Kasetsart J. (Nat. Sci.) 31 : 385 - 391 (1997)

Dissolved Oxygen Environments of the Fish Farm in Yashima Bay, Japan. I. Primary Productivity of Sea Water

Tritep Vichkovitten[1] and Hiroo Inoue[2]

ABSTRACT

The Steele's equation was applied for estimation of primary productivity of sea water from fish culture area in Yashima Bay and expressed in the term:

$$\sum P(t) = (chl-a)P_{(a)\max}\frac{e}{K_d}\left(e^{-i_z/i_{\max}} - e^{-i_0/i_{\max}}\right)$$

where P = Production rate per unit surface (mgO_2/m^2 hr), $P_{(a)max}$ = maximum production rate based on chl-a (mgO_2/mg chl-a hr), chl-a = chlorophyll-a concentration (mg/m^3), K_d = extinction coefficient (m^{-1}), i_0 = incident light at the sea surface (klux), i_z = light quantum at depth z meter (klux), i_{max} = maximum light intensity that gave maximum production rate (klux). The extinction coefficient was evaluated from the equation:

$$K_d = 0.06 + 0.060(SS) + 0.015(chl-a) + 0.020(COD_d)$$

where SS = dry weight of suspended particulate matter (g/m^3), COD_d = chemical oxygen demand of dissolved organic matter in sea water (g/m^3). Day rate integrals were calculated according to the equation based on the summation of rates of short intervals. Thus, the primary productivity in Yashima Bay was 7.40 gO_2/m^2 d with the values of $P_{(a)max}$ as 65.5 mgO_2/mg chl-a hr and i_{max} was 50.5 klux.

Key words : primary productivity, primary production, Steele's equation

INTRODUCTION

A necessary condition for a large-scale fishery to be possible in a certain sea area is that a significant part of the primary production. The outstanding importance of the phytoplankton organisms is that this population represents the first link in the primary food chain from inorganic to organic substances. The organic material produced by the primary producers is referred to as 'primary production' and primary production per unit time in a unit volume of water (or under a unit area) is called 'primary productivity'. Methods for the measurement of photosynthetic rate can be measured either directly or indirectly which usually involve a measurement of either carbon dioxide taken up or the oxygen produced per unit time. The ^{14}C-method is usually used for the measurement of CO_2 taken up since it is possible to detect very low photosynthetic rates by this method. Production estimates based on oxygen evolution can be made using either an oxygen electrode or the Winkler titration

1 Sriracha Fisheries Research Station, Sriracha, Chonburi 20210, Thailand.
2 Faculty of Agriculture, Kagawa University, Japan.

technique, but both of them are usually an order of magnitude less sensitive than the ^{14}C-technique. Thus, the oxygen technique is not particularly suitable to use in oceanic waters, but it can be used in some coastal area, or in high latitude oceanic waters with a high density of phytoplankton. In the shallow coastal area like Yashima Bay, primary production can be measured directly by oxygen technique.

MATERIALS AND METHODS

The field observation was conducted in Yashima Bay which was a shallow bay located in the Bisan-Seto inland sea with the average depth of 6.5 m and the outer part was yellowtail fish culture area (Vichkovitten, 1997), on 3-4 September 1992 over the period of 24 hours. The illumination was measured in air by a light intensity meter (TOPCON IM-3), the salinity and water temperature were measured by YSI model 33 S-T-C (Salinity-Temperature-Conductivity) meter. Depth was measured by depth meter. Outputs were recorded continuously by portable hybrid recorder (YEW Model 3087). Water samples were collected for determination of chlorophyll content, chemical oxygen demand of dissolved organic matter (COD_d), and suspended particulate matter (SS) at three hours interval.

The primary production experiment was carried out on 17 September 1992. Water samples were collected from sea surface at the yellowtail culture area in Yashima Bay. The sample was filtered through zooplankton net to separate the large particle and zooplankton. A 3.5 litre plexiglass tube (light bottle) was filled with filtered sample and stopped without air trapped with rubber stopper, oxygen probe was attached to one end of the stopper to measure the oxygen inside the apparatus.

By using PVC plastic tube (dark bottle), another experiment was done in the same way. The tubes were suspended horizontally 10 cm below water surface in a half ton fiberglass tank where temperature was controlled by continuously running tap water. The water sample was accumulated by vibrator to reduce the effect from the production of air bubbles in the tubes during the experiment. The concentration of dissolved oxygen in the tube was measured by oxygen meter (YSI Model 57). The illumination, salinity and temperature were recorded as mentioned above. The chlorophyll content, chemical oxygen demand of dissolved organic matter (COD_d), and suspended particulate matter (SS) of the sample before and after experiments were determined.

Rate of change of dissolved oxygen in the light bottle was the rate of net production of sea water and the average value of the rate in dark bottle was the respiration of sea water. Thus, summation of these two values was the rate of gross production.

RESULTS AND DISCUSSION

Gross production in sea water calculated from light and dark bottle is shown in Table 1 and Figure 1. The result presents 2.385 gO_2/m^3 d of primary productivity at sea surface. However, primary production in the sea is limited only in the photic zone and the rate of production is decreased with decreasing depth. Thus, the production rates at different depths could be obtained from plotting a photosynthesis light curve, such a curve can give important information on the dependence of production on light in the water examined.

Apply mathematical equation for calculating of gross production in Yashima Bay

The photosynthesis light curve (or *P* vs *I* curve) is a convenient reflection of environmental effects on photosynthesis and one which can be used to diagnose certain properties of algal species,

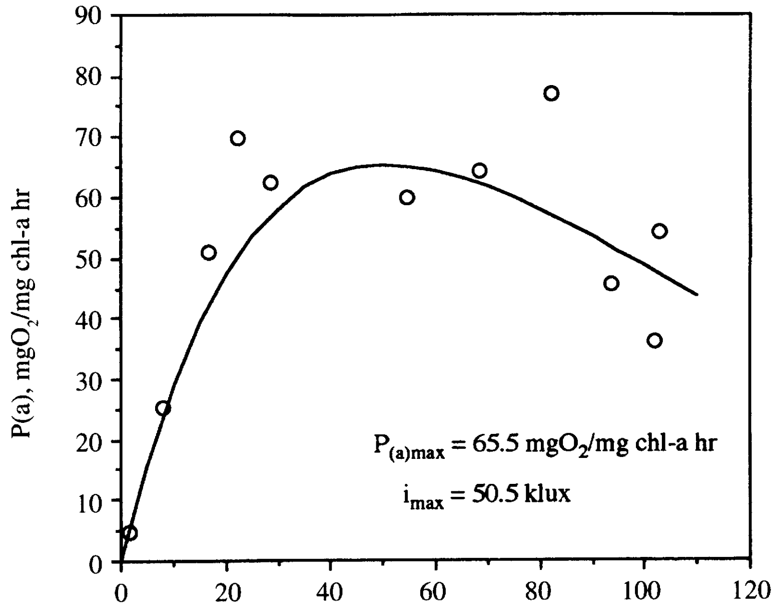

Figure 1 Photosynthesis-light curve of sea water collected from fish farm in Yashima Bay (17 September 1992).

Table 1 Gross production of sea water collected from fish farm in Yashima Bay (17 September 1992) and data used for calculation of Photosynthesis-light curve (chl-a is 4.33 mg/l).

Time	G.P (mgO_2/l hr)	Illuminance (klux)	$P_{(a)}$ (mgO_2/ mg chl-a hr)	$P_{(a)}/i$
06-07	0.0198	1.80	4.57	2.54
07-08	0.1097	7.93	25.33	3.19
08-09	0.2206	16.78	50.95	3.04
09-10	0.3020	22.22	69.75	3.14
10-11	0.3339	82.03	77.11	0.94
11-12	0.2355	103.00	54.39	0.53
12-13	0.1564	101.98	36.12	0.35
13-14	0.1972	93.68	45.54	0.49
14-15	0.2785	68.37	64.32	0.94
15-16	0.2600	54.43	60.05	1.10
16-17	0.2714	28.67	62.68	2.19

or normal sample of phytoplankton. Bannister (1974) has concluded that *P* and *I* curve described the characteristic dependence of two parameters, the instantaneous rate of photosynthesis and the incident illumination. *P* and *I* curve always refer to photosynthesis in an optical thin layer. The initial part of *P* and *I* curve, at low light intensity where the photochemical process takes place, the rate of photosynthesis rises almost linearly with illumination. At higher concentration of illuminance, the rate rises more slowly. When the enzymatic processes reach the maximum rate, at yet higher illuminance, the rate generally declines due to photoinhibition.

It is known that gross production rates beneath a unit surface area depend, among other factors, upon phytoplankton density, species composition, age and physiological stage, as well as on such environment properties as incident light, light attenuation in water, temperature, and nutrition conditions. Many investigators have constructed model to explain photosynthesis occurs in the sea, however, some of the external factors are easier to coordinate in a simple model which assumes that the phytoplankton is homogeneously distributed throughout the photosynthetic layer. A further condition of the model is that some of the basic parameters such as phytoplankton density, light attenuation, temperature, *etc.* do not change with time.

Let P_z be the production rate at depth z during any small time interval; then the total rate below a unit of surface at time t will be:

$$\sum P(t) = \int_0^\infty Pz.dz \qquad (1)$$

Steele (1962) who paid more attention on the light inhibited in the upper part of the photosynthesis curve and proposed the equation as:

$$P = ai.P_{max}.e^{(1-ai)} \qquad (2)$$

where P = the rate of photosynthesis

i = the incident illuminance

P_{max} = the maximum rate of photosynthesis

a = the relation coefficient

when ai approaches to zero (ai $\rightarrow$ 0) then e^{1-ai} = e, thus:

$$P = ai.P_{max} \qquad (2.1)$$

This equation describs that value of P is depended on ' i ' when P_{max} is constant. Therefore the rate of change of P with ' i ' is:

$$\frac{dP}{di} = (1-ai).a.P_{max}.e^{(1-ai)} \qquad (2.2)$$

when illuminance is saturated ($i = i_{max}$) rate of production becomes constant. Then, rate of change becomes zero ($dP/di = 0$) thus:

$$1-(a.i_{max}) = 0$$

$$a = 1/i_{max} \qquad (2.3)$$

Then equation (2) could be rewritten in term of i_{max} as:

$$P = (i/i_{max}).P_{max}.e^{(1-i/i_{max})} \qquad (3)$$

and expressed in exponential equation as:

$$P/i = (e.P_{max}/i_{max}).e^{i(-1/i_{max})} \qquad (4)$$

Given y = P/i, a = (e. P_{max}/i_{max}), b = $-1/i_{max}$, x = i then equation (4) will be:

$$y = a.e^{bx}$$

The unknown values a and b could be calculated from the known values of P and i obtained from the experiments. In equation (4) P_{max} and i_{max} were determined from a and b.

Light affecting primary production

To study the importance of light as a factor in primary productivity, it has been drawn attention not only to the variation in incident light falling on the sea surface but also to the relatively rapid absorption of light in the ocean. The amount of light which can penetrate the sea may therefore be considerably reduced, particularly at high latitudes, but now the problem arises of how much reaches deeper water. In temperate regions, effective light penetration (*i.e.* light of sufficient intensity for photosynthesis) probably does not go much below 50 m in summer, and with the greater obliquity of the rays is probably limited to 10-15 m in winter (Raymont, 1967). An added difficulty is that as one approaches the shore, the greater turbidity and the increased amount of detritus present in coastal waters may cut down penetration of light to a much greater degree. The rate at which the visible radiation decreases with depth is usually expressed as the extinction coefficient (K_d). Inoue (1987) proposed the equation to determined the extinction coefficient in sea water as:

Table 2 Primary productivity in Yashima Bay calculated from data obtained on 3-4 September 1992 by using the values of $P_{(a)max}$ as 65.5 mgO_2/mg chl-a hr and i_{max} is 50.5 klux.

Date	Time	K_d (m^{-1})	Chl-a (mg/l)	I_0 (klux)	Depth (m)	I_z (klux)	P(t) (gO_2/m^2 hr)	P(t)/D (gO_2/m^3 hr)
Sep 3, 1992	13-14	0.58	3.25	131.1	6.43	3.15	0.863	0.134
	14-15	0.58	3.25	115.7	6.65	2.44	0.850	0.128
	15-16	0.58	3.25	86.3	6.86	1.61	0.786	0.115
	16-17	0.58	3.25	41.6	6.90	0.76	0.545	0.079
	17-18	0.58	3.25	16.0	6.76	0.32	0.265	0.039
	18-19	0.58	3.25	3.7	6.51	0.08	0.069	0.011
	19-20			0	6.28	0	0	0
	20-21			0	6.12	0	0	0
	21-22			0	6.00	0	0	0
	22-23			0	6.00	0	0	0
	23-24			0	6.03	0	0	0
Sep 4, 1992	00-01			0	6.30	0	0	0
	01-02			0	6.48	0	0	0
	02-03			0	6.59	0	0	0
	03-04			0	6.48	0	0	0
	04-05			0	6.37	0	0	0
	05-06			0	6.13	0	0	0
	06-07	0.52	3.31	2.7	5.80	0.13	0.056	0.010
	07-08	0.52	3.31	12.0	5.53	0.68	0.225	0.041
	08-09	0.52	3.31	30.7	5.30	1.95	0.474	0.089
	09-10	0.52	3.31	55.2	5.20	3.69	0.674	0.130
	10-11	0.52	3.31	80.0	5.22	5.30	0.788	0.151
	11-12	0.52	3.31	115.6	5.38	7.05	0.906	0.168
	12-13	0.52	3.31	140.0	5.56	7.77	0.901	0.162

$$K_d = 0.06 + 0.060(SS) + 0.015(chl-a) + 0.020(COD_d) \quad (5)$$

where

K_d = extinction coefficient (m^{-1}),

SS = dry weight of suspended particulate matter (g/m^3),

chl-a = concentration of chlorophyll-a (mg/m^3),

COD_d = chemical oxygen demand of dissolved organic matter in sea water (g/m^3).

The water parameters are shown in Table 3 and the calculated extinction coefficient (K_d) are expressed as 0.58 m^{-1} and 0.52 m^{-1} from data obtained on September 3, 4, respectively.

Estimate gross production in Yashima Bay

By using Steele's equation to estimate the primary production thus, the total production rate from equation (1) will be:

$$\sum P(t) = \int_0^z P_{max} \frac{i}{i_{max}} e^{1-i/i_{max}} dz \quad (6)$$

as the fact that

$$\frac{di}{dz} = -K_d . i$$

At z = 0, i = i_0 and at z = z, i = i_z the general solution will be:

$$\sum P(t) = \int_{i_0}^{i_z} P_{max} \frac{i}{i_{max}} e^{1-i/i_{max}} \left(-\frac{1}{K_d} . \frac{1}{i} \right) di$$

$$= \frac{P_{max}}{i_{max}} . \frac{e}{K_d} \int_{i_0}^{i_z} e^{-i/i_{max}} di$$

$$= \frac{P_{max}}{i_{max}} . \frac{e}{K_d} \left| -i_{max} e^{-i/i_{max}} \right|_{i_z}^{i_0}$$

$$= \frac{P_{max}}{i_{max}} . \frac{e}{K_d} \left(-i_{max} e^{-i_0/i_{max}} + i_{max} e^{-i_z/i_{max}} \right)$$

$$= P_{max} . \frac{e}{K_d} \left(e^{-i_z/i_{max}} - e^{-i_0/i_{max}} \right)$$

If the maximum production rate is calculated per unit of chl-a, so that the solution of the equation will be of the form:

Table 3 Field observation data of water parameters on 3-4 September 1992 for calculation of extinction coefficient (K_d).

Date/Time	chl-a mg/l	SS mg/l	COD_d mg/l	T (°C)
Sep 3, 1992				
15.00	3.42	6.50	1.42	25.0
18.00	2.98	7.22	1.15	24.0
21.00	3.36	8.72	1.02	25.5
Sep 4, 1992				
00.00	3.45	6.18	1.02	24.2
03.00	2.87	5.80	1.03	25.0
06.00	3.21	6.61	0.77	23.0
09.00	3.12	7.53	0.78	25.0
12.00	3.59	6.35	1.05	25.7

$$\sum P(t) = (chl - a)P_{(a)\max} \frac{e}{K_d}\left(e^{-i_z/i_{\max}} - e^{-i_0/i_{\max}}\right) \quad (7)$$

where

P = Production rate per unit surface (mgO_2/m^2 hr),

$P_{(a)max}$ = maximum production rate based on chl-a (mgO_2/mg chl-a hr),

chl-a = chlorophyll a concentration (mg/m^3),

K_d = extinction coefficient (m^{-1}),

i_0 = incident light at the sea surface (klux),

i_z = light quantum at depth z meter (klux),

i_{max} = maximum light intensity that give the maximum production rate (klux).

The present of light at any depth from the sea surface could be calculated from the equation:

$$i_Z = i_0 . e^{-K_d . Z} \quad (8)$$

The results obtained from Yashima Bay are shown in Table 1, 2 with the values of $P_{(a)max}$ as 65.5 mgO_2/mg chl-a hr and i_{max} is 50.5 klux and the gross production of sea water in Yashima Bay is 7.403 gO_2/m^2 d or 1.257 gO_2/m^3 d. The results from light and dark bottle in this study is somewhat lower than previous study by Chotipuntu (1988) who reported the maximal production rate based on the data obtained from light and dark bottle in Yashima Bay was 11.3-71.4 mgO_2/mg chl-a hr and the saturated illuminance (i_{max}) was 16.9-72.1 klux with the average production of phytoplankton as 2.899 gO_2/m^3 d. However, Inoue (1979) estimated the annual gross primary production beneath a unit of water surface in Bisan-Seto waters off Takamatsu where Yashima Bay is located and reported the values of 3.04-5.11 gO_2/m^2 d. The quantity of gross production would be varied due to the different of the maximal production rate and the saturated illuminance of water samples, according to the qualities and quantities of the constituents especially phytoplankton in sea water. Furthermore, fish culture in Yashima Bay could induced the bulk of organic matter deposited to the sea bottom (Vichkovitten, 1997). Thus, it can be mention that minerals carried out from land or produced due to disintegration of coastal material and additional of dead organic particles and dissolved organic matter either brought out from land or found as remnants from an organic production in the water itself are the cause of the fluctuation of production in the coastal waters.

LITERATURE CITED

Bannister, T. T. 1974. Production equation in terms of chlorophyll concentration, quantum yield, and upper limit to production. Limnol. Oceanogr. 19: 1-12.

Chotipuntu, P. 1988. On DO Budget, the Gross Production in Yashima Bay. A master thesis of Kagawa Univ., Japan.

Inoue, H. 1979. The annual primary production in the Bisan-Seto waters off Takamatsu. Tech. Bull. of Fac. of Agri, Kagawa Univ. 30: 163-174.

Inoue, H. 1987. On oxygen uptake rate of bottom sediments, pp. 1-13. *In* The Symposium on the Impact of Agriculture Production on the Environment. NTRC, MIAT, JSPS, SAEDA, TUA and CMU. Chiang Mai, Thailand.

Raymont, J. E. G. 1967. Plankton and Productivity in the Oceans. Pergamon Press. Oxford. 660 p.

Steele, J. H. 1962. Environmental control of photosynthesis in the sea. Limnol. Oceanogr. 7: 137-150.

Steemann Nielsen, E. 1975. Marine Photosynthesis with Special Emphasis on the Ecological Aspects. Elsevier Scientific Publishing Company, Amsterdam. 141 p.

Vichkovitten, T. 1997. Fluxes and accumulation of organic matter loading from yellowtail culture in Yashima Bay, Japan. Kasetsart J. (Nat. Sci.) 31: 124-133.