae Bay.

ACKNOWLEDGMENTS

Deep appreciation and thanks are expressed to Mr. J.H. Lee and Dr. H.T. Huh for their enumeration of phytoplanktons and to S.R. Cho, E.S. Kim, M.O. Koo, and H.S. Kwak for their help in various phases of sampling and physico-chemical analysis.

REFERENCES

Cho, C.H. 1978. On the Gonyaulax red tide in Jinhae Bay. Bull. Korean Fish.Soc., **11**(2): 111-114.

Cho, C.H. 1979. Mass mortalities of oyster due to red tide in Jinhae Bay in 1978. Bull. Korean Fish. Soc. **12**(1):27-33.

EPA, 1979. Methods for chemical analysis of water and wastes. EPA-600/4-79-020.

KORDI, 1980. A preliminary investigation on the monitoring system for the red tides in the Jinhae Bay. KORDI Report. BSPE00022-43-7.

Lee D.S., S.H. Lee, H.S. Kwak and K.W. Lee. 1980. Determination of dissolved trace metals in sea water by atomic absorption spectrophotometry after concentration by Fe (Ⅲ)-APDC coprecipitation. J. Oceanol.Soc. Korea, **15**:66-70.

Lee, K.W. *et al.*, 1981. Report on Water Quality monitoring in coastal areas of Banweol, Ulsan, Changwon and Yeochon. KORDI Report BSPI: 00023-46-4.

Park, J.S. and J.D. Kim 1967. A study on the "red tide" caused at Jinhae Bay. Bull. Fish. Res. Dev. Agency, **1**:65-79.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Canada 167.

Yoo, K.I. and J.H. Lee. 1979. Environmental studies of the Jinhae Bay. 1. Annual cycle of phytoplankton population, 1976-1978. J. Oceanol. Soc. Korea, **14**:26-31.

Yoo, K.I. and J.H. Lee. 1980. Environmental studies of the Jinhae Bay. 2. Environmental parameters in relation to phytoplankton population dynamics. J. Oceanol. Soc. Korea, **15**:62-65.

Yoshida, Y. 1973. Changes in biological production on sediment production. Fishery Series-1. Koseisha Koseikaku. Tokyo. Japan.