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Ecological Modeling for Estimation of Environmental Characteristics in Masan Bay

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The ecosystem model was applied to estimate the regional distribution of the net production(or consumption) of phytoplankton and the net uptake(or regeneration) rate of nutrients in Masan Bay for scenario analysis to find a proper management plan. At the surface level, net production of phytoplankton is 200 $mgC/m^2/day$ at the entrance of the bay, and 400~1000 $mgC/m^2/day$ at the center of the bay. The inner area of the bay showed more than 2000 $mgC/m^2/day$. All areas of the bottom level have a net consumption, with the center of the bottom level showing more than 600 $mgC/m^2/day$. For dissolved inorganic nitrogen, the results showed a net uptake rate of 100~900 $mg/m^2/day$ at the surface level. It showed that the net regeneration is above 50 $mg/m^2/day$ at the bottom level. For dissolved inorganic phosphorus, the net uptake rate showed 10.0~80.0 $mg/m^2/day$ at the surface level, and the regeneration rate showed 0~20.5 $mg/m^2/day$ at the bottom level. Therefore, in order to control the water quality in Masan Bay, it is important to consider the re-supplement of nutrients regenerated in the water column.

Key word : Ecological Modeling, Environmental Characteristics, Phytoplankton, Nutrient, Masan bay, Ecosystem Model

1. Introduction

Masan Bay, surrounded by the cities of Masan, Changwon, and Jinhae, is one of the most contaminated bays in Korea. The bay is narrow and rectangular and its average depth is 11 m. It is a semi-closed sea area and its water quality is affected by the inflow of even small pollutants. It is noteworthy that red tides and an oxygen-deficient water mass are extensively developed in Masan Bay during summer[1].

The oxygen-deficient water mass and the red tide frequently result from the eutrophicated closing bay and this pollution is related to the proliferation of phytoplankton. In order to control and induce the standing stock of phytoplankton, it is necessary to study weather conditions, sunlight, seawater movement, water temperature, salt, and nutrients. Among these, nutrients can arbitrarily be controlled. Therefore, it is necessary to quantitatively study the production of phytoplankton and the behavior of nutrients in the sea to prevent and control eutrophication and the red tide. Although many experimental studies have been conducted on the production of phytoplankton, there is limited understanding of both the horizontal and vertical distribution of primary production. The distribution of nutrients uptake and regeneration in the inner bay are rarely studied. The ecosystem model can be useful in studying the distribution of environmental characteristics in marine ecosystem. This study uses the three dimensional eco-hydrodynamic model, the applicability of which was proven by previous studies[1~3] in the target modeling region.

Regional distributions of the net production and consumption for the phytoplankton were calculated using the ecosystem model. The net

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uptake and regeneration rates of nutrients were calculated and may be provided as basic data for scenario analysis to find a proper management plan.

2. Materials and Methods

2.1. Target Sea Area

The target sea area is Masan Bay, which include Haengam Bay and the southern region of Budo, with a width of about 78.69 Km^2, a volume of about 0.8614 Km^3 and an average depth of about 11.1 m.

2.2. Ecosystem Simulation

The three dimensional eco-hydrodynamic model used in this study consists of both a multi-level model[4] for the simulation of sea water movement and an ecosystem model[5] for the simulation of water quality. The model was modified by Kim *et. al.*[6], Cho *et. al.*[7] and Kim *et. al.*[8] and has proven applicability in the domestic bay area.

Equation (1) shows the change of components concentration according to time at the arbitrary cell of the target sea area, to which the ecosystem model is applied.

$$\frac{\partial B}{\partial t} = -u\frac{\partial B}{\partial x} - v\frac{\partial B}{\partial y} - w\frac{\partial B}{\partial z}$$

Transport process term by advection

$$+\frac{\partial}{\partial x}\left[Kx\frac{\partial B}{\partial x}\right]+\frac{\partial}{\partial y}\left[Ky\frac{\partial B}{\partial y}\right]+\frac{\partial}{\partial z}\left[Kz\frac{\partial B}{\partial z}\right]$$

Transport process term by diffusion

$$+\frac{dB}{dt}$$

Biological and chemical processes term (1)

The biological process term is defined as part of the biological and chemical processes excluding the expression terms in which target materials are transported by advection and diffusion in Equation (1). Equations (2) and (3) show the biological process terms for phytoplankton and nutrients in the model, respectively.

The photosynthesis increases the concentration of the phytoplankton in each cell of the model. The respiration, excretion, death, sedimentation, etc., decreases the concentration of phytoplankton in each cell of the model. It means that, if the sum of the biological process term is positive, net production of the phytoplankton has occurred in the cell. If negative, net consumption has occurred.

$$\left(\frac{dp}{dt}\right)^{*} = +\{1-\mu_3(P)\}\cdot v_1(T)\cdot \mu_1(DIP,\ DIN)\cdot \mu_2(I)\cdot P$$

Photosynthesys

$$- v_2(T)\cdot P \qquad - v_3(T)\cdot Z$$

Respiration Excretion

$$- v_4(T)\cdot P \qquad - W_p\frac{\partial P}{\partial z}$$

Motality Settling (2)

The nutrients uptake by the phytoplankton decreases the concentration of nutrients, and the respiration, excretion, mineralization, and etc., increases the concentration through the regeneration of nutrients. If the sum of the biological process term for the nutrients is positive, net regeneration of the nutrients has occurred in the cell. If negative, net uptake has occurred.

$$\left(\frac{d(N,P)}{dt}\right) = -\,[(N,P):C_P]\cdot v_1(T)\cdot \mu_1(DIP,\ DIN)\cdot \mu_2(I)\cdot P$$

Uptake by phytoplankton

$$+\ [(N,P):C_{POM}]\frac{1}{1+k}v_6(T)\cdot POC$$

Respiration

$$+\ [(N,P):C_P]\cdot v_2(T)\cdot P$$

Excretion

$$+\ [(N,P):C_z](\mu - v)\cdot v_3(T)\cdot Z$$

Mineralization of particulate organic matter

$$+\ [(N,P):C_{DOM}]\cdot v_7(T)\cdot DOC)$$

Mineralization of dissolved organic matter

$$+\ q_{(N,P)}$$

Loads (3)

In this study, the distribution of the net production net consumption in the target sea area was calculated as the difference between the production and consumption of the phytoplankton at each cell in the model. In the same way, the distribution of the net uptake net consumption rates were calculated.

2.3. Input Data

The target sea area was divided into 250 m mesh sections, going in an east-west and north-south direction, and its depth was divided into a surface level (0∼3 m), a middle level (3∼7 m) and a bottom level (7 m∼bottom). Table 1 shows the initial conditions, boundary conditions, and coefficients which were obtained from previous modeling studies of the sea area[1,2]. Table 2 shows the symbols, definitions, units and values of biological parameters which

Table 1. Input data for an ecosystem model

Parameters	Input values
Mesh size	$\Delta x = \Delta y = 250$ m
Level	1 (0~3 m), 2 (3~7 m), 3 (7 m~bottom)
Time interval	200sec
Pollutant loads	Refer to reference no. 1)

Initial condition for compartments

level	DO (mg/L)	COD (mg/L)	DIP (μg-at/L)	DIN (μg-at/L)	POC (mg-C/m³)	DOC (mg-C/m³)	Phytoplankton (mg-C/m³)
1	15.12	7.39	0.23	40.86	1812.3	1089.7	3722
2	8.66	4.18	0.36	20.78	1427.0	388.8	2583
3	5.83	3.19	1.51	24.50	195.0	354.2	1123

Boundary condition for compartments

level	DO (mg/L)	COD (mg/L)	DIP (μg-at/L)	DIN (μg-at/L)	POC (mg-C/m³)	DOC (mg-C/m³)	Phytoplankton (mg-C/m³)
1	14.90	6.39	0.06	1.63	904.0	347.9	4370
2	9.40	3.19	0.18	1.99	247.6	411.2	3570
3	7.90	6.69	0.21	1.33	110.2	265.5	3300

Horizontal viscosity coefficient	3.0 E5 (cm²/s)
Horizontal diffusion coefficient	3.0 E5 (cm²/s)
Vertical diffusion coefficient	Level 1 : 0.1 (cm²/s)
	Level 2~3 : 0.01 (cm²/s)
Total runtime	30 cycles

Table 2. The biological parameters used in the ecosystem model

No.	Symbol	Definition	Unit	Values
1	α_1	Maximum growth rate of phytoplankton at 0℃	day^{-1}	0.49
2	α_2	Respiration rate of phytoplankton at 0℃	day^{-1}	0.01
3	α_3	Maximum grazing rate of zooplankton at 0℃	day^{-1}	0.18
4	α_4	Mortality rate of phytoplankton at 0℃	day^{-1}	0.01
5	α_5	Natural death rate of zooplankton at 0℃	day^{-1}	0.064
6	α_6	Mineralization rate of POC at 0℃	day^{-1}	0.065
7	α_7	Mineralization rate of DOC at 0℃	day^{-1}	0.007
8	α_8	Sediment release rate for dissolved phosphorous	$mg/(m^2day)$	8.0
9	α_9	Sediment release rate for dissolved nitrogen	$mg/(m^2day)$	36.37
10	α_b	Oxygen consumption rate of sediment at 0℃	$mg/(m^2day)$	1500
11	K_{SP}	Half saturation constant for uptake of DIP at 0℃	mg/L	0.11
12	K_{SN}	Half saturation constant for uptake of DIN at 0℃	mg/L	0.41
13	P^*	Function of grazing	mg C/m³	75
14	μ	Digestion efficiency of zooplankton	%	70
15	ν	Total growth efficiency of zooplankton	%	30
16	λ	Ivlev index for grazing	$(mgC/m^3)^{-1}$	0.01
17	K^1_{DO}	Half concentration of DO for mineralization of POC	mg/L	1.0
18	K^2_{DO}	Half concentration of DO for mineralization of DOC	mg/L	1.0
19	W_P	Settling velocity of phytoplankton	m/day	0.17
20	W_{POC}	Settling velocity of detritus(POC)	m/day	0.27
21	K_a	Reaeration coefficient at sea surface	day^{-1}	0.15

were used in the ecosystem model[1,3].

3. Ecological Modeling Results

The ecosystem simulation results of Masan Bay were compared to Kim *et. al.*'s data[1] in order to determine their reliability. The correlation coefficient(r) and coefficient of determination(r^2) for dissolved inorganic nitrogen are 0.96 and 0.92, and the correlation coefficient(r) and coefficient of determination(r^2) for dissolved inorganic phosphorus are 0.86 and 0.74. Therefore, the reliability of the modeling is good.

3.1. Production and Consumption of Phytoplankton

Fig. 1 shows the net production or net consumption of phytoplankton at each level, which was calculated according to the difference between the increasing term and decreasing term of phytoplankton concentration at each cell of the ecosystem model. Equation (2) shows that positive values mean net production areas and negative values net consumption areas.

Net production of the phytoplankton occurred in all areas of the surface level. Net production is 200 mgC/m^2/day at the entrance of the bay and 400~1000 mgC/m^2/day at the center of the bay. The inner area of the bay showed more than 2000 mgC/m^2/day. Net production of 10 mgC/m^2/day occurred only in some inner areas of the middle level. Net consumption occurred by the death, and etc., of the phytoplankton at other areas of the middle level and its value was about 50 mgC/m^2/day. All areas of the bottom level have net consumption, with the center of the bottom level showing more than 600 mgC/m^2/day.

For Masan Bay, the production of phytoplankton actively progresses at the center of the surface level and especially in the inner area of the bay. Dead phytoplankton are decomposed at the center of the bottom level.

3.2. Uptake and Regeneration of Nutrients

Fig. 2 and Fig. 3 show the net uptake rate net regeneration rate of nutrients at each level, which was calculated according to the difference between the increasing and decreasing terms for nutrients at each cell of the ecosystem model. Equation (3) shows that a negative value refers to an area of net uptake and a positive value refers to an area of net regeneration.

A Net uptake for dissolved inorganic nitrogen occurred at all areas of the surface level. The net uptake rate at the entrance of the bay is 100 mg/m^2/day, and the center of the bay shows more than 900 mg/m^2/day. The net uptake rate of the middle level at the center and inner bay is 10 mg/m^2/day and the net

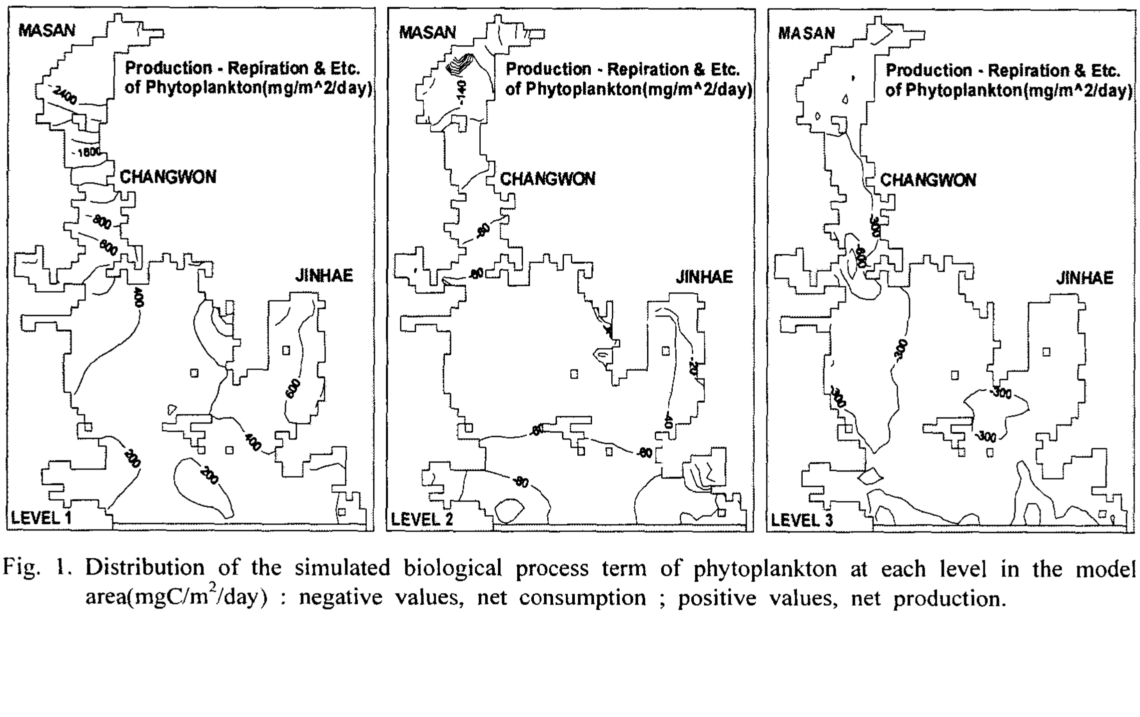

Fig. 1. Distribution of the simulated biological process term of phytoplankton at each level in the model area(mgC/m^2/day) : negative values, net consumption ; positive values, net production.

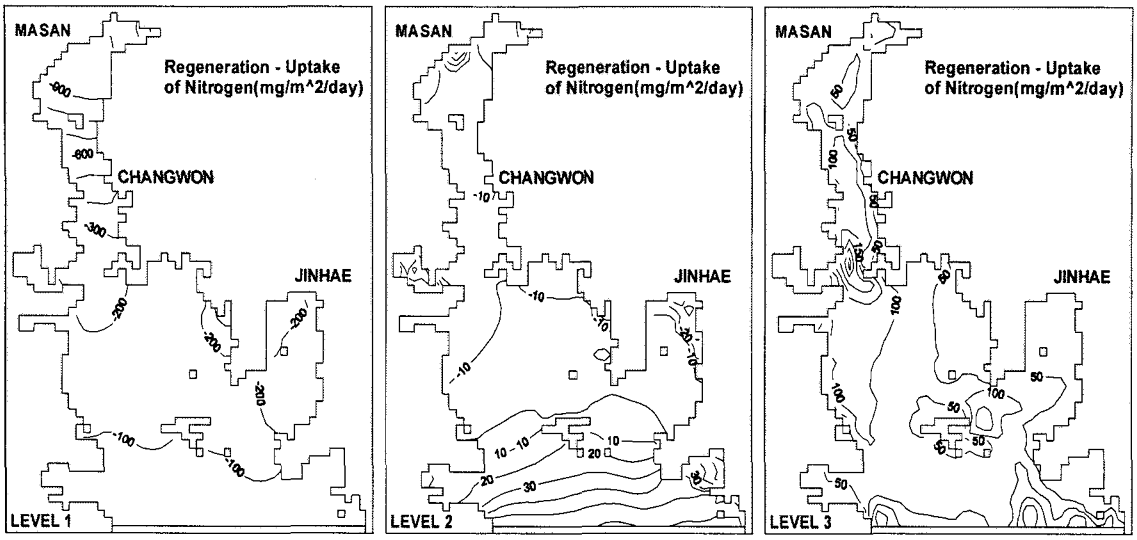

Fig. 2. Distribution of the simulated biological process term of nitrogen at each level in the model area ($mg/m^2/day$) : negative values, net uptake; positive values, net regeneration.

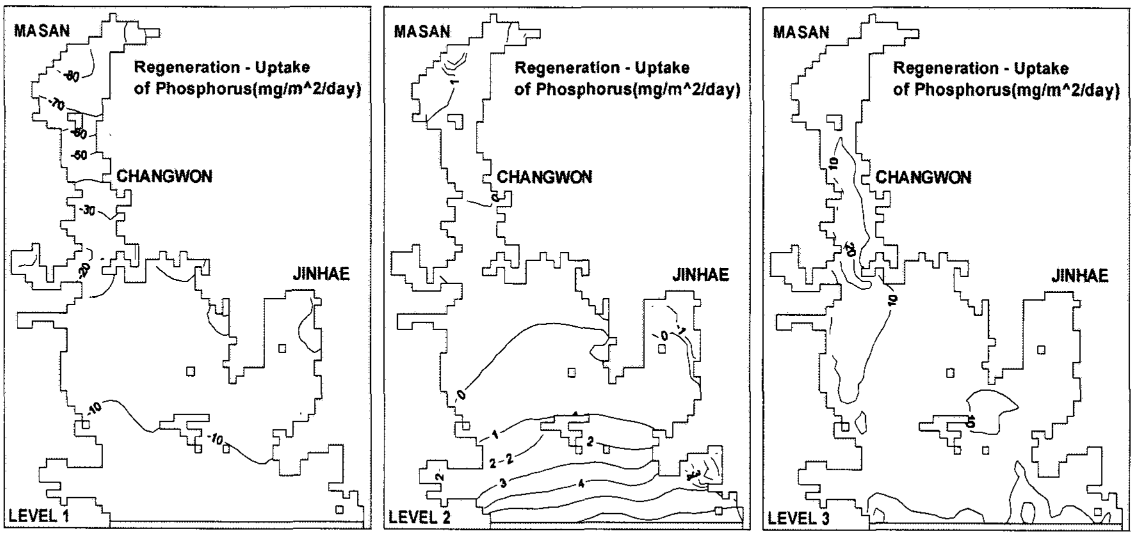

Fig. 3. Distribution of the simulated biological process term of phosphorus at each level in the model area ($mg/m^2/day$) : negative values, net uptake; positive values, net regeneration.

regeneration rate of 10~30 $mg/m^2/day$ occurred at the entrance of the bay. Net regeneration occurred at all areas of the surface level, and the center of the bay showed more than 100 $mg/m^2/day$.

A net uptake rate of 10.0~80.0 $mg/m^2/day$ for dissolved inorganic phosphorus occurred at all areas of the surface level, and the inner area of the bay shows a higher value than the outer area. A net uptake rate of less than 1.0 $mg/m^2/day$ occurred at the center of the bay at the middle level and other areas showed net production of 1.0~6.0 $mg/m^2/day$. All areas of the bottom level showed net regeneration and the center of the bay showed 20.0 $mg/m^2/day$.

Masan Bay has an excellent net uptake at the surface level and an excellent net regeneration at its bottom level. At the middle level, the inner and center areas of the bay show a net uptake and the entrance of the bay shows a net regeneration. The size of the net regeneration rate and net uptake rate of nutrients in Masan Bay is 10 times as large as that of Kamak Bay, the value of which was calculated by Kim[9]. Therefore, it is important to consider the re-supplement of nutrients due to water level regeneration.

4. Conclusions

The ecosystem model was applied to estimate the regional distribution of environmental characteristics in Masan bay for a scenario analysis in order to find a proper management plan. The reliability of the modeling is good.

For surface levels, net production is 200 $mgC/m^2/day$ at the entrance of the bay and 40 $0\sim1000$ $mgC/m^2/day$ at the center of the bay. The inner area of the bay showed more than 2000 $mgC/m^2/day$. All areas of the bottom level have net consumption, with the central region of the bay showing more than 600 $mgC/m^2/day$.

For nutrients, Masan Bay has a net uptake at the surface level and a net regeneration at its bottom level. The range of the net regeneration rate and net uptake rate of nutrients in Masan Bay is 10 times as high as that of Kamak Bay. Therefore, in order to control the water quality in Masan Bay, it is important to consider the re-supplement of nutrients regenerated throughout the water column.

References

1) Kim, D. M., C. K. Park and J. G. Kim, 1998, The estimation of N, P mass balance in Masan Bay using a material cycle model, J. Environ. Sci., 7, 833-843.
2) Kim, J. G., C. K. Park and K. S. Kim, 1994, The application of ecosystem model for the eutrophication control in Masan Bay in summer, J. Environ. Sci., 3, 185-195.
3) Choi, W. J., C. K. Park and S. M. Lee, 1994, Numerical simulation of the formation of oxygen deficient water-masses in Jinhae Bay, J. Kor. Fish. Soc., 27, 413-433.
4) Horiguchi, F., J. Yamamoto and K. Nakata, 2001, A numerical simulation of the seasonal cycle of temperature, salinity and velocity fields in Tokyo Bay, Mar. Pol. Bul., 43, 145-153.
5) Nakata, K., 1991, A model of the formation of oxygen depleted waters in Tokyo Bay, KAIKOU, 5(2), 1-26.
6) Kim, G. S., D. M. Kim and C. K. Park, 1999, A rough estimation of environmental capacity in the Yellow Sea using a numerical hydrodynamic model, J. Kor. Soc. Mari. Environ. Eng., 2, 63-73.
7) Cho, E. I., C. K. Park and S. M. Lee, 1996, Estimation of carrying capacity in Kamak Bay -(1) Estimation of primary productivity using the eco-hydrodynamic model-, J. Kor. Fish. Soc., 29, 369-385.
8) Kim, D. M., 1999, The eutrophication modeling in the Yellow Sea using an ecosystem model, Thesis for Ph. D., Pukyong National University, 143pp.
9) Kim, D. M., 2003, Estimation of nutrients transport in Kamak Bay using the eco-hydrodynamic model, J. Environ. Sci., 12, 745-751.