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Relationship between chlorophyll specific productivity and temperature at the surface in Sagami Bay, Japan

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Primary production was monthly measured from September 2001 to July 2003 at the surface in Sagami Bay, Japan. The variation in the primary production was primarily due to the variation in Pb (chlorophyll specific productivity). The values of Pb positively correlated with temperature. This may be due to relatively low contribution of diatoms in Sagami Bay.

Key words: chlorophyll specific productivity, temperature, Sagami Bay

1. Introduction

To compute primary production using ocean-colour data requires the assignment of values of chlorophyll specific productivity (P^b) . The assignment of P^b values would be made using satellite data on the same spatial and temporal resolution as the pigment biomass field. The values of P^b vary with changes in phytoplankton species [1]. However, there is no direct way of obtaining this physiological parameter by remote sensing. We must exploit information on the major factors of phytoplankton physiology. Sea surface temperature is currently accessible directly by remote sensing among the major factors.

Eppley [1] showed that P^b depends on temperature in coastal regions. On the other hand, Han and Furuya [2] showed that the P^b was consistently more stable on seasonal scale in Tokyo Bay, where large-sized diatom was the most abundant in the abundance of phytoplankton species, though temperature seasonally varied. When large-sized diatom dominated, the correlation was relatively weak between the P^b and temperature, and the values of P^b tended to be lower and less variable [3]. In this study we examined a relationship between chlorophyll specific productivity and temperature in Sagami Bay.

2. Materials and Methods

Sagami Bay, situated on the eastern coast of Japan, covers an area of 2700 km^2, with a mean depth of 750 m (Fig. 1). Fresh water flows into Sagami Bay from 2 main rivers (Sagami and Sakawa) and other minor rivers. The amount of fresh water is greater in summer (7 to 10 × 106 m^3 d^{-1}) than in winter (3 to 5 × 106 m^3 d^{-1}) [4]. Counterclockwise currents along the coast are dominant in the bay, independent of the season. The contribution of diatoms was relatively low, while flagellates, mainly chlorophytes or cryptophytes, was quite high [5].

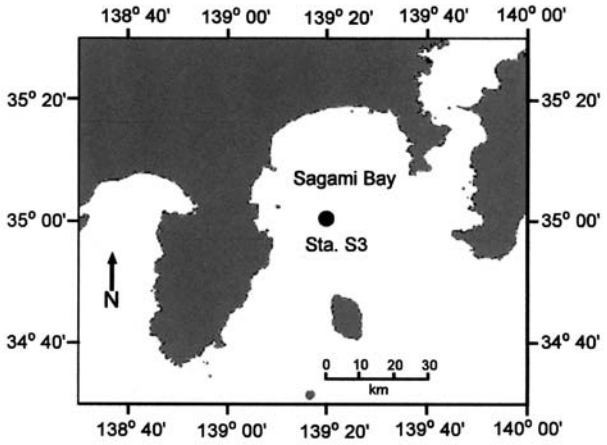

Fig. 1. Sampling location in Sagami Bay, Japan.

Time-series observations were carried out monthly at the surface in the Sagami Bay from September 2001 to July 2003 at Sta. S3 (35°00' N, 139°20' E) on board the T/V *Seiyo Maru* of Tokyo University of Marine Science and Technology (Fig. 1). Hydrographic data (water temperature, salinity) and water samples were collected using

a CTD (Falmouth Scientific, Inc.) rosette system fitted with Teflon-coated Niskin bottles of 8 L capacity. PAR was monitored with a LiCor 2π sensor during the incubation experiments.

Aliquot of 200-300 mL of samples were filtered onto 25 mm Whatman GF/F filters under gentle aspiration (<200 kilopascals). Chlorophyll *a* (Chl *a*) was immediately extracted by immersing the filter in *N,N*-dimethylformamide [6], and the samples were preserved at -20℃ until on shore analysis. Chl *a* concentrations were determined using a Turner Design Model 10-AU Fluorometer calibrated with commercial Chl *a* (Wako Pure Chemical Industries), according to the method of Parsons *et al.* [7].

Samples were transffered in polystyrene bottles, frozen immediately after collection and stored at -20℃ until analysis. Nitrate + nitrite concentrations were measured with a Bran and Luebbe AACS III.

Seawater samples were immediately transferred into three transparent 250 mL acid-cleaned polycarbonate bottles. Seawater in the bottle was spiked with a ^{13}C-$NaHCO_3$ (99 atm% ^{13}C, Shoko Corporation) solution. The ^{13}C enrichment was about 10% of the total inorganic carbon in the ambient water. Incubation experiments were begun within about 1 hour after the sample collection. The samples were incubated for 24 h in an on-deck incubator. The deck incubator was equipped with a cooling and heating system so as to keep the water temperature within ± 0.5℃ during incubation. During hours of darkness, the incubators were covered with opaque screens to prevent artifacts due to the ship's deck light. Immediately following the incubation, the samples were filtered directly through pre-combusted (450℃ for 4 h) Whatman GF/F filter under gentle vacuum (<200 kilopascals), and the particulate matter on the Whatman GF/F filters was rinsed with pre-filtered seawater. The filtered samples were immediately frozen and stored at -20℃ until isotope analysis on land. The filters were treated with HCl fumes for 4 h to remove inorganic carbon, and were completely dried in a vacuum desiccator. The isotopic ratios of ^{13}C to ^{12}C and particulate organic carbon were determined by a combined system of a EA1110 (CE instruments, Italy) elemental analyzer and DELTA Plus (Finigan MAT, Germany) mass spectrometer. Primary productivity was calculated according to the equation described by Hama *et al.* [8].

3. Results and Discussion

PAR ranged from 7.6 to 55.5 mol quanta m^{-2} d^{-1} during the experimental period (Table 1). When PAR was compared between September 2001and July 2003, the large differences were found from May to July in both years though theses variations were relatively small from September to February (Table 1). The surface temperature was 15-27℃ and more than 20℃ in May/June-October (summer) and about 15℃ during January-March (winter) (Table 1). The surface waters had high temperature-low salinity in summer and low temperature-high salinity in winter. Nitrate + nitrite concentrations were more than 5 μM during fall to winter in the water column, while the concentrations were less than 1 μM during spring to summer (Table 1).

Chl *a* concentration ranged from 0.37 to 1.94 mg m^{-3} during the observed period and was the highest in November 2002 (Table 1). The fluctuation of Chl *a* was irregular and did not show seasonal variation [9]. The Chl a concentrations did not show a significant correlation with PAR, temperature, Nitrate + nitrite concentration (Table 1, t-test, $P > 0.5$). This implies that phytoplankton biomass is not greatly affected by physicochemical factors in Sagami Bay. Hashimoto *et al.* [10] reported that phytoplankton biomass is strongly affected by microzooplankton grazing in Sagami Bay.

^{13}C uptake rates ranged from 6.5 to 113.4 mgC m^{-3} d^{-1} during the observed period (Table 1). P^b, an index of growth rate [11], ranged from 17.6 to 114.1mgC mg Chl a^{-1} d^{-1} (Table 1). The variation of ^{13}C uptake rates tended to be relatively high during spring to fall, especially higher in fall. The seasonal trend of P^b almost matched that of ^{13}C uptake (t-test, $P < 0.001$, $r = 0.76$). The Chl *a* concentration in November 2002was the highest during the observed period, whereas the P^b was not quite high. According to Hashihama *et al.* [5],

diatoms predominated in November 2002 at the surface in Sagami Bay. Diatom-dominated waters have low P^b values [3]. The values of P^b positively correlated with temperature (Fig. 2, t-test, $P < 0.005$, $r = 0.60$). The same results have been showed by previous studies, indicating a relationship for *in situ* temperature and maximum productivity in small-sized phytoplankton [12, 13]. On the other hand, Han and Furuya [2] showed that the P^b was consistently more stable on seasonal scale in Tokyo Bay, where large-sized diatom was the most abundant in the abundance of phytoplankton species, though temperature seasonally varied. The contribution of diatoms was relatively low, while flagellates was quite high during the observation period in Sagami Bay [5].

When large-sized diatom dominated, the correlation was relatively weak between the P^b and temperature, and the values of P^b tended to be lower and less variable [3]. The P^b of large-sized phytoplankton is not correlated with temperature [12, 14]. Consequently, P^b values are likely to be temperature dependence in the regions where large diatoms are less abundant. However, it is possible that the values of P^b do not correlate with temperature when large-sized diatoms are dominant.

Various primary productivity algorithms have been developed in order to estimate distribution of primary production from satellite derived chlorophyll data [15-17]. Behrenfeld and Falkowski [17] defined P^b as a function of temperature. Kameda and Ishizaka [18] constructed a P^b model based on two phytoplankton community cell size incorporated into the model proposed by Behrenfeld and Falkowski [17]. Isada *et al.* [19]

Table 1. Summary of daily photosynthetic active radiation (PAR: mol quanta m^{-2} d^{-1}), temperature (℃), salinity, nitrate + nitrite (μM), chlorophyll a (Chl *a* : mg m^{-3}), ^{13}C uptake (mgC m^{-3} d^{-1}), Chl *a*-specific ^{13}C uptake (P^b: mgC mg Chl *a* $^{-1}$ d^{-1}), at the surface in Sagami Bay.

Year	Month	PAR	Temperature	Salinity	$NO_3 + NO_2$	Chl *a*	^{13}C uptake	P^b
2001	Sep	18.3	25.5	33.47	1.30	0.62	68.7	111.1
	Oct	29.3	24.5	33.96	1.33	0.99	113.4	114.1
	Nov	20.6	19.7	33.85	4.65	0.70	37.0	52.8
	Dec	19.3	17.7	34.34	4.79	0.61	26.8	44.0
2002	Jan	7.6	14.7	34.56	9.61	0.91	17.3	19.1
	Feb	27.5	14.7	34.56	4.39	0.50	10.9	21.7
	May	10.2	19.4	34.65	0.63	0.78	37.7	48.2
	Jun	53.5	19.7	34.6	0.20	1.46	23.8	32.5
	Jul	51.0	22.0	33.77	0.42	0.98	43.9	45.0
	Aug	55.5	27.2	no data	0.15	0.99	53.9	54.3
	Sep	30.6	26.1	33.73	0.21	0.55	44.6	80.9
	Oct	30.8	25.1	34.11	0.36	0.54	37.0	69.2
	Nov	11.2	17.5	34.43	6.09	1.94	81.4	41.9
	Dec	14.5	19.9	34.66	2.09	0.62	38.9	63.3
2003	Jan	20.8	16.0	34.65	5.82	0.78	52.8	67.9
	Feb	26.1	14.8	34.63	7.08	0.59	12.8	21.6
	Mar	35.0	15.2	34.63	4.19	0.37	6.5	17.6
	Apr	14.5	16.0	34.56	3.18	0.72	62.4	86.5
	May	42.0	20.2	34.52	0.29	0.98	38.2	39.0
	Jun	16.2	21.9	33.93	0.12	0.40	22.3	56.2
	Jul	18.5	21.5	34.12	0.03	1.12	30.4	27.1

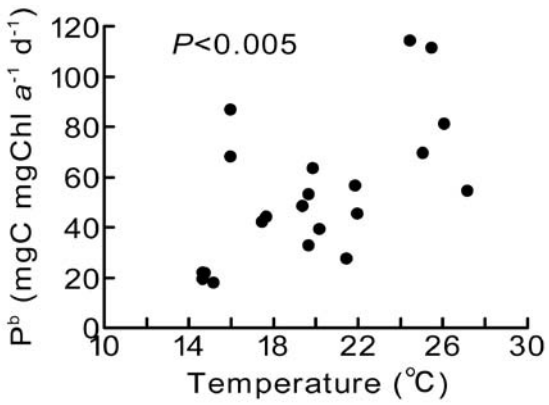

Fig. 2. Relationship between chl a-specific ^{13}C uptake (P^b) and temperature at the surface in Sagami Bay.

indicated that the models of Behrenfeld and Falkowski [17] or Kameda nd Ishizaka [18] did not accurately reproduce *in situ* P^b in the Oyashio regions of the North western Pacific, where large-sized diatoms predominate in every spring. The P^b of large-sized diatom may not be largely affected by temperature. Consequently, if the model based on P^b as a function of temperature from satellite is used for estimation of primary production, the primary production may not be accurately calculated in the regions where large-sized diatoms predominate.

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