D-1.2 Modeling of element matter cycle by marine phytoplankton

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Abstract Ecological model of Emiliania huxleyi was developed and calibrated with experimental data using a large axenic culture tank (1 m^3 volume) in order to understand element matter cycle in the sea. The growth of E. huxleyi was controlled by quota model and nutrients uptake rates were described by Michaelis - Menten equation. The concentrations of the carbonate species was determine from the combination of pH and total carbonate. The model explained observed cell concentration, nutrient concentrations, total carbonate, pH and cell quota of nitrogen, phosphate and carbon.

Key Words photosynthesis, calcification, Emiliania huxleyi, carbon cycle, ecological model

1. Introduction

Coccolithophore blooms are widespread in the ocean. Their roles in oceanic and global carbon cycling are of potentially great importance, because of not only their capacity for organic matter production by photosynthesis but also their unique ability to synthesize external plates of calcite, called coccoliths. Recently E. huxleyi blooms have been observed extensively in the North Atlantic in field observations (Fernandez et. al., 1993, Holligan et. al., 1993, Robertson et. al., 1994), and it has been concluded that dense blooms of E. huxleyi become sources of CO_2 to the atmosphere. However, detection of E. huxleyi populations from field observations has only been possible during late stages of bloom development and their impact on the carbon cycle during bloom onset and growth has been unknown. Here laboratory experiments were conducted in a 1 m^3 axenic culture tank (Watanabe et. al., 1991). We present data describing the carbon cycle coupling of photosynthesis and calcification in a complete E. huxleyi bloom cycle. Ecological model of E. huxleyi was developed based on C, N, P element cycle, and calibrated with laboratory experiments.

2. Ecological model of E. huxleyi

Model consists of 13 independent variables, namely cell concentration (C_1), PO_4-P (C_2), particulate organic P (C_3), cell quota of P (C_4), NO_3-N (C_5), particulate organic N (C_6), cell quota of N (C_7), total carbonate (C_8), particulate inorganic carbon (C_9), dissolved organic carbon (C_{10}), particulate organic carbon (C_{11}), cell quota of carbon (C_{12}), atmospheric CO_2 (C_{13}), as shown in Fig. 1. Based on cell cycle data, it is assumed cell division occurs at t = 24:00 hour. The growth of E. huxleyi was controlled by Droop quota model, and uptake of nitrogen and phosphate are expressed by Michaelis - Menten equation (Rhee, 1987). Nutrient uptake and growth parameters for E. huxleyi were given in Table 1.

The concentrations of carbonate species were calculated from the combination of pH and total carbonate under equilibrium condition (Stumm and Morgan, 1981). It was assumed that Henry's law was applicable between CO_2 concentration in sea water and pCO_2

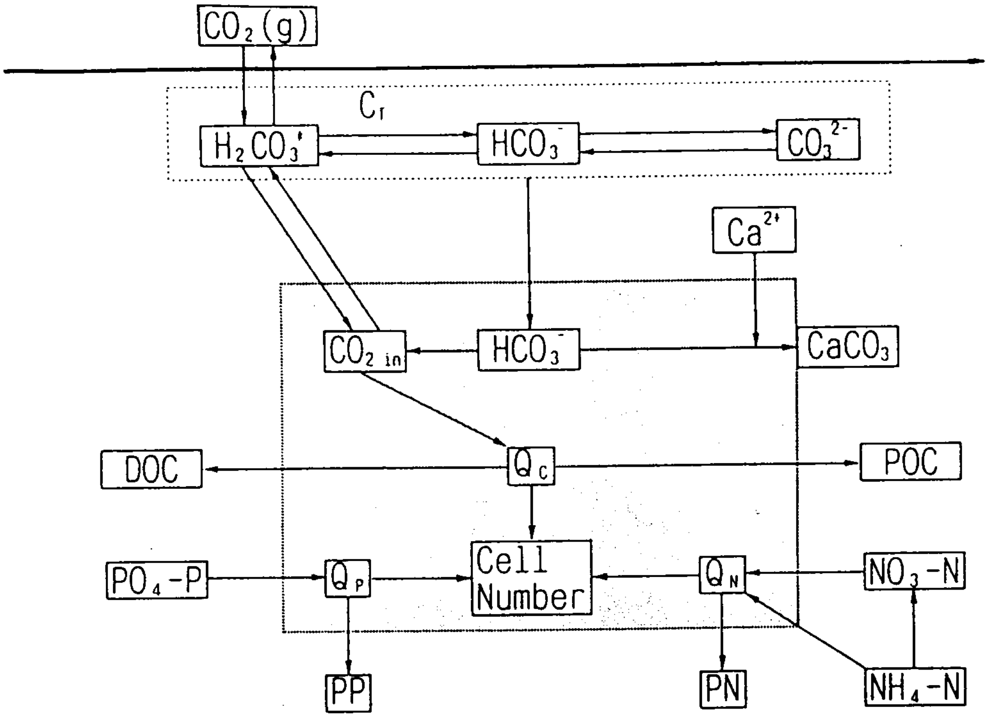

Fig. 1 Structure of Emiliania huxleyi model

Table 1 : Nutrient uptake parameters for E. huxleyi

NO_3	K_S[μ M]	4.0
	Vmax[fmol・cell^{-1}h^{-1}]	3.0
	q_O^N[fmol・cell^{-1}]	33.3
PO_4	K_S[μ M]	0.6
	Vmax[fmol・cell^{-1}h^{-1}]	0.2
	q_O^P[fmol・cell^{-1}]	1.2

Table 2 : Initial values for E. huxleyi experiment

Cell conc.	N_O[mL^{-1}]	1450
DON	NO_3-N[μ M]	35.6
DOP	PO_4-P[μ M]	1.56
Total carbonate	C_T[μ M]	1910
P-cell quota	[fmol・cell^{-1}]	37
N-cell quota	[fmol・cell^{-1}]	853
C-cell quota	[fmol・cell^{-1}]	8401
PIC	[fmol・cell^{-1}]	6.2
CO_2 in atmosphere	[ppm]	410

in the air which was equilibrium with sea water. Exchange of CO_2 between atmosphere - sea was driven by the difference in pCO_2 between atmosphere and sea. Initial values for E. huxleyi experiment are given in Table 2, and CO_2 concentration in atmosphere was measured as constant (410 ppm). Vertically one - dimensional mass balance equations were applied for independent variables and solved with these initial values in Table 2.

3. Results and Discussion

The model predicted observed cell concentration (Fig. 2), the concentrations of PO_4-P and NO_3-N (Fig. 3), cell quota of C, N, P (Fig. 4), pH and total carbonate (Fig. 5). In this model calculation, growth rate was always determined from N-limited or P-limited condition and it was assumed that C was not limiting for growth. Satisfactory agreement between predicted and observed values indicated that C, N, P cycles in E. huxleyi system and in the sea were well discribed by the model presented here.

From stable carbon isotope ratio measurement in this experiment, $\Delta\delta^{13}C$ values indicated that E. huxleyi had the capability to utilize HCO_3^- directly for the growth. At the stage of maximum production (day 8), the concentration of CO_2 in sea water was close to zero (< 1 μM). However, the cells continued for growth and C was never limiting. The model assumed that CO_2 was the only source for photosynthesis, but the model predicted rather low value of organic carbon production at the stage of maximum production (day 8). This suggested that E. huxleyi could utilize other carbon source than CO_2 for growth.

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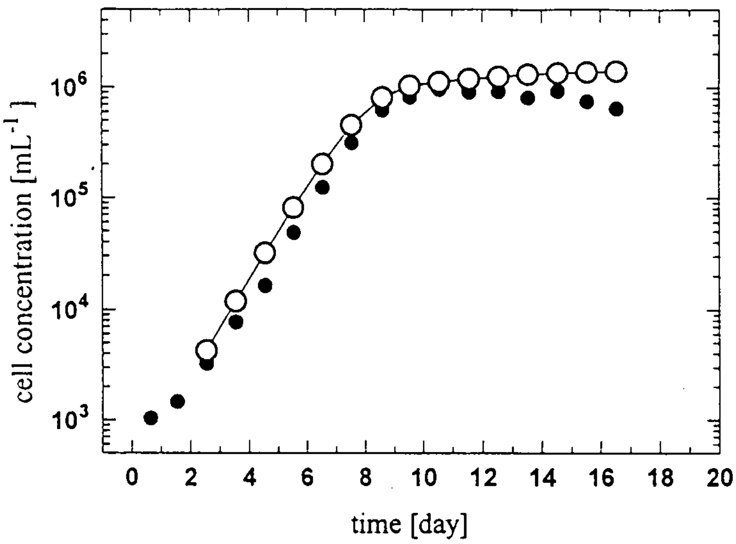

Fig. 2 Changes in E. huxleyi cell concentration
(● : measured value, ○ : calculated value)

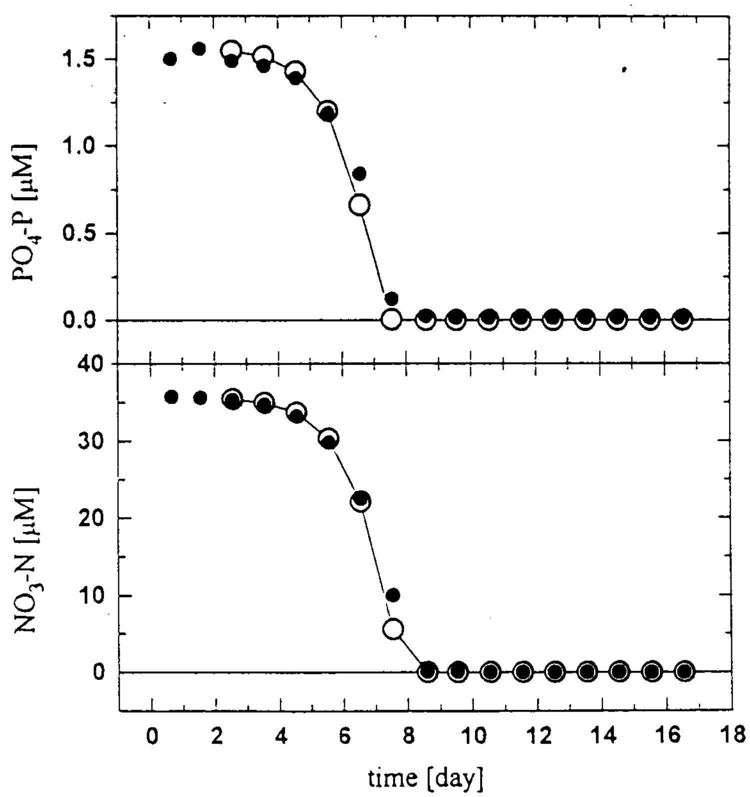

Fig. 3 Changes in dissolved total phosphate and inorganic nitrate concentration
(● : measured value, ○ : calculated value)

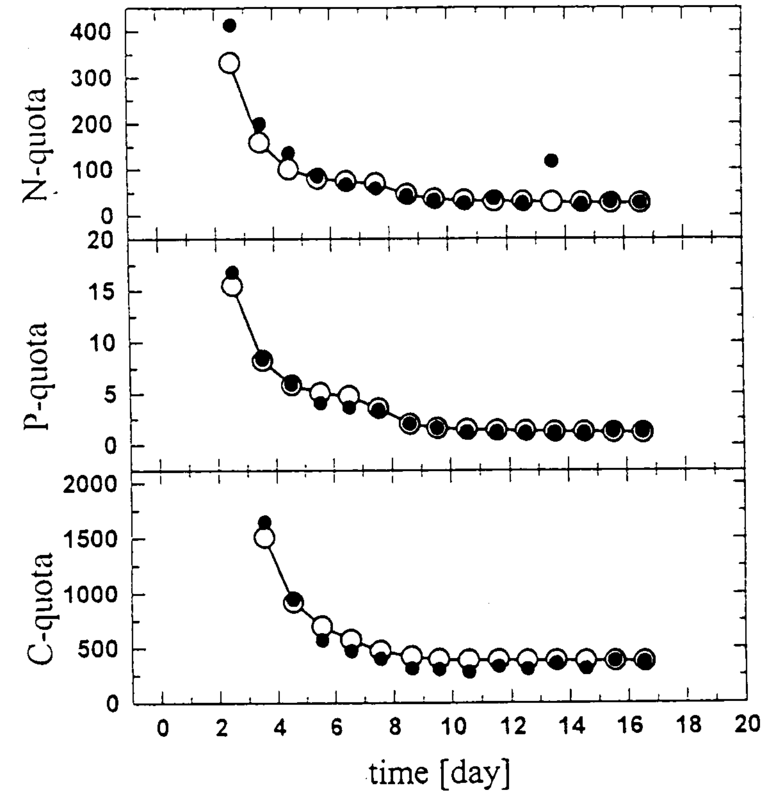

Fig. 4　Changes in C, N, P cell quota
(● : measured value, ○ : calculated value)

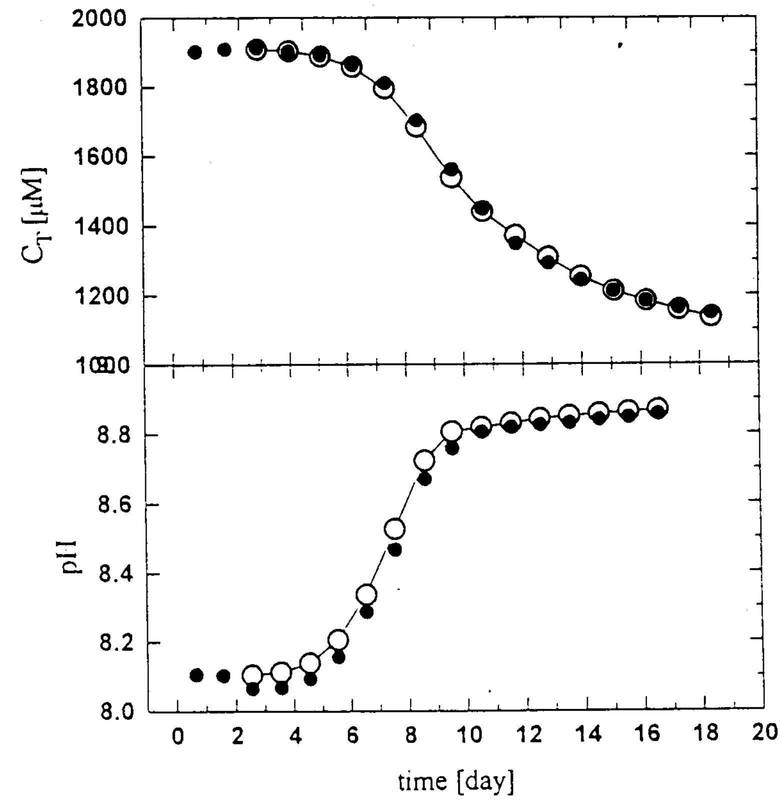

Fig. 5　Changes in dissolved inorganic carbon and pH
(● : measured value, ○ : calculated value)