Primary Production Determination in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam Waters

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ABSTRACT

Primary production in the South China Sea, off Sabah, Sarawak and Brunei Darussalam was determined from *in situ* fluorescence, light intensity and the uptake of radioactive carbon incubation on the MV.SEAFDEC cruise in July-August, 1996. Depth integrated primary production varies between 0.13–0.88 gC/m^2/day in the coastal zone and 0.23–0.89 gC/m^2/day in the open sea. The magnitude was high along the north off Brunei Darussalam and Sabah and gradually decreased with depth. The elevated daily primary production was generally found at the sea surface mixed layer and subpycnocline chlorophyll maximum. The decreasing virtual light intensity was tending to restrict the vertical distribution in daily primary production with accompanied by the chlorophyll-a concentration.

Key words: primary production, South China Sea

Introduction

A broad picture of primary production over most regions of the world's ocean is now available, due largely to the widespread use of the radiocarbon method for estimating production, first introduced by Steemann Nielsen (Raymont, 1980). The regional photosynthetic pigment variations and temporal change in the rate of primary production that are of importance through the marine ecosystem. For many reservoirs phytoplankton production is limited by light attenuation (Lind *et al.*, 1992). Variations in primary production must be accompanied by an overall view of the hourly light intensity profile in the water column, the relative importance of light decrease with depth and chlorophyll concentration (Berman *et al.*, 1995).

The study area is observed along the north off Sabah, Sarawak and Brunei Darussalam, a part of the South China Sea. It is approximately rectangular with depth between 30-2,893 m (from sounding depth). In this area considering that the maximal of daily primary production was strongly influenced by light attenuation and/or biomass of chlorophyll-a. This experiment was examined the magnitude and vertical pattern of primary production. Because of spatial and temporal problems, direct measurements of daily primary production in the same time over the whole area were impossible; these results demonstrated a high spatial and temporal variability of primary production.

Sites and methods

The location of the stations (57 stations) was shown in Fig. 1. Seawater samples were collected from several levels of depth (from sea surface to deep water however, only surface to mid water column were analyzed for primary production) by the Rosette sampler during cruise off-Sabar, Sarawak

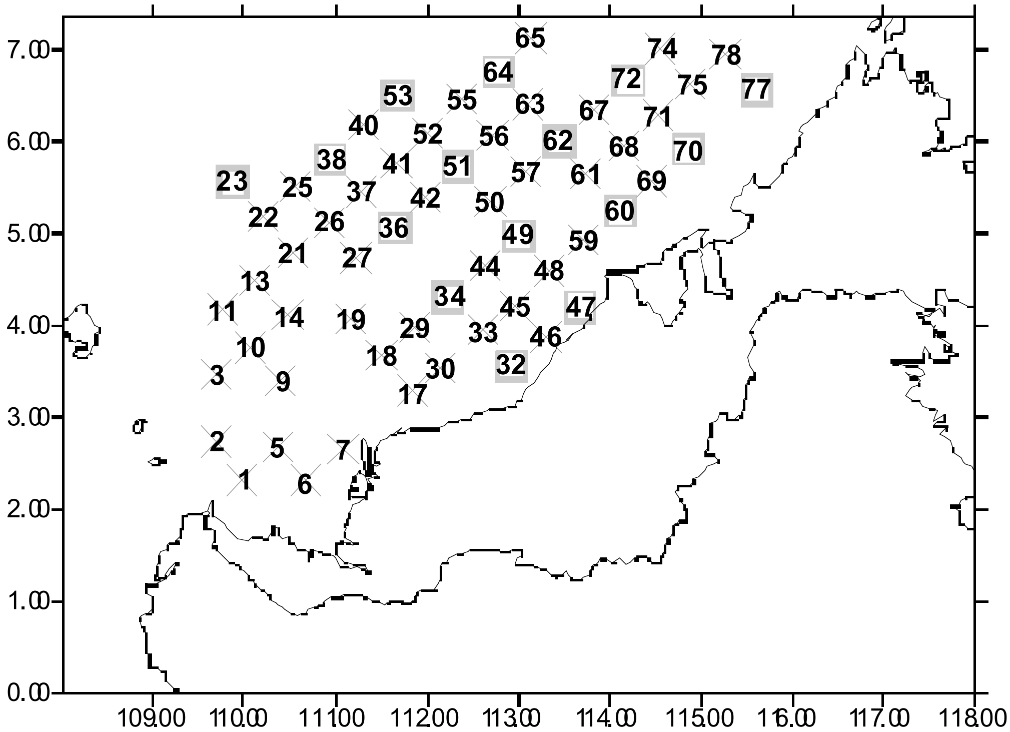

Fig. 1 Location of srvey stations to previous study. square represents stations for carbon-14 incubation

and Brunei Darussalam, on MV SEAFDEC in July-August 1996. Data of water depth and pH were determined with a CTD profiling on cruise. Table 1 was shown the sounding depth, obtained depth of daily primary production and deployment times of the primary production experiment.

Light intensity in water was measured in µE/m^2/s by a quantummeter. *In situ* fluorescence was recorded every one meter depth in volt by Sea Tech submersible fluorometer. The chlorophyll-a values discussed in this study was converted from *in situ* fluorescence by correlated linearly with the actual chlorophyll concentration and determined on cruise with spectrophotometer (Parson *et al.*, 1984).

Total alkalinity analyses was performed by 50-ml of filtered seawater mixed with 10-ml of 0.015N HCl and shaking vigorously. The final pH of the solution was measured by pH-meter, Fisher Scientific model 1002. Total alkalinity value was computed by Parson *et al.* (1984), and then the carbonate alkalinity and total carbon dioxid were calculated (carbonate alkalinity (meq/l) = total alkalinity-0.05, total carbon dioxide (meq/l) = 0.96*carbonate alkalinity).

Seawater samples for primary production were taken for incubation using ^{14}C technique (Parson *et al.*, 1984). Each sample was transferred into 300-ml glass bottles (3 bottles of clear glass and 1 bottle of dark glass for each level of depth). Each bottle was inoculated with 1.66 µCi of ^{14}C and incubated immediately in the incubator with setting the temperature in ranges 20-25 C^o. After incubation for 3 hours, samples were took away from sunlight and filtered by syring filtration with GF/F membranes. Membranes were kept frozen in scintillation vials until analyzing. In the laboratory, each vial was filled with 5-ml of scintillation fluid. Allow standing overnight after shaking the sealed vials. Counted the vials in a β-scintillation counter, model GC-9A, Shimadzu.

The method for primary production calculations was described here only briefly. It was based on radioactive carbon technique by Parson *et al.* (1984). Thus,

$$\text{Primary production in mgC/m}^3\text{/hr} = (R_S\text{-}R_B)\text{*}W/R\text{*}N, \qquad \textbf{(1)}$$

Where R = total activity of 1.66 μCi of ^{14}C solution (dpm),
N = number of hours of sample incubation (hr),
R_S = the light bottle count (dpm),
R_B = the dark bottle count (dpm),
$W_{(\text{the concentration of total carbon dioxide in mgC/m}^3)}$ = 12,000*TC,
TC = total carbon dioxide (meq/l).

Light-Time curve — Light-time equation was made from the time series of light at sea surface and regressed the equation for daily primary production (Fig.2, 3) and the relationship was:

Equation for time between 6 A.M.-12 Noon

$$Light = 1.7964\, e^{0.5489time} \qquad r^2 = 0.8494,$$

Equation for time between 12 Noon–6 P.M.

$$Light = 2E{+}09e^{-0.9434time} \qquad r^2 = 0.8001, \qquad \textbf{(2)}$$

where unit of light intensity = μE/m²/s.

Light-Depth curve — Data of light (μE/m²/s) and depth (m) were combined and correlated linearly then made for the light-depth relationship (Fig. 4):

The overall equation for the light-depth curve

$$L = 542.28\, e^{0.0698D} \quad r^2 = 0.6724, \qquad \textbf{(3)}$$

where L = light intensity (μE/m²/s) in water column, D = depth (m).

Primary production–Light intensity curve — Primary production and light intensity (P–I curve) was made by plotting primary production normalized to chl-a (as *in situ* fluorescense) against light intensity and used for P/Chl-a: light intensity relationship (Fig. 5):

The overall equation for the P–I curve

$$P = 2.3714\, Ln(L) – 1.8141 r^2 = 0.5228, \qquad \textbf{(4)}$$

where P = primary production (mgC/m³/hr), L = light intensity (μE/m²/s) in the incubator.

Estimation of daily primary production — Photosynthetic rate in the incubated bottles was calculated for primary production rate in mgC/m³/hr using equation- (1). Assuming surface intensity to be 100% and integrated daily primary production over 6 A.M. to 6 P.M. by equation- (2). Then extrapolated primary production over the water column to obtain the rate per sq.m using the *in situ* biomass and light intensity (hourly light intensity profile) by equation- (3), and (4).

Result

The wide range of depth integrated primary production in the site analyzed was 0.13–0.89 gC/m²/day (Table 1) which resulted between 0.13–0.88 gC/m²/day for the coastal zone and 0.23–0.89 gC/m²/day in the open sea, the trend became high along the north off Brunei Darussalam and Sabah (Fig. 6). This lowest value was noted at station 32 and highest at station 61.

The patterns of relation declined with depth between light intensity, concentration of chl-a and daily primary production were given in Fig. 7-11. At the shallow stations that total depth approximately 80-m daily primary production would be found through water column (Fig. 7). It was high in surface, decrease with depth and increase again in subpycnocline chlorophyll maximum. At stations which no light penetrated to mid layer (at morning or evening), any primary production also (Fig. 8).

For the stations, which total depth more than 150 m (Fig. 9-11), the result of primary production was somewhat similar distribution to the shallow water. It was common to find maximum of

Table 1 Date, time, sounding depth (m) and primary production (p-depth)

Station	Date	Time	Sounding depth	P-depth
1	10-Jul-96	6.3	38	36
2	10-Jul-96	10.2	54.5	52
3	10-Jul-96	16.2	79.8	77
5	11-Jul-96	7	79.5	57
6	11-Jul-96	10.2	43.5	40
7	11-Jul-96	15	32.5	28
9	12-Jul-96	6.3	68.5	52
10	12-Jul-96	10.2	86	84
11	12-Jul-96	14.3	100	95
13	13-Jul-96	7	115.5	84
14	13-Jul-96	10	93.5	91
17	14-Jul-96	6.55	33	25
18	14-Jul-96	11.3	49.5	45
19	14-Jul-96	16	70	65
21	15-Jul-96	6.3	119	42
22	15-Jul-96	9.5	146	58
23	15-Jul-96	14.1	145	75
25	16-Jul-96	6.3	200	28
26	16-Jul-96	10.1	123	86
27	16-Jul-96	14.3	95.5	89
29	17-Jul-96	7	56	40
30	17-Jul-96	10.2	32	29
32	19-Jul-96	6.3	34	13
33	19-Jul-96	10.2	49	46
34	19-Jul-96	14.3	71	66
36	20-Jul-96	6.3	108	34
37	20-Jul-96	10.2	384	84
38	20-Jul-96	15.1	1031	63
40	21-Jul-96	6.3	1018	55
41	21-Jul-96	10.3	1207	94
42	21-Jul-96	15.2	134	82
44	22-Jul-96	6.3	89	46
45	22-Jul-96	10	66	63
46	22-Jul-96	14.1	20	18
48	24-Jul-96	9	78	71
49	24-Jul-96	13.1	105	100
50	24-Jul-96	17.3	425	70
51	25-Jul-96	7	192	58
52	25-Jul-96	10.2	1650	110
53	25-Jul-96	16	1924	91
55	26-Jul-96	6.3	1316	85
56	26-Jul-96	10.5	1148	120
57	26-Jul-96	15.5	2340	117
59	27-Jul-96	6.3	1619	73
60	27-Jul-96	10	178	106
61	27-Jul-96	15	2148	120
63	28-Jul-96	7	1628	76
64	28-Jul-96	11.15	1242	60
65	28-Jul-96	16	1457	56
67	29-Jul-96	6.3	2814	36
68	29-Jul-96	12	1789	110
69	29-Jul-96	16	97	90
71	31-Jul-96	14	1892	120
74	1-Aug-96	9.5	2893	117
75	1-Aug-96	15	1782	116
77	2-Aug-96	6.3	96.5	90
78	2-Aug-96	10.5	1515	120

Table 2 Depth integrated primary production (gC/m^2/day)at different stations

Station	P(gC/m^2/day)	Station	P(gC/m^2/day)
1	0.3	40	0.39
2	0.39	41	0.61
3	0.62	42	0.59
5	0.46	44	0.33
6	0.34	45	0.44
7	0.34	46	0.17
9	0.37	48	0.52
10	0.58	49	0.69
11	0.68	50	0.54
13	0.63	51	0.39
14	0.89	52	0.76
17	0.27	53	0.66
18	0.43	55	0.62
19	0.55	56	0.66
21	0.33	57	0.8
22	0.41	59	0.56
23	0.54	60	0.77
25	0.23	61	0.88
26	0.56	63	0.52
27	0.71	64	0.4
29	0.34	65	0.4
30	0.28	67	0.28
32	0.13	68	0.76
33	0.39	69	0.64
34	0.5	71	0.83
36	0.26	74	0.69
37	0.57	75	0.81
38	0.46	77	0.63
		78	0.76

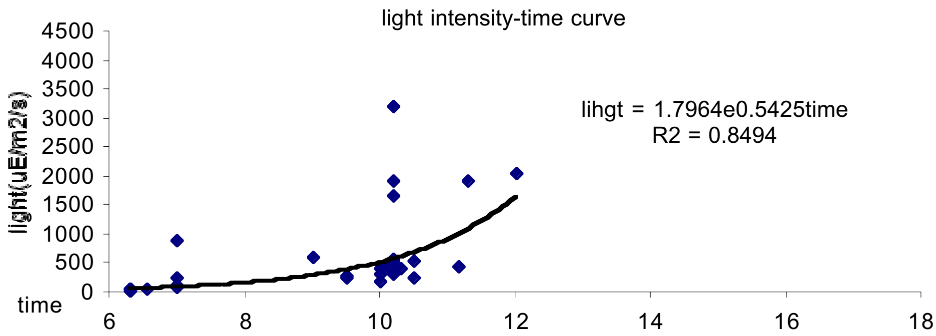

Fig. 2 The light-time relationship between 6 A.M.-12 Noon

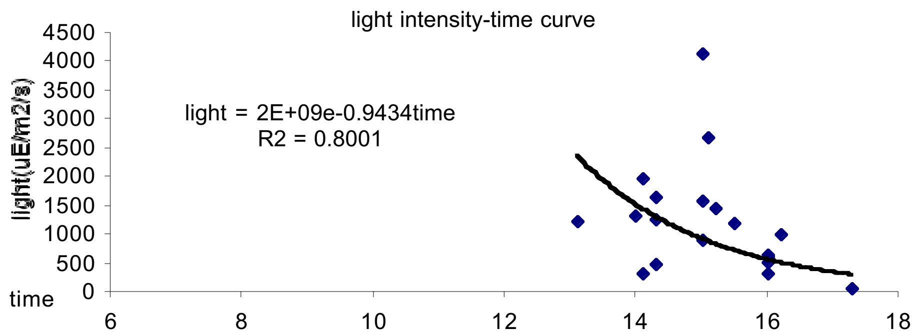

Fig. 3 The light-time relationship between Noon - 6 PM

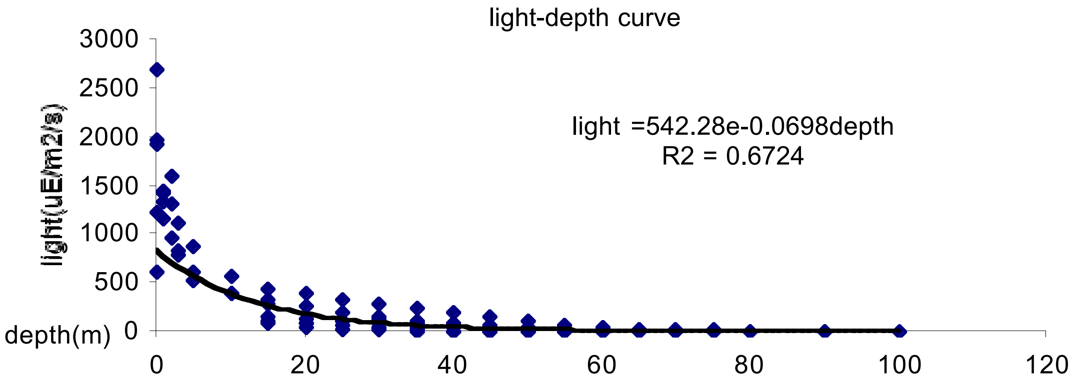

Fig. 4 The relationship of light intensity from 6 A.M.to 6 P.M. and depth of the investigation study area

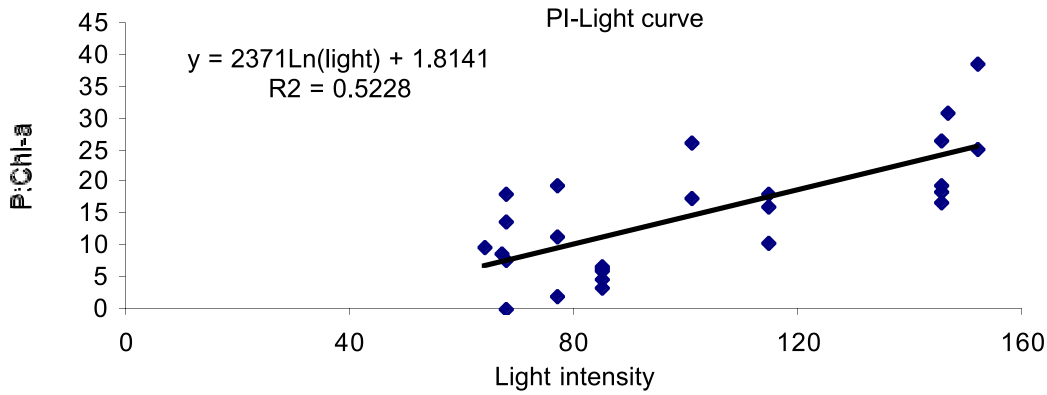

Fig. 5 The relationship between light intensity and daily primary production normalized to phytoplankton biomass

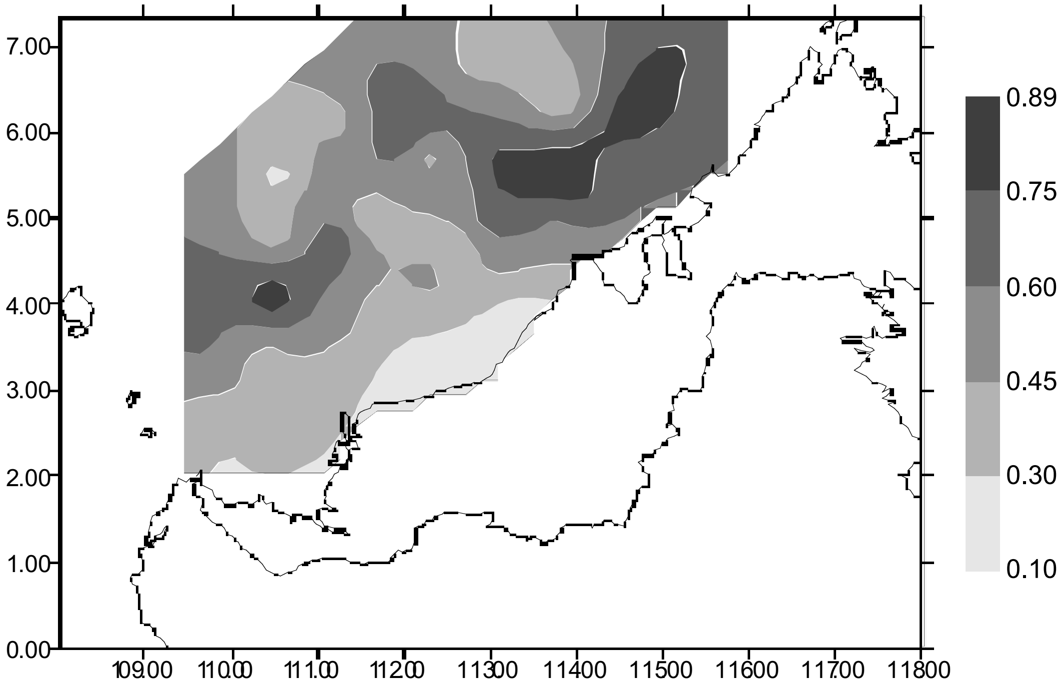

Fig. 6 Demonstration of depth integrated primary production in $gC/m^2/day$

primary production near the surface and subpycnocline chlorophyll maximum: which the generally decrease with depth. In the deep, so reduce light penetration, continuous vertical distribution of chlorophyll-a, most of primary production was usually supported by light attenuation.

The general distribution of daily primary production at different depth was demonstrated in Fig. 12-17.

Discussion

Solar input to the water was saturated for photosynthesis and light factors relating incident solar radiation due to elevate the primary production. As reported previously by Mallin and Paerl, 1992 in shallow water photosynthesis reveal various increasing to alter light intensity and chlorophyll-a. Vertical pattern of primary production due to sea surface daily radiant energy available (Raymont, 1980). In this experiment, it was noteworthy that in surface and subsurface mixed layer, daily primary production was more closely correlated to chlorophyll-a and light intensity. In subpycnocline chlorophyll maximum, daily primary production was tightly linked correlation between photosynthetic pigment and timely light intensity profile.

The depth dependence of the relationship between primary production, light intensity and chlorophyll-a was also examined (Fig. 9-11). The phytoplankton was so concentrated in the subsurface mixed layer and subpycnocline chlorophyll maximum: this depth was found between 10-25 m and 50-70 m respectively. Daily primary production would be important strategy followed by chlorophyll-a concentration in stable stratified water which light was most intense near surface mixed layer. Increased chlorophyll-a content markedly reduced light intensity with depth (Krause-Jensen and Sand-Jensen, 1998). In mid depth chlorophyll maximum, the photosynthetic pigments would like acclimatizing to the low light intensity and might stimulate the daily primary production.

Summary

These results indicated that more realistic assessments of integrated daily primary production in this area could be made by the light- field condition.

Acknowledgement

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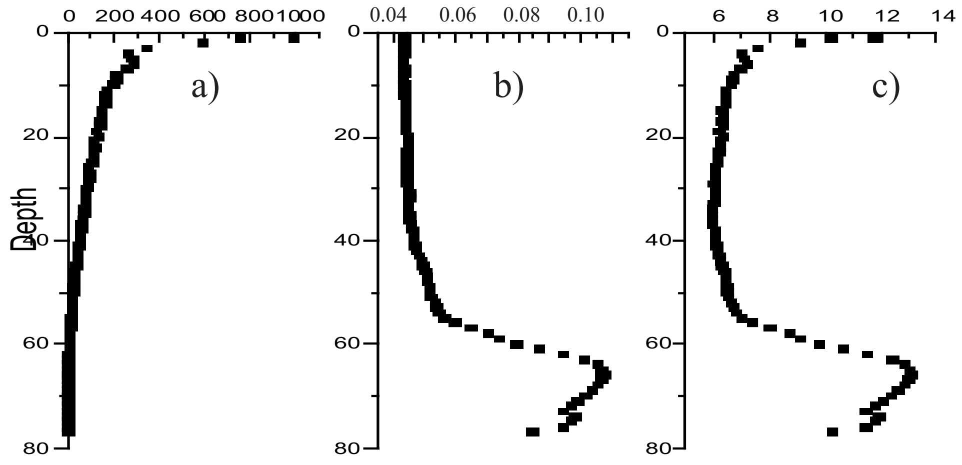

Fig. 7 Light intensity (a), Chl-a (b) and daily primary production (c) from station 3 at time 16.20 P.M.

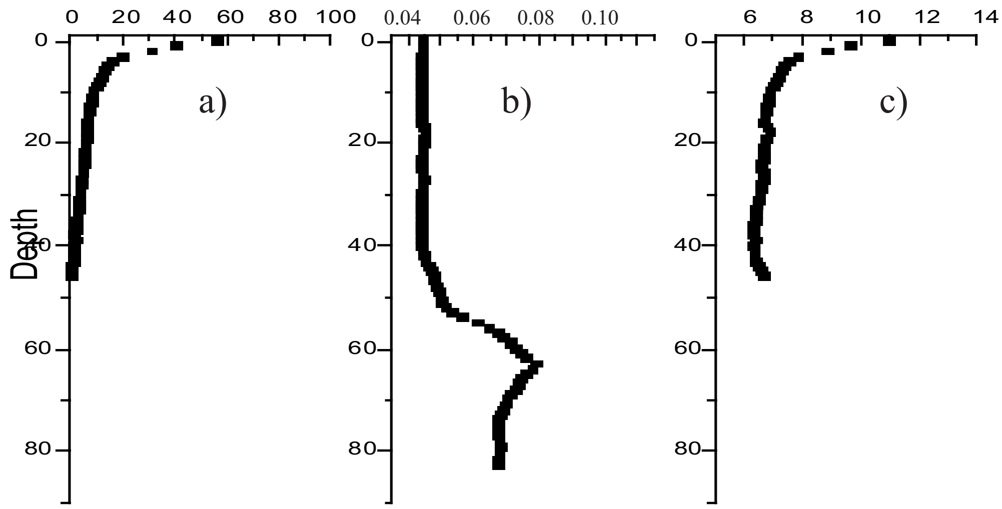

Fig. 8 Light intensity (a), Chl-a (b) and daily primary production (c) from station 44 at time 6.40 A.M.

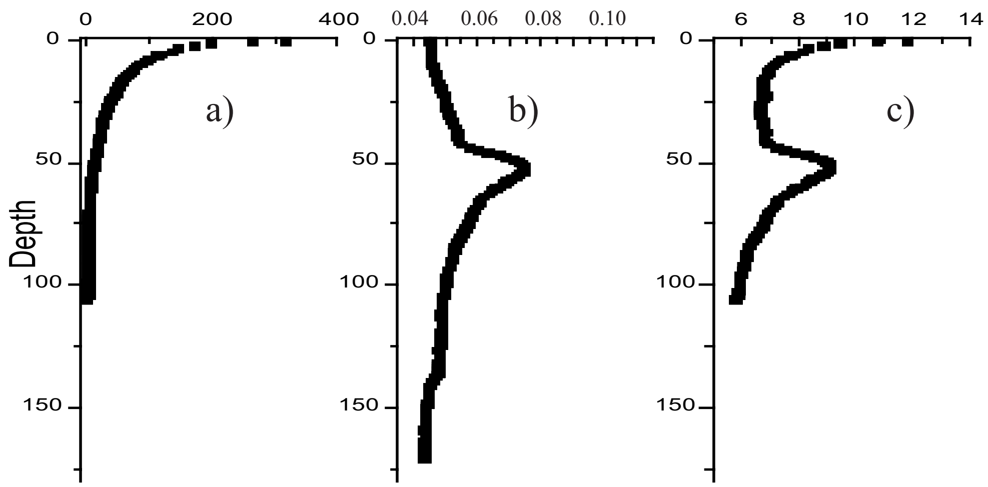

Fig. 9 Light intensity (a), Chl-a (b) and daily primary production (c) from station 60 at time 10 A.M.

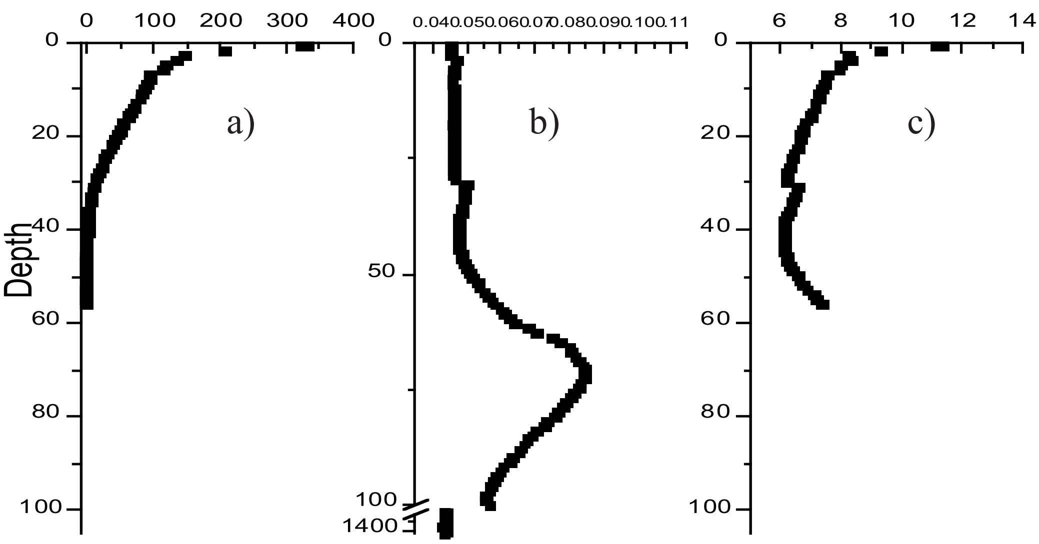

Fig. 10 Light intensity (a), Chl-a (b) and daily primary production (c) from station 65 at time 4PM.

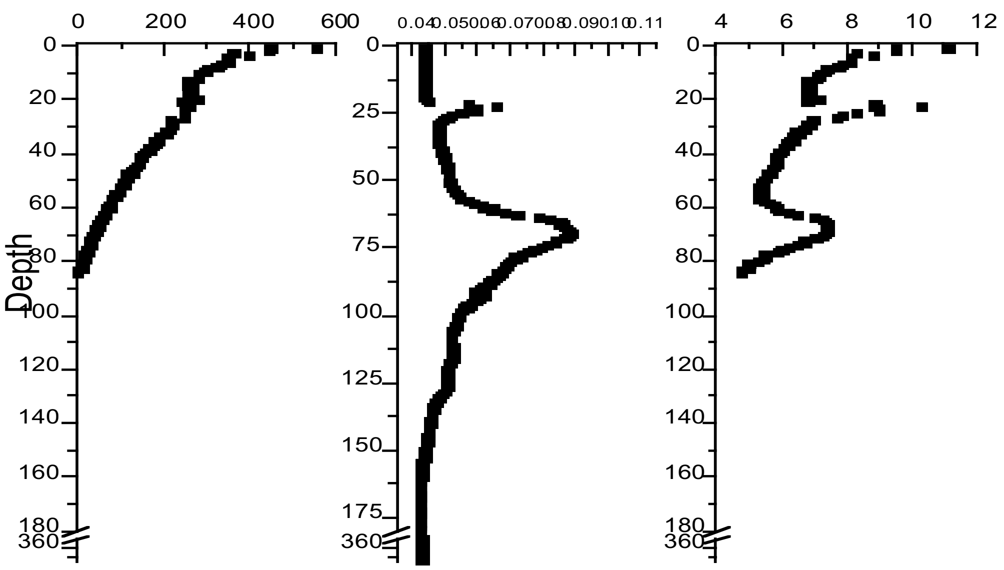

Fig. 11 Light intensity (a), Chl-a (b) and daily primary production (c) from station 37 at time 10:20 AM.

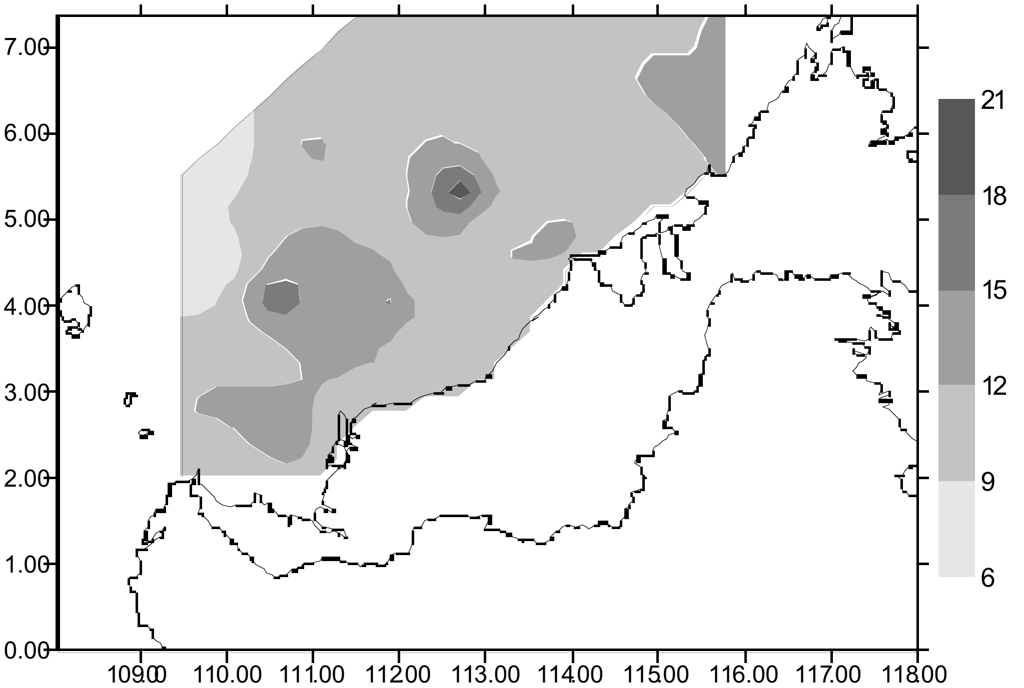

Fig. 12 Investigation dialy primary production of the general surface-water in mgC/m^3/day

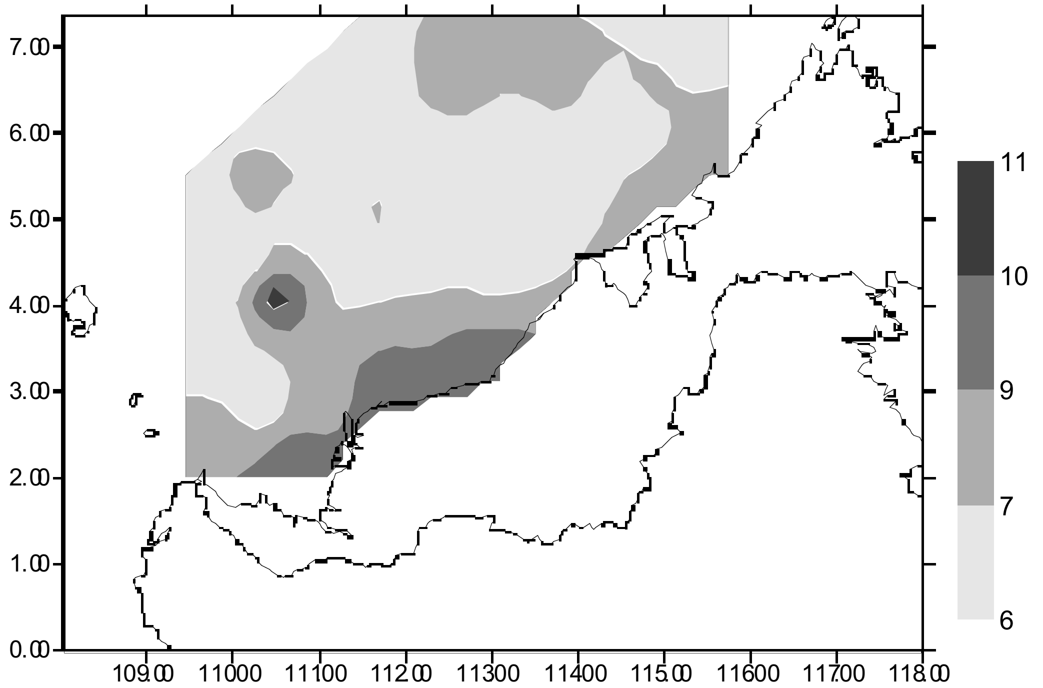

Fig. 13 Investigation dialy primary production of the general 10m water depth in mgC/m^3/day

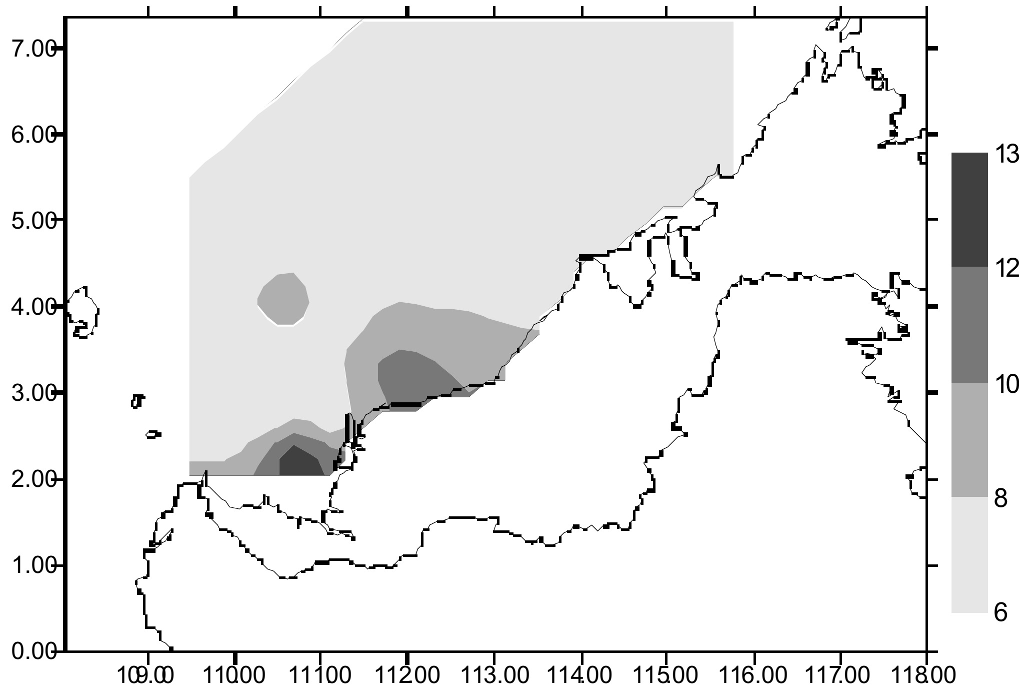

Fig. 14 Investigation dialy primary production of the general 20m water depth in mgC/m^3/day

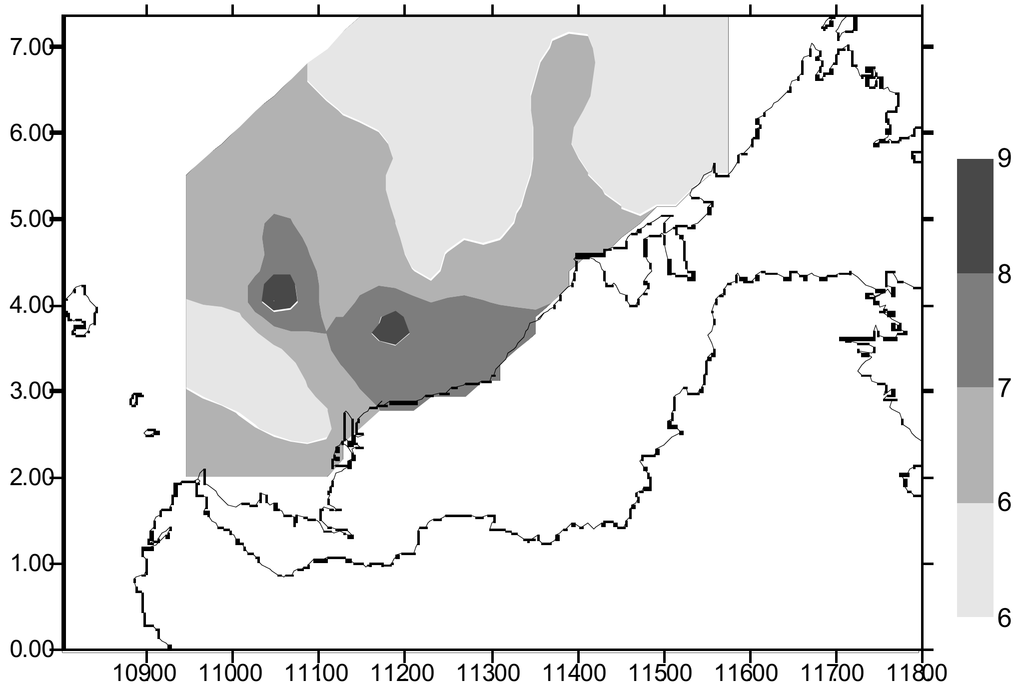

Fig. 15 Investigation dialy primary production of the general 30m water depth in mgC/m^3/day

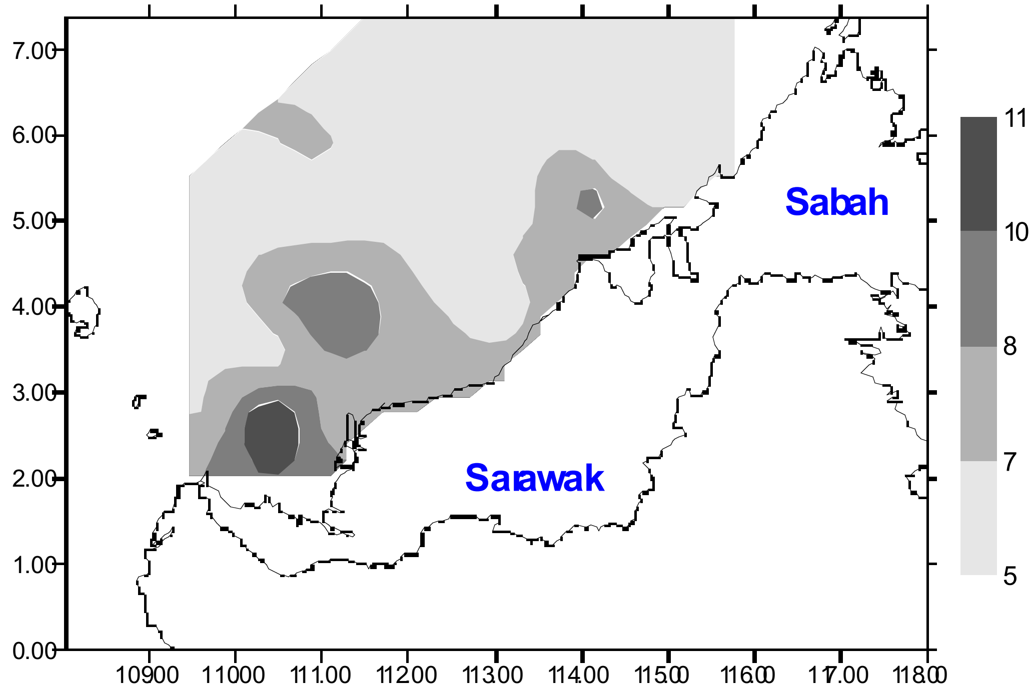

Fig. 16 Investigation dialy primary production of the general 50m water depth in mgC/m^3/day

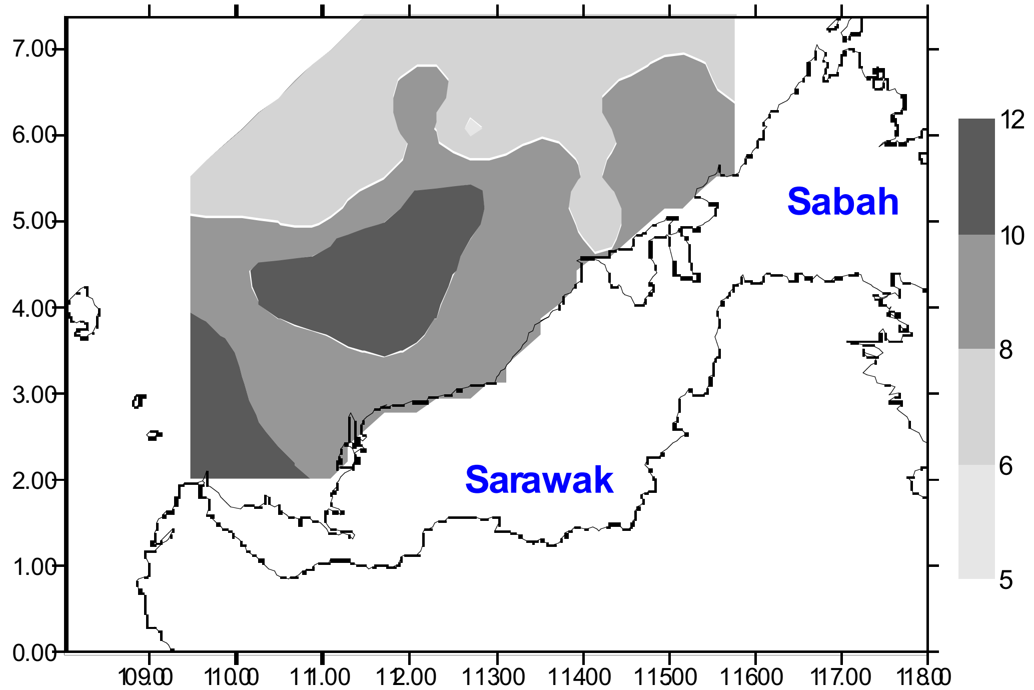

Fig. 17 Investigation dialy primary production of the general 70m water depth in mgC/m^3/day