The Primary Productivity in the South China Sea, Area III: Western Philippines

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ABSTRACT

In this paper the relative concentrations and vertical distributions of primary production were investigated off Western Philippines of the South China Sea during tradewinds from April 15 to May 11, 1998. Primary productivity measurements were conducted using conventional "light-and-dark bottle" oxygen method. The net primary production estimates at ten (10) different stations established between 19° 59.2'N, 119° 58.7'E and 11° 13.5'N, 118° 03.1'E ranged from 0.10 ~ 1.53 g C m^{-2} d^{-1}. The result suggests that the present net production estimates in the area is remarkably higher than the estimates from other parts of the South China Sea (viz., northern coastal waters off Taiwan and southwestern parts of the SCS which included marine waters of Thailand, Indonesia and Malaysia). The highest primary production occurred at the upper 60-m well-mixed layer of station 1 in the northwesternmost part of the area. Results have shown that some other hydrographic and chemical parameters (viz., temperature, salinity, light and fluorescence) greatly complicate and may not coherent with the analyses of relative distribution and abundance of primary production in the area.

Key words: Primary production, vertical mixing and upwelling

Introduction

Despite the vast expanse of the South China Sea, little is known of its fisheries status, in general and its primary productivity status, in particular. The factor that has to be reckoned with, is that few ASEAN countries are equipped and capable to do high seas explorations, with the South China Sea (SCS) as a vast oceanic waters. It could be noted that offshore studies in the South China Sea have been less extensively documented than those of its coastal waters. Over the last decade, limited oceanographic studies dealing with the physical, chemical and biological characteristics of the northern coastal waters off Taiwan of the SCS (24°N 120°E ~ 26°N 123°E) were done in a series of expedition by Chinese researchers (Hung *et al*. 1980). Likewise, oceanographic studies, mostly at the coastal waters in the southwestern part of the SCS were carried out in Thailand (Andersen 1977, Limpsaichol and Poopeth 1984), Indonesia (Ilahude, 1978) and Malaysia (Shamsudin 1987, Shamsudin *et al.* 1988 and Shamsudin 1988). The results of these cruises provided some important information regarding the environmental factors affecting the primary productivities of these areas.

In particular, the status of water quality and fisheries in the South China Sea (SCS) off western Philippines has never been documented. There is no available information on aquatic biota, and the level of primary production in the area. Such data are important to evaluate the productivity of the area and its capacity as a fishing ground, before it could be considered as one of the major sources of fish and other fishery resources in the Philippines.

Phytoplankton is the principal source of organic material (primary production) in the sea and its importance was long recognized as the initial stage in the marine food chain. Primary productivity, in this study, was measured in terms of the quantity of carbon fixed. However, considering that the *in situ* method for assessing the actual carbon fixation in the water column needs too much time in a ship survey, the simulated on-board incubation experiment with oxygen method was used during the oceanographic cruise.

This study serves as a starting point in obtaining essential information about the relative distribution and level of primary productivity in relation to abundance of phytoplankton and some other hydrographic and chemical parameters (*viz.,* temperature, salinity, light and fluorescence) in the area. Specifically, the study was the first attempt to estimate the vertical profiles of primary production for the whole western Philippine waters. The results of this study offered the first data in support to the available fishery resources in the area.

Materials and Methods

The study was carried out from April 15 to May 11, 1998, in the South China Sea off Western Philippines on board M/V *SEAFDEC* as a third phase of the collaborative research program of Southeast Asian Fisheries Development Center (SEAFDEC) in the South China Sea. Out of 31 pre-established stations, ten stations (*i.e.,* Station Nos. 1, 5, 7, 10, 15, 17, 22, 25, 30 and 31) located between 19° 59.2'N, 119° 58.7'E and 11° 13.5'N, 118° 03.1'E, which represented the middle transect of the area were occupied for ten days (Figure 1). The water samples for primary productivity were collected at six fixed depths (*i.e.,* 0-m, 20-m, 40-m, 60-m, 80-m and 100-m depths) in the euphotic zone of each station by a Van Dorn twin-type water sampler of 20*l* x 2 capacity. Initially, the samples were filtered through a 0.3-mm mesh net to separate zooplankton component from phytoplankton. The samples were carefully siphoned into 3 types of BOD bottles, *viz.,* control, light and dark bottles. The oxygen content of the control bottle is fixed when the experiment commences while those of the paired bottles; one transparent and the other darkened were incubated in a lighted tub (dimensions: W=35 cm x H=45 cm x L=70 cm) of seawater on board the ship. Light and dark sample bottles were exposed to both overlying and underlying fluorescent lights of about 400 μmol photons m^{-2} s^{-1} during incubation. The distance of the incubated bottles from the overlying lights is about 40 cm. Quantitatively, light intensity at various levels in the tub with each designated depth was measured using light meter (Model: Light Quantum Meter with LI-193SA Spherical Quantum Sensor, 4Pi detector, LI-COR, Inc.). Dissolved oxygen contents of unincubated water samples were first determined. After incubation of the other water samples for 4 hours, the dissolved oxygen content was measured quantitatively by the Winkler titration method, in which, upon acidification causes the liberation of tri-valent iodine quantitatively equivalent to the amount of dissolved oxygen in the water sample. One-hundred ml of the acidified solution is then titrated with a standard sodium thiosulfate solution.

The hydrographic and chemical data used here were taken from the iCTD sampling during the survey. The parameters that were used in relation to primary productivity data analysis were selected as follows: temperature, salinity, light and amounts of fluorescence. Fluorescence was measured by the integrated CTD fluorometer at the same depths where primary productivities were observed.

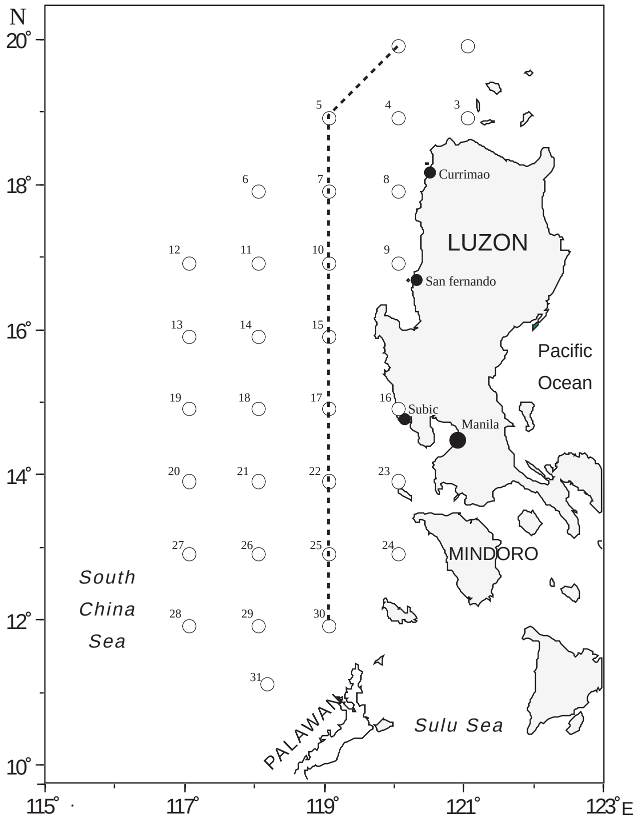

Fig. 1. Stations for oceanographic survey in the South China Sea, Area III: off Western Philippines.

Results

Vertical Distribution of Gross Primary Production

The results of gross primary productivity observations were presented in Figure 2a. The sampling area which was situated off the western part of the Philippines, have values ranging from 0.10 to 2.52 g C m^{-2} d^{-1}. The upper 60-m layer of station 1 in the northwestern part and of station 31 in the southwestern part yielded relatively high gross production. The highest gross production which were recorded in the upper 60-m layer of station 1 have values ranging from 1.4 to 2.52 g C m^{-2} d^{-1}.

Relatively low concentrations of gross production which ranged from 0 to 0.2 $gCm^{-2}d^{-1}$ were noted throughout the water column of stations 5 and 7 in the northwestern part, except at 60-m depth of station 5 where a value of 0.4 g Cm^{-2} d^{-1} was recorded.

Generally, going southward (*i.e.,* from stations 10 to 31) the gross production tends to increase. Fairly high gross production ranging from 0.33 to 0.61 g Cm^{-2} d^{-1} were recorded in the surface and sub-surface layers (0~20 m depths) of station 10, off Lingayen Gulf and station 15, off Cape Bolinao and these values gradually decreased with depths of both stations. Similar vertical profiles were observed at station 25 off Mindoro Island with gross production rates ranging from 0.19 to 0.88 g Cm^{-2} d^{-1} and at station 31 off Palawan which ranged from 0.44 to 1.13 g Cm^{-2} d^{-1}.

Stations 17 and 22, off Manila Bay in the central part, have relatively high gross production rates ranging from 0.1 to 1.01 g Cm^{-2} d^{-1} which increased with depths. Relatively high gross production with sub-surface maxima at 40 m depth was observed in station 30 off Calamian Group of Island.

Vertical Distribution of Respiration Rates

A decreasing trend of relatively high respiration rates which ranged from –1.13 to 2.23 g Cm^{-2} d^{-1} were observed in station 1 at the northwestern part. The highest value of 2.23 g Cm^{-2} d^{-1} was recorded at 20-m depth of this station.

Generally, almost all stations (stations 5, 7, 10, 15, 17, 22, 25, 30 and 31), except station 1, were characterized with fairly low uniform distribution throughout depths, which ranged from –0.12 to 1.09 g C m^{-2} d^{-1}. Remarkably high respiration rates were noted at 100-m depth of station 7 off Cape Bojeador and both at 80- and 100-m depths of station 22 off Manila Bay and station 31 off Palawan (Figure 2b). Moreover, the results showed that the oxygen concentrations in the dark bottles in the said depths turned out to be higher than the light bottles after four hours of incubation.

Vertical Distribution of Net Primary Production

Figure 2c shows the result of the vertical profile of net primary production in the area with values ranging from 0.1 to 1.53 g Cm^{-2} d^{-1}. Relatively high net productions were recorded throughout the water column of station 1 in the northwestern part with rates ranging from 0.21 to 1.53 g Cm^{-2} d^{-1}.

Relatively low net primary production, which ranged from 0.1 to 0.71 g Cm^{-2} d^{-1} were observed all throughout the water column of stations off northwestern Luzon (*i.e.,* stations 5, 7, 10 and 15). Going farther to the southwestern part (*i.e.,* from stations 17 onward), the net primary production tends to increase although it varies with depths at different stations. Net production rates seemed to increase with depths at station 17 off Subic Bay, whereas, stations situated off Manila Bay and Mindoro Island (*i.e.,* stations 22 and 25) and off Calamian Group and Palawan Islands (*i.e.,* stations 30 and 31) yielded net production rates that decreased with depths. On the other hand, maximum net production was found at 40-m depth of station 30 (Figure 2c).

Vertical Distribution of Phytoplankton

Figure 3a showed the vertical distribution and relative abundance of phytoplankton in the sampling area. Water masses with relatively high phytoplankton densities that ranged from 2,064 to 5,628 cells per liter of seawater predominated at the intermediate depths (between 40- and 70-m depths) of stations 5 and 7 in the northwestern part, at 60-m depth of station 15 off Cape Bolinao and at 40-m depth of stations 30 and 31 off Calamian Group and Palawan Islands in the southwestern part. Station 25, which is located off Mindoro Island in the southwestern part yielded relatively low phytoplankton densities all throughout its water column.

The highest phytoplankton density of 5,628 cells per liter was found in a water mass that lies at 60-m depth of station 5 in the northwestern part. Ironically, relatively low phytoplankton densities which ranged from 208 to 1,824 cells per liter were observed mostly from the surface to sub-surface layers (0- ~ 30-m depths) of all stations except the surface layer of stations 30 and 31, which yielded high phytoplankton densities (Figure 3a).

Vertical Distribution of Fluorescence

The results of fluorescence observation varies among stations with values ranging from 0.096 ~ 1.98 volts. Relatively high fluorescence occurred at about 40- to 100-m depths of

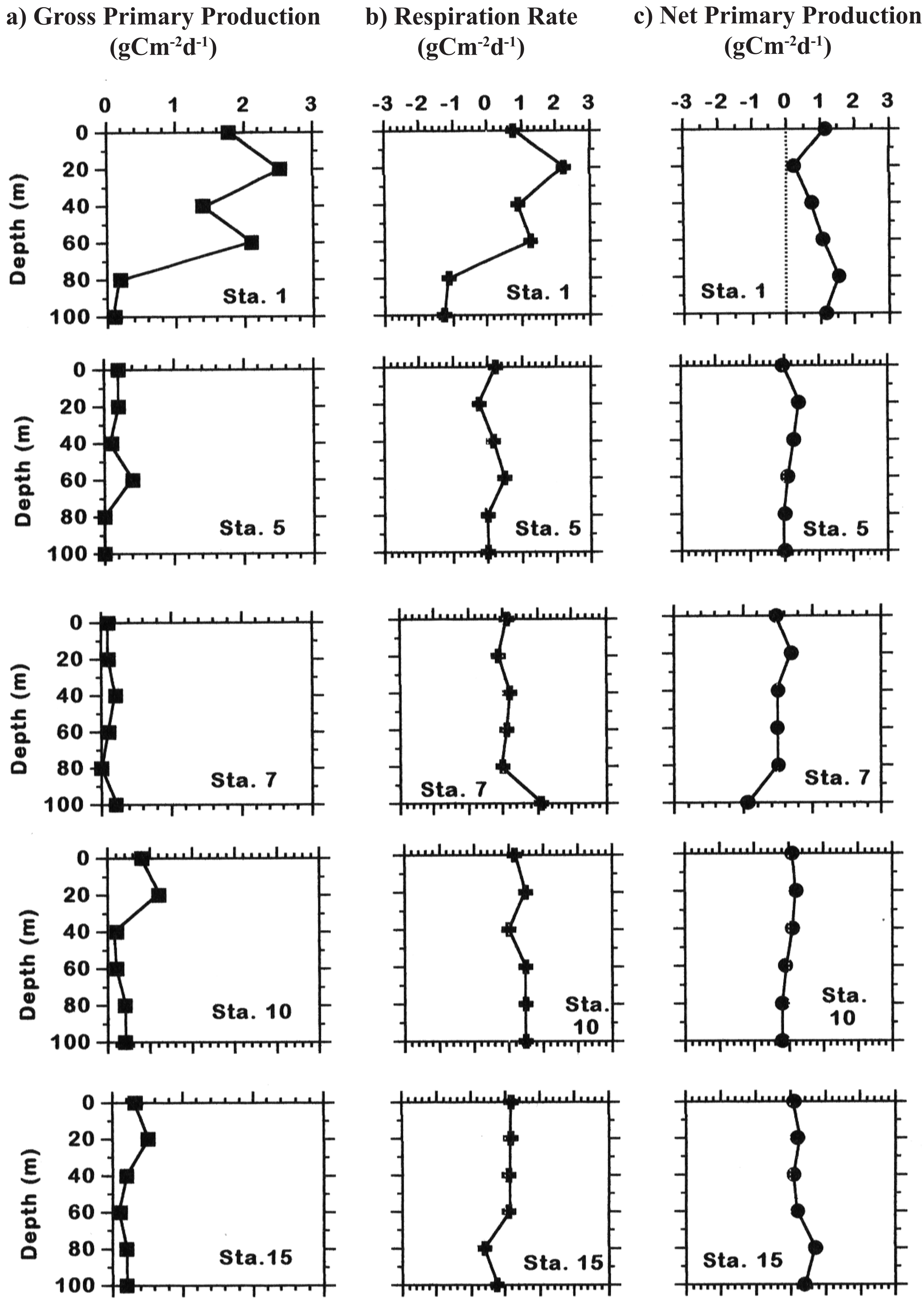

Fig. 2/1. Vertical profiles of primary production (gross, respiration and net production) at various depths of different stations in the SCS, off Western Philippines (M/S *SEAFDEC,* Apr. 15-May 11, 1998).

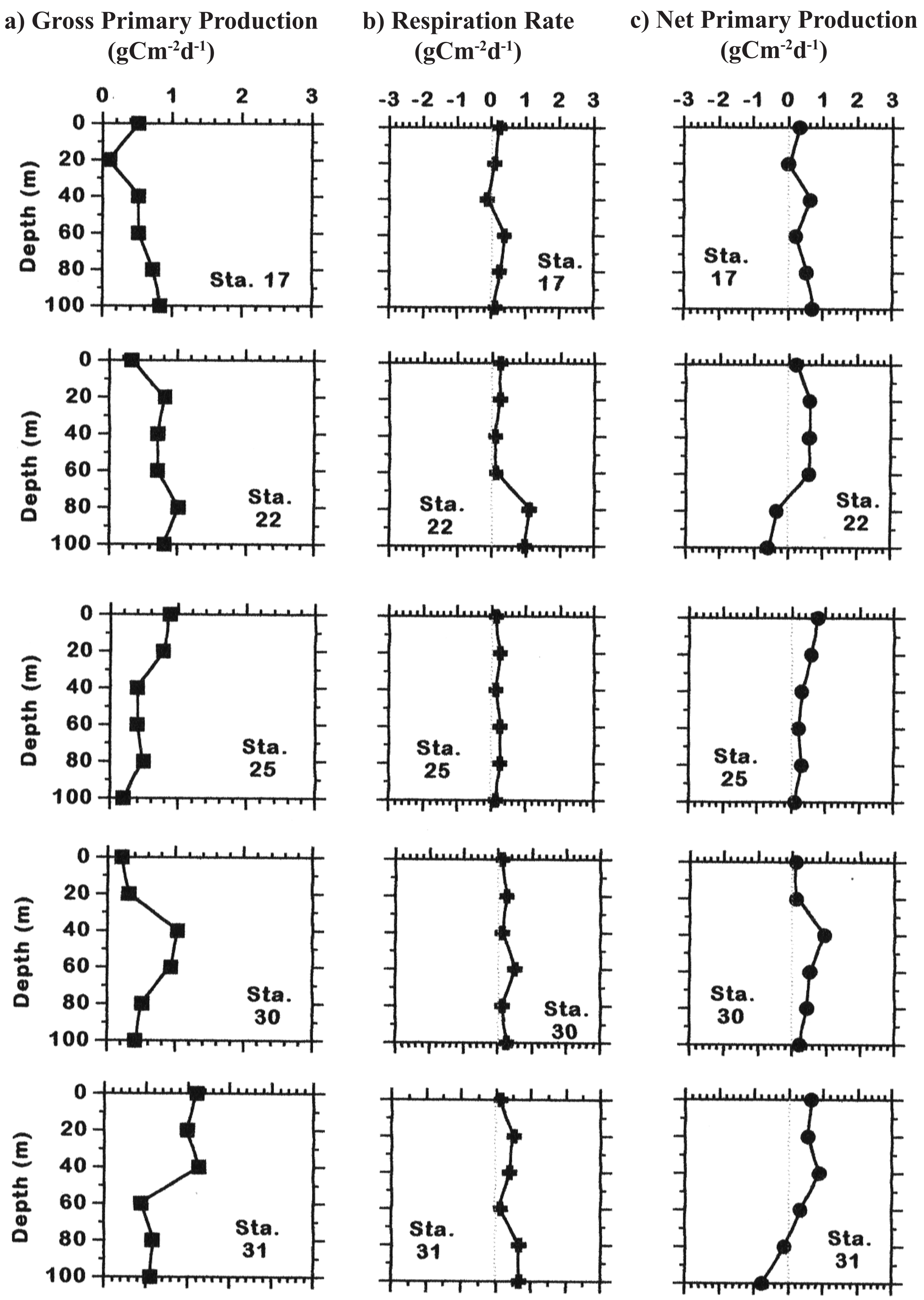

Fig. 2/2. Vertical profiles of primary production (gross, respiration and net production) at various depths of different stations in the SCS, off Western Philippines (M/S *SEAFDEC,* Apr. 15-May 11, 1998).

stations 5 and 7 and spread to deeper layer (100 m) of stations contiguous in the northwestern Luzon (*i.e.,* stations 1, 5, 7 and 10) and station 15 in the central part (Figure 3b).

A ring-like water mass, which occurred at 40- to 100-m depths of station 7, yielded the highest, range of fluorescence from 1.04 to 1.98 volts. Generally, sampling stations situated off northwestern and central Luzon of the area (*viz.,* Stations 1, 5, 7, 10, 15 and 17) have increased amount of fluorescence at increasing depths. The magnitude of variability of fluorescence tends to decrease going farther southward (*i.e.,* from stations 17 to 31, Figure 3b). The stations at the southwestern part showed uniform distribution of relatively low amounts of fluorescence.

Vertical Distribution of Temperatures

Temperature values that were obtained in the area during the survey ranged from 17.58°C to 31.02°C. A thermally-homogeneous layer of >27.0°C ~ >28.0°C down to about 60 m depth occurred at station 1 in the northwesternmost part (Figure 3c). Under the homogeneous layer lies the relatively cold-water masses where the temperature decreased from >26.0°C at about 80 m to >23.0°C at 100-m depth.

Upwelling occurred between stations 5 and 10 at the northwestern part where the thickness of the homogeneous layer that was described at station 1 decreased to about 20 m deep with a colder water mass ranging from >27.0°C to >28.0°C. The upwelling causes the water mass to rise up to about 20 m as indicated by the 27.0°C isotherm, which showed the thermocline layer between 40-m and 60-m depths between stations 7 off Cape Bojeador and at station 10 off Lingayen Gulf where the temperature decreased from 27.0°C at 40 m to >23.0°C at 60 m.

A warm water mass with temperatures ranging from >29.0°C to 30.0°C occupies the upper 30 m layer of several stations contiguous from the northwestern Luzon (*i.e.,* stations 10, 15 and 17) to southwestern part area (*i.e.,* stations 22, 25, 30 and 31). The highest temperature of >30.0°C occurred at the upper 20 m of station 15 off Cape Bolinao, station 22 off Manila Bay, station 25 off Mindoro Island, station 30 off Calamian Group Is. and station 31 off Palawan. Moreover, relatively cold-water masses between stations 15 and 17 off Cape Bolinao and Subic Bay in the central part are sinking, which temperature decreased from >28.0°C at 40 m to <23.0°C at 100 m.

Relatively cold-water masses which temperatures decreased from >28.0°C at about 30 m to >18.0°C at 100-m depths were observed from station 22 off Manila Bay to the southwestern part (*i.e.,* stations 25, 30 and 31, respectively, Figure 3c).

Vertical Distribution of Salinity

A water mass of relatively low salinity (<33.90‰ ~ >34.00‰) occupies the upper 60 m of the homogeneous layer at station 1 in the northwestern part (Figure 3d). The same feature with the temperature distribution that is the presence of upwelling between stations 5 and 7 in the northwestern part can be noted in the salinity distribution. It consists of salinity concentrations that increased from >34.10‰ at about 5 m to 34.70‰ at 100 m. The sinking of relatively low salinity-water mass with values ranging from 33.70‰ to 34.40‰ occurred between stations 10 and 22 off Lingayen Gulf and Manila Bay, respectively. Apparently, a tongue-like water mass that occurred at the upper 40-m layer between stations 15 and 22 off Cape Bolinao and Manila Bay, respectively, yielded the lowest salinity concentrations ranging from <33.70‰ to <33.90‰.

Different forms of water masses with relatively high salinity values were observed at stations in the southwestern part of the area. A ring-like water mass that occurred between the

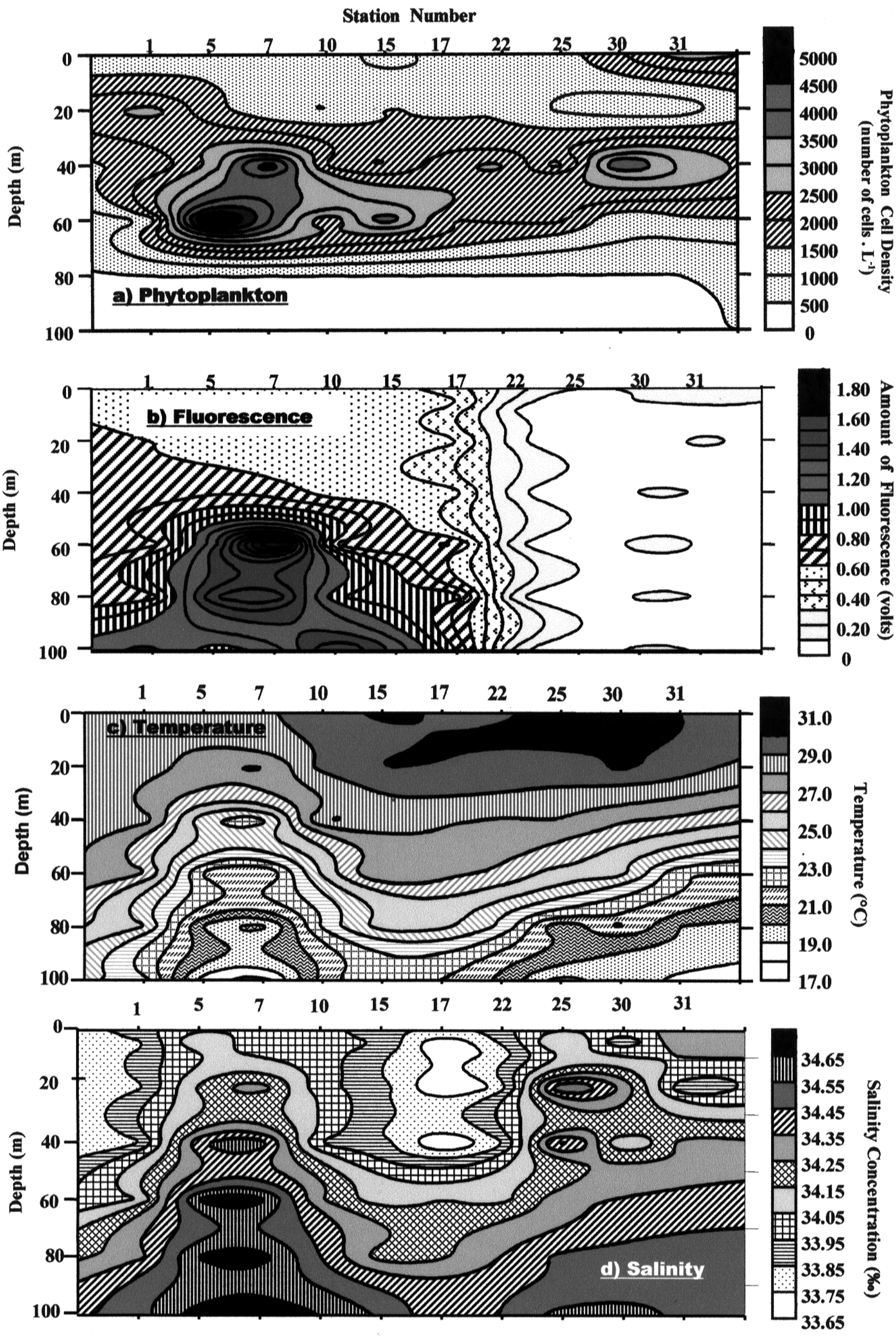

Fig. 3. Vertical profiles of (a) phytoplankton cells, (b) fluorescence intensity, (c) temperature, and (d) salinity concentrations at various depths of different stations in the SCS, off Western Philippines (M/V *SEAFDEC*, Apr. 15-May 11, 1998).

surface layer and 40-m depths of stations 25 off Mindoro Island, station 30 off Calamian Group Is. and station 31 off Palawan, have high salinity values ranging from 34.1 ‰ to 34.4 ‰ (Figure 3d).

In Situ Vertical Light Attenuation and Simulated Light On Board Incubation

The actual light data in few selected stations, where light measurements during daytime observations were possible, were used and simulated during on board incubation experiments. Analyses of the results have shown that the *in situ* surface insulation and vertical attenuation within the water column in the SCS off western Philippines vary from 3,419 μmol photons m^{-2} s^{-1} at 0-m depth to 0.084 μmol photons m^{-2} s^{-1} at 100-m depth. Each station showed different light intensities, which vary enough to explain the magnitude of variability observed in primary productivity in the area.

Moreover, the light simulated during on board incubation was standardized at about 400μmol photons m^{-2} s^{-1}. The vertical profiles of the simulated light intensities vary among stations, which ranged from 1.01 to 431.30 μmol photons m^{-2} s^{-1} (Figure 4).

Discussion

The net primary production in the South China Sea, Area III: off western Philippines between 19° 59.2'N, 119° 58.7'E and 11° 13.5'N, 118° 03.1'N ranged from -0.1 ~ 1.53 g C m^{-2} d^{-1}. These estimates are generally higher than previous estimates reported for other waters of the ASEAN and tropical regions (Table 1). The present estimates showed that the primary production in this area is higher than that of the northern coast off Taiwan of the SCS, which yielded 0.90 ~ 1.11 g C m^{-2} d^{-1} (Hung *et al.* 1980). Small variation of only 0.42 g C m^{-2} d^{-1} was noted. However, a great difference is obvious if one considers to compare the present estimates of primary production than among other regions of the South China Sea such as in the west coast off Phuket Island and at the Andaman Sea, Thailand (*i.e.,* 0.023 ~ 0.085 g C m^{-2} d^{-1}, Andersen 1977, Limpsaichol and Poopetch 1984); off Southern Makassar Strait, Indonesia (*i.e.,* 0.4 ~ 0.7 mg m^{-3} Chl-*a*, Ilahude 1978); and off the Sarawak waters of Malaysia (*i.e.,* 0.43 g C m^{-2} d^{-1}, Shamsudin 1988). The comparison of different results which were shown in Table 1 are not viable because of the different methods of sampling that were used by those authors. These facts showed that the method of sampling is very important in revealing the consistency of the level of primary productivity among areas.

The variations in vertical profiles of primary productivity in the area did not seem correlated with any precise light intensity obtained during the incubation experiment on board the ship. Primary production obtained from the incubated bottles at a series of depths in a lighted tub, exhibit characteristic patterns of photosynthetic rate with depth in relation to the vertical distribution of simulated light. Net primary production obtained at the water surface of most station display a pronounced light inhibition with maximum photosynthetic rates occurring below the surface (Figure 4a & c). On the other hand, the light regime in the top water layers of stations 1 and 25 are seemingly favorable for phytoplankton photosynthesis. Specific observation, however, showed that high primary productivity in station 1 off northwestern Luzon, station 17 off Subic Bay, station 22 off Manila Bay, station 25 off Mindoro Island, stations 30 and 31 off Palawan, appear to occur in response to relatively high vertical light intensities obtained at various light levels in the tub of seawater (Fig. 4a & c). Relatively high net primary production

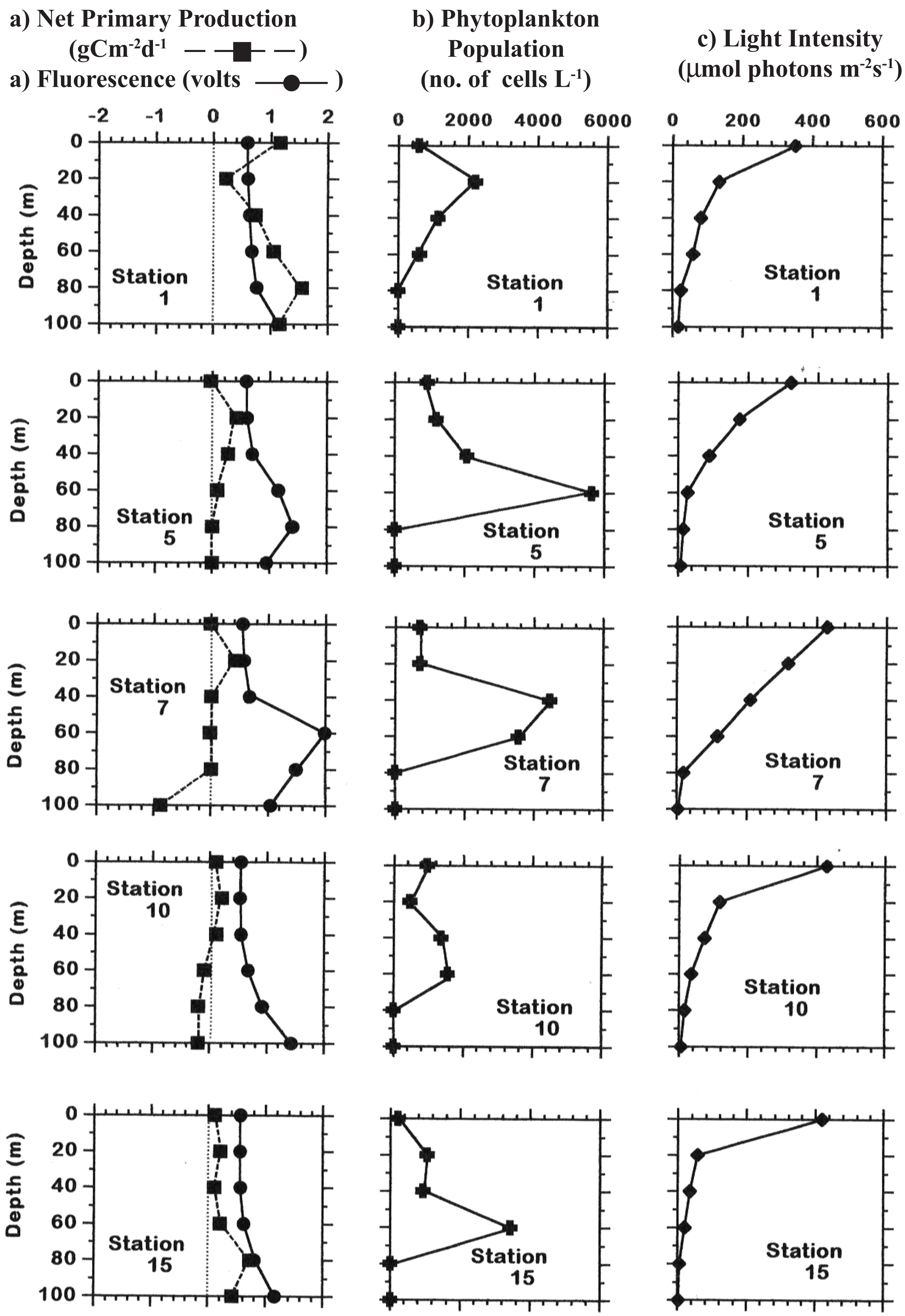

Fig. 4/1. Vertical profiles of (a) net primary production and (c) light intensity obtained during on board incubation and the *in situ* vertical profiles of (a) fluorescence and (b) phytoplankton cell density at various depths of different stations in the SCS, off Western Philippines (M/V *SEAFDEC,* Apr. 15-May 11, 1998).

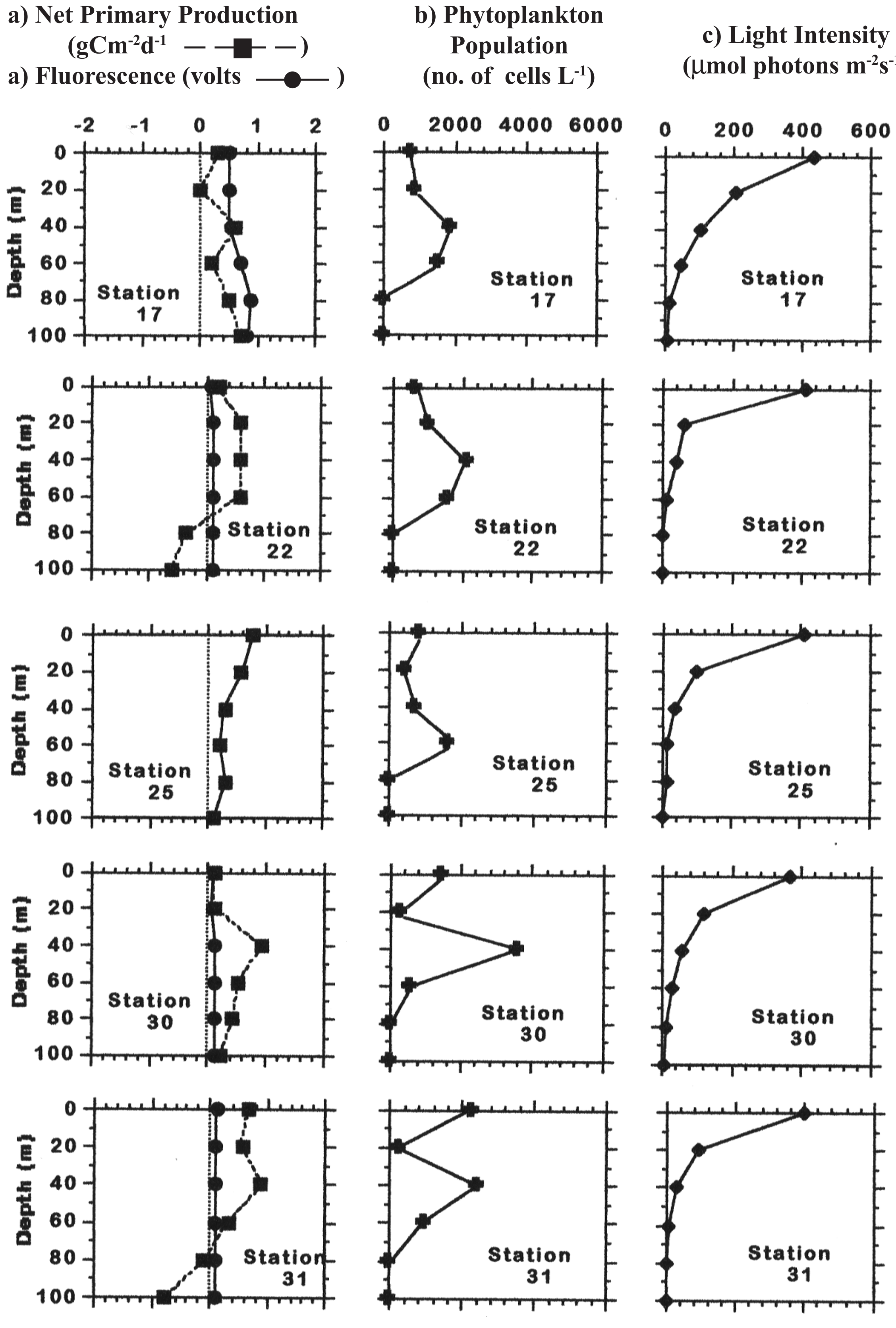

Fig. 4/2. Vertical profiles of (a) net primary production and (c) light intensity obtained during on board incubation and the *in situ* vertical profiles of (a) fluorescence and (b) phytoplankton cell density at various depths of different stations in the SCS, off Western Philippines (M/V *SEAFDEC,* Apr. 15-May 11, 1998).

Table 1. Comparative estimates of net primary productivity among regions of South China Sea (SCS).

Waters of the ASEAN & other Tropical Regions	**Methods**	**Daily Production Estimates (g C m^{-2} d^{-1})**	**Source**
Northern Coast off Taiwan	*In situ* C-14	0.90~1.11 g C m^{-2} d^{-1}	Hung *et al.* (1980)
West Coast off Phuket Island, Thailand	*In situ* C-14	0.023~0.085 g C m^{-2} d^{-1}	Andersen (1977), Limpsaichol and Poopetch (1984)
Off Southern Makassar Strait, Indonesia	Chlorophyll method	0.4~0.7 mg m^{-3} Chl-*a*	Ilahude (1978)
Off the Sarawak Waters, Malaysia		0.43 g C m^{-2} d^{-1}	Shamsudin (1987)
Five areas of western tropical and sub-tropical Pacific Ocean	Both *in situ* and simulated *in situ* using C-14		Taniguchi and Kawamura (1970)
a) Kuroshio Counter Current	a) *In situ* ----------------- b) Simulated *in situ* ----	0.16 g C m^{-2} d^{-1} (0.44~0.45mg Cm^{-3} hr^{-1})	
b) North Equatorial Current	a) *In situ* ---------------- b) Simulated *in situ* ---	0.08~0.09 g C m^{-2} d^{-1} (0.07~0.28mg Cm^{-3} hr^{-1})	
c) Equatorial Counter Current	a) *In situ* ---------------- b) Simulated *in situ* ----	0.19 g C m^{-2} d^{-1} (0.07~0.58 mg Cm^{-3}hr^{-1})	
d) South Equatorial Current	a) *In situ* ---------------- c) Simulated *in situ* ----	0.27~0.31 g C m^{-2} d^{-1} (0.29~1.49 mg Cm^{-3}hr^{-1})	
e) North Fiji Islands	a) *In situ* ---------------- b) S imulated *in situ* ---	- (0.12~0.61 mg Cm^{-3}hr^{-1})	
Kuroshio and its adjacent area	C-14 incubation by using 3 different techniques as follows: a) *In situ* ------------- b) Simulated *in situ* – c) Water tank in ship laboratory	0.1~0.2 g C m^{-2} d^{-1} in high sea areas 0.2~0.4 g C m^{-2} d^{-1} in the coastal waters -	Saijo *et al.* (1970)
Off Western Philippines	Light-and-Dark Oxygen Bottle using light simulated incubation	0.10~1.53 g C m^{-2} d^{-1}	Present study

were recorded in these areas with light intensities ranging from 100.0 µmol photons m^{-2} s^{-1} at 40-m depth to 5.16 µmol photons m^{-2} s^{-1} at about 60~80-m depths. Such range of irradiance in the tub of seawater could probably be less saturated for phytoplankton cells to begin photosynthesis. Thus, the high levels of primary productivity probably indicate an actively photosynthesizing activity of phytoplankton under such light intensities in the area (Fig. 4a and c). At one instance, the condition of high light attenuation that was demonstrated at *in situ* observation for prevailing bright sunlight, clear sky, calm weather and vertical mixing. Vertical mixing is also important in regulating the availability of light for phytoplankton productivity. It enhances primary production by simultaneous downward diffusion of light attenuation throughout the mixed water column, which allow phytoplankton cells to use for photosynthesis [Day, Jr. *et al.* (1989)].

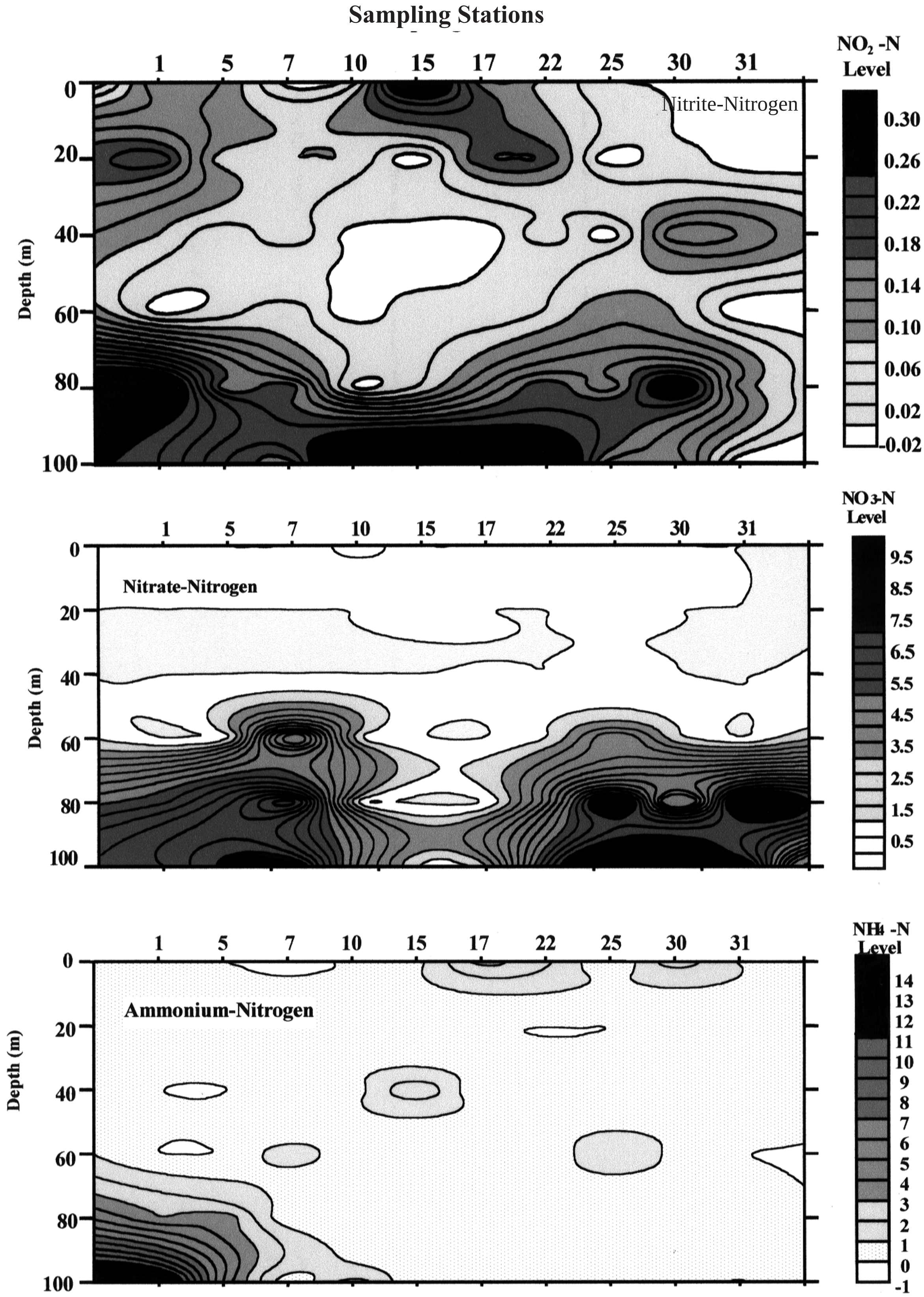

Fig. 5. Vertical profiles of nitrogen-ion (nitrite-, nitrate- and ammonium-) concentrations at various depths of different stations in the SCS, off Western Philippines (M/V *SEAFDEC*, Apr. 15-May 11, 1998).

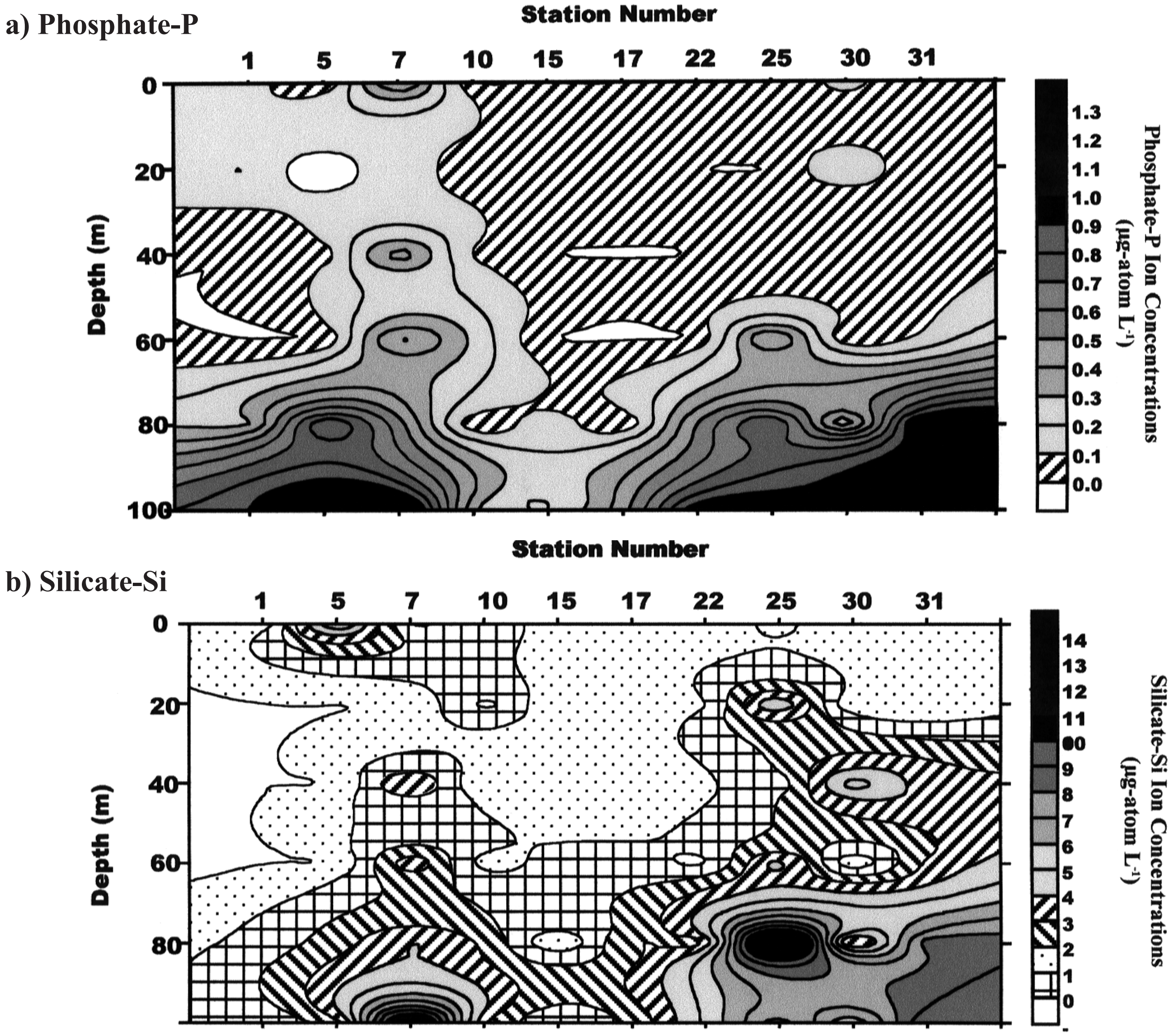

Fig. 6. Vertical profiles of phosphate- and silicate-ions concentration at various depths of different stations in the SCS, off Western Philippines (M/V *SEAFDEC*, Apr. 15-May 11, 1998).

The high net primary productivity values, which ranged from 0.21 to 1.53 g C m^{-2} d^{-1} at station 1 in the northwestern most part is associated with vertical mixing as noted by the homogeneous layer of cold water masses as indicated by 27.0°C ~ 28.0°C at the upper 60 m layer and a relatively low salinity concentrations which ranged from 33.90‰ to >34.00‰ (Figures 3c~d and 4a) in the area. The turbulent water circulation from the northeast side of the Pacific Ocean [Takenoute (1970)] causes the vertical mixing along the northwestern Luzon (station 1, 19° 59.2’N, 119° 58.7’E) that converged with the northward longitudinal current of the SCS during the month of April [O’Niel and Eason (1982] and [Wyrtki (1961)] had probably contributed also to the relatively high net primary production in the area. Likewise, during the month of May, the water circulation induced by the southwest monsoonal surface current from the Mindoro Strait and from the southern part of the SCS [Wyrtki (1961)] had probably contributed also to the relatively high net primary production at station 17 off Subic Bay, station 22 off the mouth of Manila Bay, station 25 off Mindoro Island, and stations 30 and 31 off Palawan. Unfortunately, data on water circulation pattern off the western Philippines was not obtained during the cruise and any further discussion on whether it affects the distribution of primary production in the area would be pure speculation. Consideration can also be given to the direct or indirect influence of vertical mixing to the nutrient enrichment (*viz.,* nitrite contents) throughout the water column of station 1 (Fig. 5, data taken from work of Montojo as part of this collaborative study), thereby enhancing phytoplankton productivity in the area [Oudot and Morin (1987)].

The amount of fluorescence in the water has been measured for an equivalent amount in lieu of chlorophyll contents of phytoplankton in marine areas. Fluorescence is a property closely associated with the chlorophyll molecule. Chlorophyll, like many other organic molecules, possesses the ability to fluoresce (Lorenzen, 1966). The results in this study revealed that there is no satisfactory explanation in relating the relative abundance and distributions of primary productions with degree of fluorescence and the number of phytoplankton cells in different stations (Figs. 4a & b). The amount of fluorescence is somewhat higher in the northwestern and central Luzon. Generally, fluorescence attributed to chlorophyll pigments of phytoplankton has no correlation with the distribution and abundance of primary production in the area. It could be noted that the high amounts of fluorescence spread between 40- and 100-m depths of stations 5 and 7 also coincided with the highest number of phytoplankton cells in the area (Figs. 4a & b, phytoplankton data was taken from the work of Bajarias as part of this collaborative study). This parameter do not affect, to any great extent, to the distribution of primary production in the area (Figures 4a & b). On the other hand, such peak in fluorescence and numbers of phytoplankton cells could probably be the effect of upwelling that was observed between stations 5 and 7 in the northwestern Luzon (Figs. 3a & b). Likewise, upwelling causes the rise of deeper water with relatively high nutrient (*viz.,* nitrate-, phosphate- and silicate-ions) levels from 100-m depth to about 50~60-m depths that probably support the phytoplankton abundance in these areas (Figs. 5 and 6). Bauerfeind (1986) and Ilahude (1978) stress the importance of upwelling on the hydrology, in general, and productivity, in particular, in tropical and equatorial waters also. Upwelling is a powerful, but complex, factor affecting productivity in marine areas. Results, however, have shown that the occurrence of upwelling in this area (between stations 5 and 7) yielded no direct links with primary productivity although both high amounts of fluorescence and number of phytoplankton cells at depths between 40- and 60-m depths showed linkage to the effect of upwelling.

To focus on probable factors that control primary production in the SCS, off western Philippines, detailed series of meteorological, hydrological and chemical measurements are needed. The difficulty in obtaining consistency in primary productivity measurements results, in part, from a very crude method of simulation experiments. In lieu of the most commonly used C-14 method, which was restricted during the survey, an on-board incubation experiment with the light-and-dark bottle oxygen method was used. The type of method and the considerations of other laboratory equipment and facilities (such as incubators with controllable temperatures and light source) are critical in obtaining accurate primary productivity measurements. Further study of the same objectives may help to refine our methodologies which may enable us to obtain accurate primary productivity measurement and to enable us to understand which invironmental factor will dominate/control their variable distribution in the area.

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