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A Preliminary Survey on Primary Productivity Measured by the ^{14}C Assimilation Method in the KEEP Area

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ABSTRACT

Primary productivity (PP) at the four sampling stations in the KEEP (Kuroshio Edge Exchange Processes) area, which located on the southern East China Sea north of Taiwan, was measured by the ^{14}C assimilation method from May 4 to May 10, 1994. Stations 1, 8 and 11 and 17 represented the coastal, the upwelling and the Kuroshio waters respectively. PP varied among stations and depths, ranging from < 11 to 134 mgC m^{-3} d^{-1} with the highest and lowest values observed at stations 1 and 17 respectively. The euphotic zone integrated productivity (EIP) for stations. 1, 8, 11 and 17 were 1901, 418, 1537 and 425 mgC m^{-2} d^{-1} respectively. Higher PP and EIP values and chlorophyll *a* concentration observed at stations 1 and 11 might be explained by the high nitrate supply rates. Normalized productivity (P^B) ranged from 0.6 to 10.9 mgC $mgChl^{-1}$ h^{-1} with higher values observed at stations 8 and 11. Both PP and P^B decreased exponentially with depth at all sampling stations, indicating a possible effect of light exerted on P^B. The EIP value derived from the in situ incubation (569 mgC m^{-2} d^{-1}) was 36% higher than that of the on deck incubation. This might be due to the tilting of the in situ incubation array which allowed the in situ bottles to expose to higher light level.

(Key words: Phytoplankton, Marine Ecology, Southern East China Sea, Kuroshio)

INTRODUCTION

Phytoplankton are the major organisms that fix inorganic carbon (i.e. CO_2, HCO_3^-, etc.) into organic carbon, either in particulate or dissolved forms via photosynthetic processes. They constitute the base of the marine food webs and thus, may affect the dynamics of higher trophic levels due to the variability in their biomass and productivity. More importantly, the sinking of dead phytoplankton to the deep ocean (i.e. export production) which may act as an important sink for atmospheric CO_2 (i.e. biological pump).

Studying the temporal and spatial variability of primary productivity and its controlling

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mechanisms are essential to understand the biogeochemical cycle of carbon in the ocean (Cullen et al., 1992; Knauer, 1991; Longhurst & Harrison, 1989), which is also the ultimate goal for the upcoming KEEP II (Kuroshio Edge Exchange Processes 2) project. To fulfill this goal, the first step is to adopt an accurate and reliable method to measure primary productivity.

Primary productivity (PP) can be measured by different ways (Bender et al. 1987 and citations therein), such as (1), the ^{14}C assimilation method; (2), the ^{13}C uptake method; (3), the O_2 light-dark bottle method; (4), the CO_2 light-dark bottle method; (5), the $H_2{}^{18}O$ uptake method and (6), the increase of biomass over time method. Like most other methods, there is some uncertainties about the ^{14}C method (Carpenter & Lively, 1980; Richardson, 1991). As shown in Figure 1, phytoplankton respiration is not taken into account by this method and this has led to the question of what the ^{14}C method actually measures. It is generally accepted that the PP derived from the ^{14}C method is an intermediate between gross and net production (Bender et al. 1987, Davies & Williams, 1984). One unsettled problem is that some chemolithotrophs, such as the nitrifying bacteria, can also fix CO_2 (dark fixation) although its impact on the ^{14}C method is still in debate (Li et al. 1993). Usually, only particulate part of the water samples is collected after incubation, PP may be severely underestimated if exudation rate of dissolved organic carbon (DOC) is high. Generally, it is recognized that < 15% of the PP is exudated as DOC (Zlotnik & Dubinsky, 1989; Wood et al., 1992) although much higher and lower values have been reported (Sondergaard, 1990; Sell & Overbeck, 1992). In spite of these uncertainties, the ^{14}C assimilation is still the most commonly deployed method of determining PP due to its high sensitivity. This method is particularly useful in areas with very low productivity, such as the oligotrophic open ocean, and in waters near the bottom of the euphotic zone.

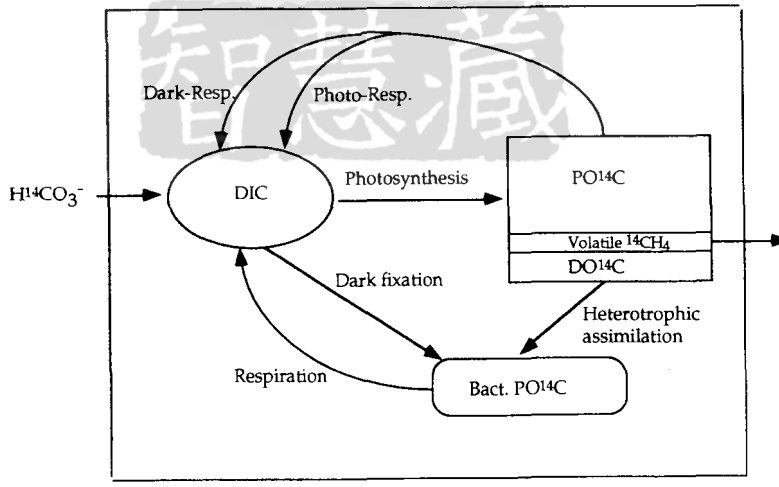

Fig. 1. Distribution of ^{14}C in different carbon pools in water sample inoculated with $H^{14}CO_3^-$. DIC, dissolved inorganic carbon; POC, particulate organic carbon; DOC, dissolved organic carbon; Resp., respiration and Bact., bacteria.

Primary productivity in the East China Sea and the Kuroshio areas has been studied by many researches (e. g. Hung et al. 1980; for review, see Guo, 1991). For this study, the ^{14}C

assimilation method is used for the first time in the KEEP project. The major purposes of this paper were to examine the applicability of the ^{14}C assimilation method and present the primary productivity data obtained in the KEEP area during a 7 days cruise. The difference between the on deck and the in situ incubation and the spatial variability of the primary productivity in the study areas were discussed.

MATERIALS AND METHODS

1. Sampling

This study was performed at the four stations in the KEEP area in the southern East China Sea north of Taiwan (Fig. 2) from May 4 to May 10, 1994. Water samples were collected by 20 liter Go-Flo bottles attached to a CTD-Rosette assembly which record temperature, salinity and fluorescence profiles at the same time. Light intensity at different depths was measured every meter by a portable 2π light meter from surface down to 22 m. A linear correlation between depth and the natural logarithmic transformed light intensity was calculated immediately to estimate the light intensity below 22 m. The bottom of the euphotic zone was defined as the depth where 1% of the surface light intensity reaches. Sampling depths of each station were shown in Table 1, ranging from 5 m below sea surface to 80 m.

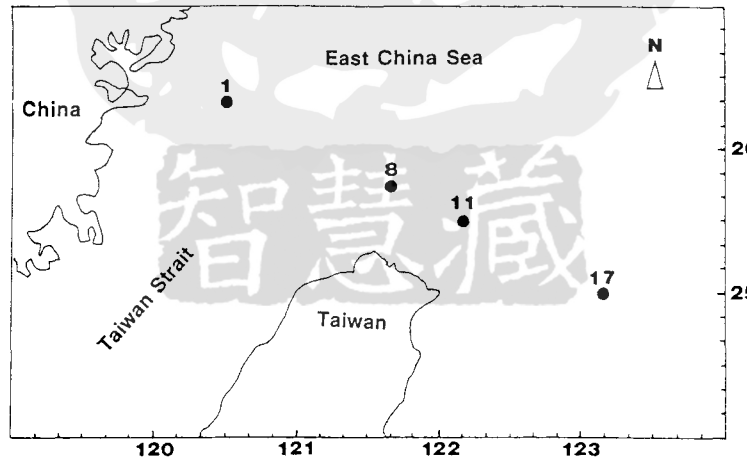

Fig. 2. Map of the southern East China Sea north of Taiwan area showing sampling stations.

2. Primary Productivity

Phytoplankton photosynthesis rate was measured by $H^{14}CO_3^-$ assimilation method (Parsons et al. 1984). Seawater samples collected before dawn (usually, 4:00 - 5:00 am) were filtered through 200 μm nylon mesh to remove large zooplankton. Immediately thereafter, aliquots of 250 ml water samples of each depth were transferred to 280 ml polycarbonate bottles, including three clear and one dark ones and then inoculated with 0.1 ml $H^{14}CO_3^-$ solution. The final specific activity in each bottle was 10 μCi. One clear bottle was immediately filtered as the

time zero sample. This was to determine the amount of $H^{14}CO_3^-$ adsorbed on the filters via abiological processes and/or the biological fixation during sample fixation. Incubation bottles were all prewashed by soaking in a 10% HCl solution overnight and rinsing at least three times with Milli-Q water and also rinsed with sample waters before incubation. Incubation was performed either in situ (JGOFS, 1993) or on deck (Table 1). Note that the comparison of the on deck vs. in situ incubation was performed at station 8 only and the incubation period for experiment performed at station 11 was 24 h.

Table 1: Incubation design, sampling and some physical properties for the four sampling stations located on the KEEP-Key transect.

Items	Station 1	Station 8	Station 11	Station 17
Incubation	on deck,12 h	on deck,12 h in situ, 12 h	in situ, 24 h	on deck,12 h
Bottom depth (m)	60	110	140	2000
Sampling depth (m)	5,10,15,20,45,50,60	5,10,15,20,25,30	5,10,15,20,25,30	5,10,15,20,30,80
Euphotic zone depth (m)	20	25	45	55
Temperature (^oC) in euphotic zone	19 - 20	24	23 - 24	26 - 27
Water types	coastal	upwelling	upwelling	Kuroshio

For the in situ incubation, two light and one dark bottles for each depth were placed individually in nylon mesh bags which were in turn tethered onto the in situ array (Fig. 3). The array which was either a singular nylon line or a sediment trap array, was lowered down to the water column such that the samples would be situated at their original depth if the array was entirely vertical. A 50 m tag line connected to the top of the array was tied to the stern of the research vessel. The recovery of the sample bottles from the array line was performed right after dusk. The deployment and recovery took about 30 to 40 minutes. For the on deck incubation, duplicate light bottles for certain depth were covered with different layers of nylon stockings to simulate the degree of the light penetration at that particular depth. The correlation between layers of nylon stockings (N) and I_Z/I_O (the ratio between light intensity at depth Z and that at sea surface which refereed to as the relative light intensity) previously determined at laboratory is: $N = 0.03 - 3.93 \times \ln (I_Z/I_O)$, $n = 10$, $R^2 = 1.00$. All bottles were incubated in a 2m $\times$ 2m $\times$ 1m transparent plastic tank with surface seawater running through during entire incubation period.

Following retrieval, the bottles were stored in the dark and processed immediately. From each light bottle, 0.25 ml is taken and transferred to a 15 ml scintillation vial containing 2.5 ml of Milli-Q water and 0.25 ml of ethanolamine, and then 10 ml of scintillation cocktail (Ultima Gold) was added. This was to determine the total activity of $H^{14}CO_3^-$ in the sample. Theoretically, this value should be closed to 22200 dpm (0.25 ml/250 ml $\times$ 10 μCi $\times$ 2.22 $\times$ 10^6 dpm/μCi). The

water samples were then filtered through 25 mm GF/F filters. Pumping pressure was maintained below 100 mmHg to prevent the possible damage of cells. The filters then were placed in scintillation vials and 0.5 ml of 0.5 N HCl was added to remove residual $H^{14}CO_3^-$. After returned to laboratory, the vials containing filters were left open and dried in the hood at room temperature overnight. The time zero sample, total activity and incubated samples were counted in a liquid scintillation counter (PACKARD 1600) after addition of 10 ml scintillation cocktail in vials. The radioactivity (in dpm, disintegration per minute) of each sample was converted to daily productivity using the following equation:

$$\text{Productivity (mgC m}^{-3}\text{ d}^{-1}) = \text{dpm/V} \times \text{W} \times 0.25 \times 10^{-6}/\text{TA} \times 1.05$$

where V: volume of filtered sample in m^3;
W: 25000 mgC m^{-3} (in seawater);
TA: total activity in dpm in 0.25 ml;
1.05: discrimination factor for ^{14}C uptake (BATS, 1991).

This calculation was made for light and dark bottles respectively. The dark bottle rate was subtracted from the mean rate of the duplicate light bottles to correct for non-photoautotrophic carbon fixation or adsorption. Euphotic zone integrated productivity (mgC m^{-2} d^{-1}) was calculated with individual depth measurements by trapezoidal integration. The rate nearest the surface was assumed to be constant up to 0 m. Normalized productivity (i.e. P^B; mgC $mgChl^{-1}$ h^{-1}) was calculated by dividing productivity (mgC m^{-3} d^{-1}) with chlorophyll *a* concentration (mgChl m^{-3}) and the daylight incubation period (i.e. 12h).

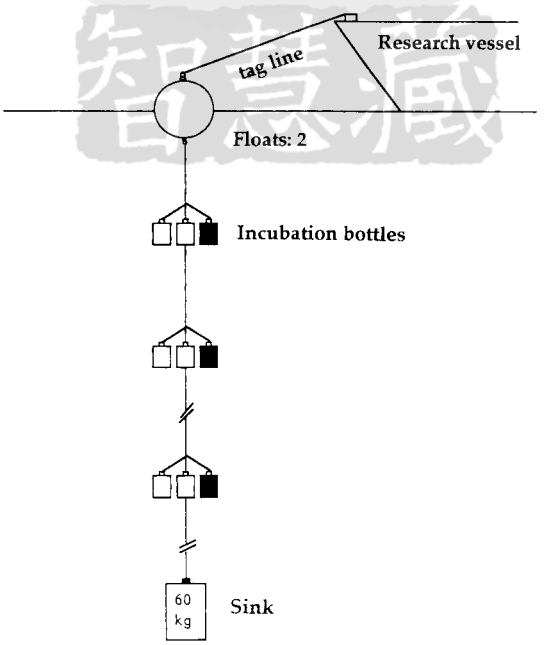

Fig. 3. Experimental setup of the in situ incubation array.

3. Chlorophyll *a* And Nitrate Concentrations

Chlorophyll *a* and nitrate concentration collected from Go-Flo bottle was filtered through 47 mm Whatman GF/F filters which then stored immediately at - 20°C. Chlorophyll *a* retained on filters were determined fluorometrically. The filters were ground in 10 ml 90% acetone followed by extraction in a 4°C shaking incubator for 2 h. After centrifugation at 1000 g for 5 min., the chlorophyll *a* concentration in the supernatant was measured on a Turner fluorometer (model 10-AU-005). Nitrate concentration was determined by reducing nitrate to nitrite with a cadmium wire which was activated with a copper sulfate solution, and the nitrite was converted to the pink azo dye for colorimetric determination.

RESULTS

The hydrographic and chemical conditions of stations 1, 8 and 11 and 17 are shown in Figures 4A-C. The waters are readily classified into three water types according to temperature and salinity (Fig. 4A). The low salinity of station 1 represented the coastal water; the high salinity of station 17 represented the Kuroshio water; the intermediate salinity with relatively low temperature of stations 8 and 11 represented the upwelling water (Chern & Wang 1989; Liu et al., 1992; Gong et al., 1994). Table 1 showed that the depth of euphotic zone increased from 20 m (station 1) to 55 m (station 17). Temperature ranged from 19 to 27°C and did not change much within the euphotic zone at each station.

Nitrate concentration ranged from under detection limit (0.1 μM) to 1.9 μM (Fig. 4B), being the highest at station 11 at the depth of 30 m. However, at station 1, nitrate concentration was all greater than 0.5 μM in the upper 20 m. Figure 4C showed that at station 1, chlorophyll *a* concentration (Chl. a) decreased exponentially with depth with a value of 3.10 mgChl m^{-3} at the surface water and values < 0.32 mgChl m^{-3} below 40 m. Chl. a at station 17 were low, ranging from 0.16 - 0.24 mgChl m^{-3} at the upper 30m. Chl. a of station 11 (0.67 - 0.94 mgChl m^{-3}) were about twice those of station 8 (0.25 - 0.46 mgChl m^{-3}), although both profiles did not vary much with depth. Euphotic zone integrated Chl. a for stations 1, 8, 11 and 17 were 43.4, 10.8, 35.8 and 10.8 mgChl m^{-2} respectively.

Figure 5 showed the ranges of dpm containing results for different categories of samples. The mean value of the total activity in the light bottles was 20099 dpm with a standard deviation of 1054 dpm. This mean value was about 9% lower than the expected value (i.e. 22200 dpm) mentioned above. This is because the Milli-Q water (2.5 ml) added in vials may slightly quench the radioactivity. Nevertheless, the low c. v. (coefficient of variation; 5%) value indicated that there was no dilution of radioactivity due to leak-in of sea water during incubation period. The radioactivity of the time zero samples ranged from 225 to 385 dpm which is negligible in comparison with most values observed in the light bottles except the least productive samples. The values for the dark bottles varied from 235 to 2478 dpm with a mean of 590 dpm, suggesting that dark fixation caused by chemolithotrophic bacteria might occur in study areas.

The depth profiles of primary productivity (PP) and normalized productivity (P^B) in all four stations showed a common trend although the absolute values for PP and P^B varied from station to station. Both PP and P^B decreased exponentially with depth and no subsurface

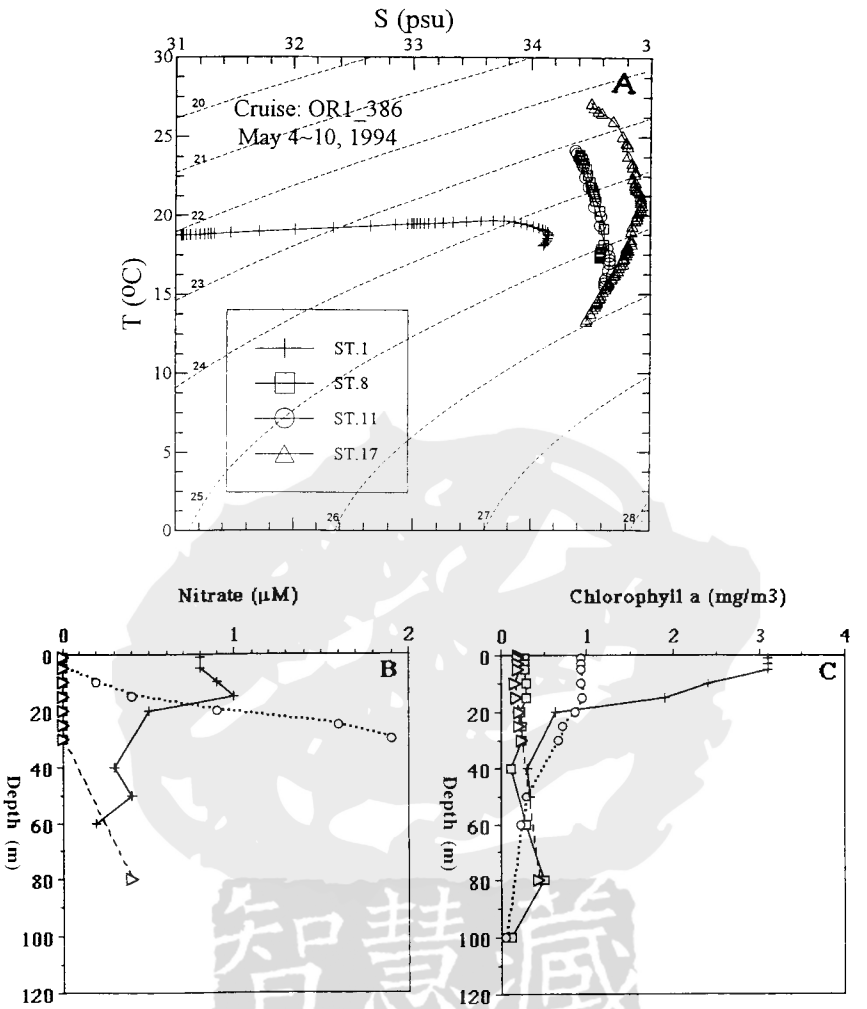

Fig. 4. Temperature-salinityy diagram (A) and depth profiles of nitrate (B) and chlorophyll *a* (C) measured at sampling stations.

maximum were observed (Figs. 6A & 6B), at least at depths > 5 m. Within euphotic zone, the highest PP (134 mgC m^{-3} d^{-1}) was observed at 5 m at station 1 while lowest PP appeared at station 17 with values < 11 mgC m^{-3} d^{-1}. PP at the upwelling stations (i.e. stations 8 and 11) showed intermediate values ranging from 19 to 93 mgC m^{-3} d^{-1}. The EIP values for stations 1, 8, 11 and 17 were 1901, 418, 1537 and 425 mgC m^{-2} d^{-1} respectively. P^B values at stations 8 and 11 (1.4 - 10.9 mgC $mgChl^{-1}$ h^{-1}) were about twice as high as those observed at station 1 (1.3 - 3.8) and station 17 (0.6 - 4.8).

Figure 7 showed the results of the on deck and the in situ incubation performed at station 8. The PP values for samples at 5 m were pretty much the same for both methods. However, below 10 m, the PP values derived from the in situ method were always higher than those from the on deck incubation although both PP profiles showed similar trend. The difference between

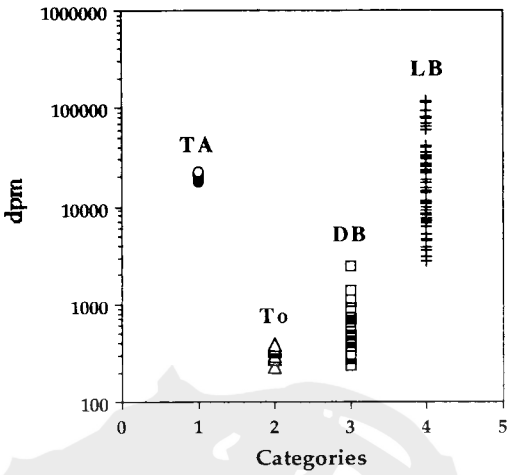

Fig. 5. The dpm (disintegration per minute) reading in samples of the total activity (TA), time zero (To), the dark bottles (DB) and the linght bottles (LB) measurements. Note Y axis is in log scale.

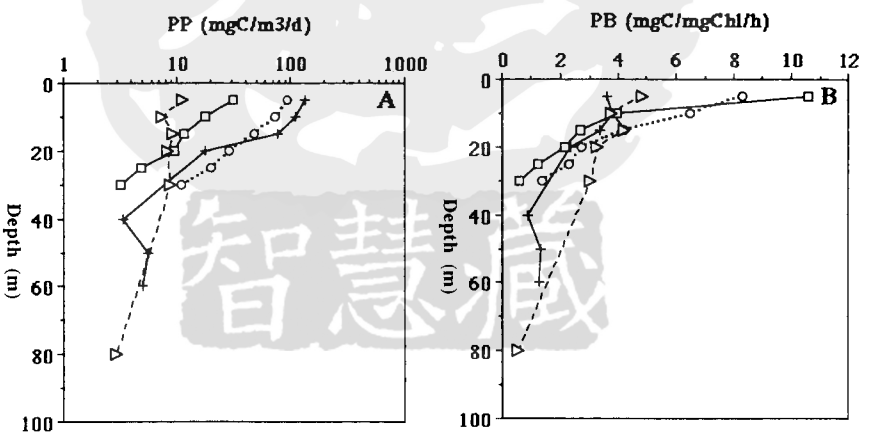

Fig. 6. Profiles of primary productivity (PP, A) and chlorophyll *a* normalized productivity (P^B, B) of sampling stations. Symbols for the four sampling stations are the same as Fig. 4. Note X axis of (A) is in log scale.

them increased from 62% at 10 m to 314% at 30 m. The EIP value of the in situ incubation (569 mgC m^{-2} d^{-1}) was 36% higher than that of the on deck (410 mgC m^{-2} d^{-1}) incubation.

DISCUSSION

Light, temperature and nutrients have been recognized as the three most important factors in controlling primary productivity (Parsons et al., 1984a, Cullen et al., 1992). Theoretically, the in situ incubation should be better than the on deck incubation, because the former is believed to

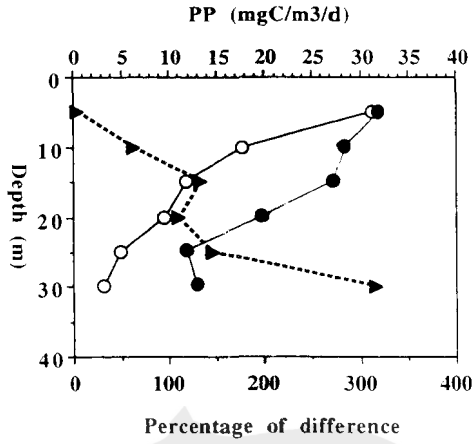

Fig. 7. Profile of primary productivity (PP, upper X axis) measured by the *in situ* incubation (solid circles) and the on deck incubation (open circles) in station 8. Solid triangles, the percentage of difference between these two method (lower X axis).

be more analogous to the natural conditions. However, the results shown in Figure 7 does not necessarily mean that the PP of the on deck incubation ($PP_{on\ deck}$) was less accurate in our study. The PP of the in situ incubation ($PP_{in\ situ}$) might be overestimated if the depth where incubation bottles located in water column was shallower than the designed depth. This situation is possible since the in situ array was attached astern of the research vessel and might tilt up when the research vessel adjusted its position. If we assume that the $PP_{on\ deck}$ were correct, then the tilting angel of the array can be calculated from the relationships among $P^B_{on\ deck}$ (normalized PP of the on deck), depth (Z) and I_Z/I_O. The relationships among them were: $\ln(I_Z/I_O) = - 0.29 + 0.31 \times P^B_{on}$ deck, $n = 6$, $R^2 = 0.85$ and $Z = 22.4 - 5.7 \times \ln(I_Z/I_O)$, $n = 6$, $R^2 = 0.98$. A 53° tilt up is necessary to satisfy the assumption we made above. That is, the incubation bottles at 30 m was in fact at 18 m when the in situ experiment was performed. Even if this is the case, it does not mean the $PP_{in\ situ}$ values were unrealistic. Within one diurnal cycle, phytoplankton in the water column may fluctuate up and down 20 m due to the vertical motion of waters such as tides, internal waves (Walsh et al., 1974). A semi-diurnal internal tide with an amplitude of 40 m has been reported by Chern & Wang (1990) in this study area. However, in doing these back calculations, we assumed that there was no light stress exerted on the photosynthetic activity of phytoplankton at any given depth when exposed to different light intensity abruptly. Falkowski (1981; in his Fig. 4) showed that when the water column was well mixed, P^B of phytoplankton taken from different depths responded to light intensity equally, suggesting that the cells were adapted to the mean light intensity in the mixed layer (i.e. no sign of light stress). The hydrographic data of station 8 showed that the thermocline was at the depth of 70 m and there was no pycnocline observed at depths < 100 m, indicating that the euphotic zone (25 m) was well mixed. Besides, in several light manipulation experiments performed in the same area later in July, 1994, Shiah (unpublished data) also found the same phenomena described by Falkowski (1981). Thus, our speculation of tilting proposed here should be valid. Whatsoever, we suggest a

free floating in situ array deployment should be adopted for the future study to avoid the tilting caused by the attachment of the in situ array. On the other hand, since the PUR (photosynthetically utilizable radiation) was attenuated by water column and nylon stockings for the in situ and on deck incubation respectively, the $PP_{on\ deck}$ values might be underestimated if the amount of PUR in the on deck bottles was less than that in the in situ bottles. Unfortunately, we do not have any evidence to prove this speculation.

The in situ experiments performed at stations 8 and 11 were at different time scales (i.e. 12 vs. 24 h). People may wonder that the length of incubation period might affect PP reading. Bender et al. (1987) and Davies & Williams (1984) showed that the amount of $H^{14}CO_3^-$ incorporated into particulate form reached maximum after 12 h daylight incubation and remained constant during the night time. The major reason for doing a 24 h experiment at station 11 was due to collaboration with a sediment trap experiment. To do this, we tethered the incubation bottles to the sediment trap setup and waited for 24 h, which was required for the sediment trap experiment. The EIP value of station 11 was derived from the in situ incubation, while those of stations 1, 8 and 17 were from on deck incubation. Given a 50% overestimation for the in situ incubation at station 11 (36% for station 8 only), the EIP value was 769 mgC m^{-2} d^{-1} and still much higher than those of stations 8 (418 mgC m^{-2} d^{-1}) and 17 (425 mgC m^{-2} d^{-1}).

The higher PP, EIP and chlorophyll *a* concentration (i.e. biomass) observed at stations 1 and 11 probably can be explained by nutritional condition. Nitrate concentration in station 1 ranged from 0.2 to 1.0 μM which was typical for coastal waters. The hydrography clearly indicates that the water samples taken at station 11 were upwelling waters laden with high concentration of nitrate. At station 11, > 0.2 μM of nitrate was observed at depth > 10 m although its concentration in the upper 9 m were under detection limit.

Normalized productivity (P^B) can be affected by nutrients, temperature, light and phytoplankton species composition (Cullen et al., 1992). Our results indicated that temperature and nitrate concentration did not explain much of the variation of P^B among stations. This might due to the limited samples available for analysis. On the other hand, the exponential decrease of P^B with depth indicates that P^B might be controlled by light intensity. A hyperbolic function of P^B vs. I_Z/I_O modified from Jassby & Platt (1976) was used to analyze the light effect. There are two reasons for not using absolute light intensity (i.e. I_Z) in our analysis. First, we only measured light intensity once for each station and the timing of these measurement were not the same. Secondly, the relative light intensity for any given depth should be constant though absolute light intensity varies over the day time. Figure 8 showed that the hyperbolic functions fit the field data very well. The R^2 values for the model values on the observed values were all > 0.97. We do not intend to discuss much of the ecological and physiological implications of our results due to the limited data set. However, the strong correlation between light and P^B do suggest that it is necessary to install a light meter on the research vessel, so the quantity of light can be recorded continuously during incubation period.

The validity of our study can be verified by comparing our results with other studies. Table 2 showed that the EIP and P^B values of the coastal (station 1), the upwelling (stations 8 & 11) and the Kuroshio (station 17) areas derived from our study were all within or closed to the ranges reported by other surveys.

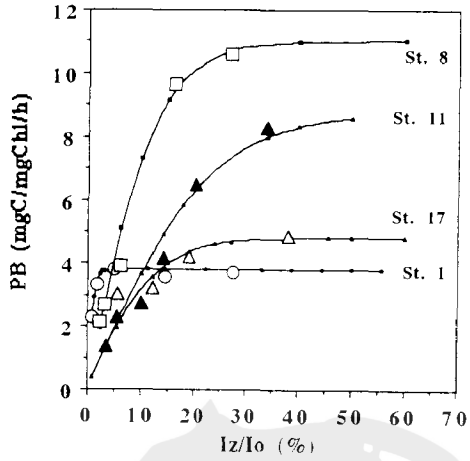

Fig. 8. Scatter plot of normalized productivity (P^B) on relative light intensity (Iz/Io) for data collected from sampling stations. Symbols for the four sampling stations are the same as Fig. 4. Solid lines, model values, see text for explanation.

Table 2: A list of euphotic zone integrated productivity (EIP) and normalized productivity (P^B) from this and other studies.

Areas	Waters	EIP	P^B	References
		(mgC m^{-2} d^{-1})	(mgC $mgChl^{-1}$ h^{-1})	
St. 1	Coastal	**1901**	**0.9 - 3.8**	this study
East China sea	Coastal	500 - 1500	0.3 - 11.2	Fei et al. 1987
Sts. 8 & 11	Upwellig	**418 - 1537**	**1.4 - 10.9**	this study
S. Benguela	Upwellig	990 - 7850	0.5 - 10.0	Mitche-llines & Walker, 1991
Peru	Upwellig	1680 - 4340	4.2 - 12.7	MacIsacc et al. 1985
NW Africa	Upwellig	1000 - 3000	2.2 - 4.5	Huntsman & Barber, 1977
Chile	Upwellig	-	0.5 - 7.9	Peterson et al. 1988
Baja California	Upwellig	4100 - 7500	1.4 - 2.5	Walsh et al. 1974
Oregon	Upwellig	-	1.0 - 5.0	Small & Menzies, 1981
SE US cont. slope	Upwellig	1900	15.6	Yoder et al. 1985
Minnan-Taiwan	Upwellig	400 - 860	-	Li & Wang, 1991
Equat. Pacific	Upwellig	480 - 540	3.8 - 5.0	Chavez & Barber, 1987
St. 17	Kuroshio	**425**	**3.0 - 4.8**	this study
	Kuroshio	50 - 1500	0.3 - 11.2	Guo, 1991
	Kuroshio	138 - 140	-	Fei et al. 1987
	Kuroshio	50 - 380	-	Zhu & Wang, 1990
	Kuroshio	130	-	Fei et al. 1990

CONCLUSIONS

For the first time, primary productivity measured by ^{14}C assimilation method for the KEEP project is reported in this paper. The results look very promising although not many physiological and ecological implications can be derived due to the limited data set. However,

there are several important conclusions can be drawn from our study. First, light meter installed on research vessel is absolutely necessary for the future primary productivity study. Secondly, to obtain accurate primary productivity data, a free floating in situ array should be adopted. However, on deck incubation should also be considered to save operation time on cruise. Finally, in addition to the field works, a bio-optical model which estimate water column primary productivity as function of light and phytoplankton biomass (Morel, 1991; Andre, 1992; Platt & Sathyendranth, 1993) should be developed simultaneously to collaborate with the upcoming satellite sea color remote sensing project.

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智慧藏

KEEP 海域內以^{14}C吸收法測量初級生產力之探討

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摘　要

本文報導在 KEEP海域內以^{14}C吸收法測量初級生產力之初步結果。調查時間爲1994年5月4日至10日，地點爲位於 KEEP-Key測線上的4個測站。測站1爲近岸站，測站 8及 11代表湧升流站，測站 17爲黑潮站。初級生產力隨測站及取樣深度而異；測值在第 1站最高(134 mgC m^{-3} d^{-1})，第17站最低（11mgC m^{-3} d^{-1}）。透光層積分初級生產力在第 1, 8, 11及17測站分別爲 1901, 418, 1537及 425 mgC m^{-2} d^{-1}。第 1及11測站的高初級生產力及透光層積分初級生產力可能與高養分（如硝酸鹽）供應速率有關。葉綠素單位生產力值界於 0.6到 10.9 mgC $mgChl^{-1}$ h^{-1}之間，以第 8及 11測站較高。初級生產力及葉綠素單位生產力在此四測站均有隨水深而遽減之現象，顯示光線對此二參數之重要性。現場培養法所得之透光層積分初級生產力值（569 mgC m^{-2} d^{-1}）較船上培養法高出 36%，此可能肇因於現場培養裝置之置放方式使得培養瓶之水深位置較原先計劃中之水深爲淺。

（關鍵詞：浮游植物，海洋生態，東海南部，黑潮）