Dissolved Nutrients in the South China Sea, Area III: Western Philippines

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ABSTRACT

This paper discusses the distribution of dissolved nutrients and the hydrology of the first 100 m depth of Western Philippines, South China Sea (SCS). The object of the study was to understand variations in the distribution of these parameters by comparing the results of the April-May 1998 survey to previous studies made in the SCS and the Pacific side of Philippine waters. Water samples at different sampling depths (surface, 20, 40, 60, 80 and 100 m) were collected from 31 oceanic stations, from 11º-20ºN and 117º-121ºE. Results of this study confirmed that the chemical and hydrological profiles in SCS were similar but the range of values obtained for different parameters were dependent on the seasonal and spatial variations. The higher average temperature observed relative to the previous summer data may be attributed to the El Niño phenomenon. The mixed layer was deeper compared to the NE monsoon data. Conversely, western and eastern Luzon waters demonstrated differences in hydrological profile, except for the surface temperature, which was almost similar to the 1967-68 Pacific waters summer data. Among the nutrients investigated, phosphate and nitrate demonstrated a direct relationship with temperature, salinity and dissolved oxygen, from the surface down to 100 m depth. The behavior of phosphate and nitrate can be evaluated in terms of their hydrological structure in contrast to the more reactive silicate and nitrite ions.

Key words: dissolved nutrients, hydrology, South China Sea, Western Luzon, Northwestern Palawan.

Introduction

Assessment of the nutrient regime of an aquatic system is the first step in understanding the fishery dynamics of the area. As defined by Furnas (1992) nutrients refers to the material currency of energy flow and structural form in a biological system. These include inorganic compounds of nitrogen (N, in the form of nitrite and nitrate ion), phosphorous (P in the form of phosphate ion) and to a lesser degree, silicon (Si, in the form of silicate ion).

Dissolved nutrients are of prime interest because they are synthesized and utilized by phytoplankton in the aquatic community. N and P, in particular, are involved in soft tissue formation (e.g., synthesizers of ATP and cell membrane), while silicon on the other hand, is a hard tissue builder (e.g., enhances the bloom of silicoflagellates and diatoms) [Sommer (1994)].

The survey area covered part of the Philippines' Exclusive Economic Zone (EEZ) and the South China Sea (SCS). The whole area is a part of the Southeast Asian (SEA) Seas that contribute almost 11 % of the world's marine catch [Weidenbach and Lindenfelsen (1983)]. The region's richness in marine fisheries is due to its favorable physical and chemical characteristics [Weidenbach and Lindenfelsen (1983)].

There were several investigations carried out in the past regarding hydrological and nutrient concentrations of the area and its adjacent waters. [Wrytki (1961), Watts (1970), Uda et al. (1972), Han (1982), Zhiging et al. (1983), Law et al. (1987), Saleh et al. (1986), Toshihiro et al. (1987) and Gong et al. (1992)].

The purpose of this paper is to provide an update on the spatial distribution of nutrients, as well as their relationship to some of the hydrological parameters (e.g., dissolved oxygen (D.O.), salinity (S) and temperature (o), and to compare the data with previous investigations done in the area and the Pacific waters of the Philippines.

Methods

An oceanographic survey was conducted in the South China Sea, Area III (western Philippines) using the research vessel MV SEAFDEC in April and May 1998 occupying 31 survey stations [Fig. 1].

Salinity, D.O and temperature, were measured at 1 m intervals at every station using a CTD-Rosette (Falmouth Scientific Instrument). Niskin bottles of 2.5 l capacity (General Oceanics Inc.) attached to a Rosette sampler were used in the sample collection. Samples were taken at 20

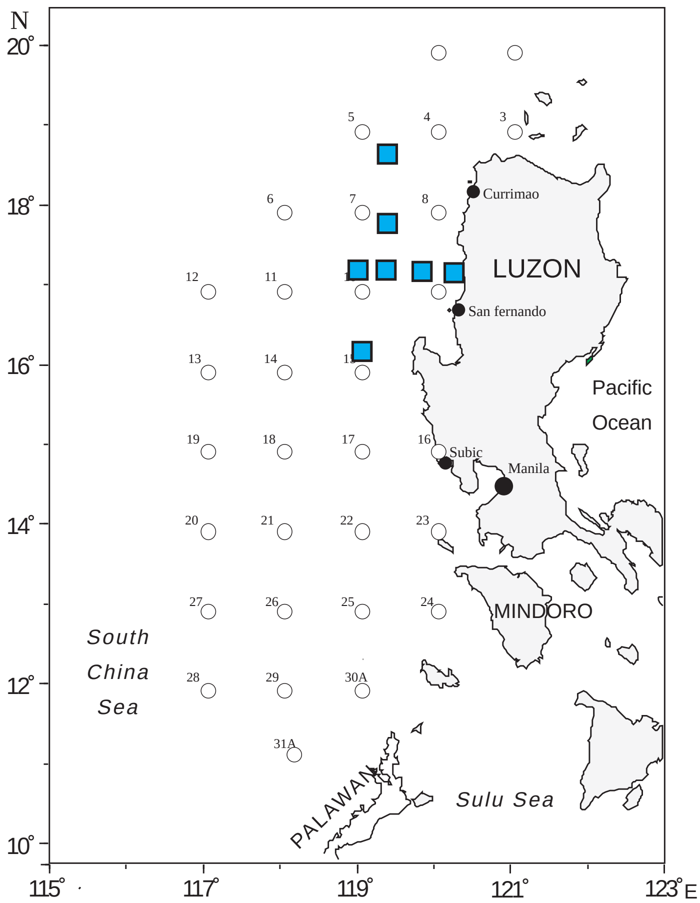

Fig. 1. The oceanographic and sampling locations for nutrients in the Western Philippines, SCS from April 18 – May 4, 1998. (■) refers to stations surveyed in December 16-30, 1990.

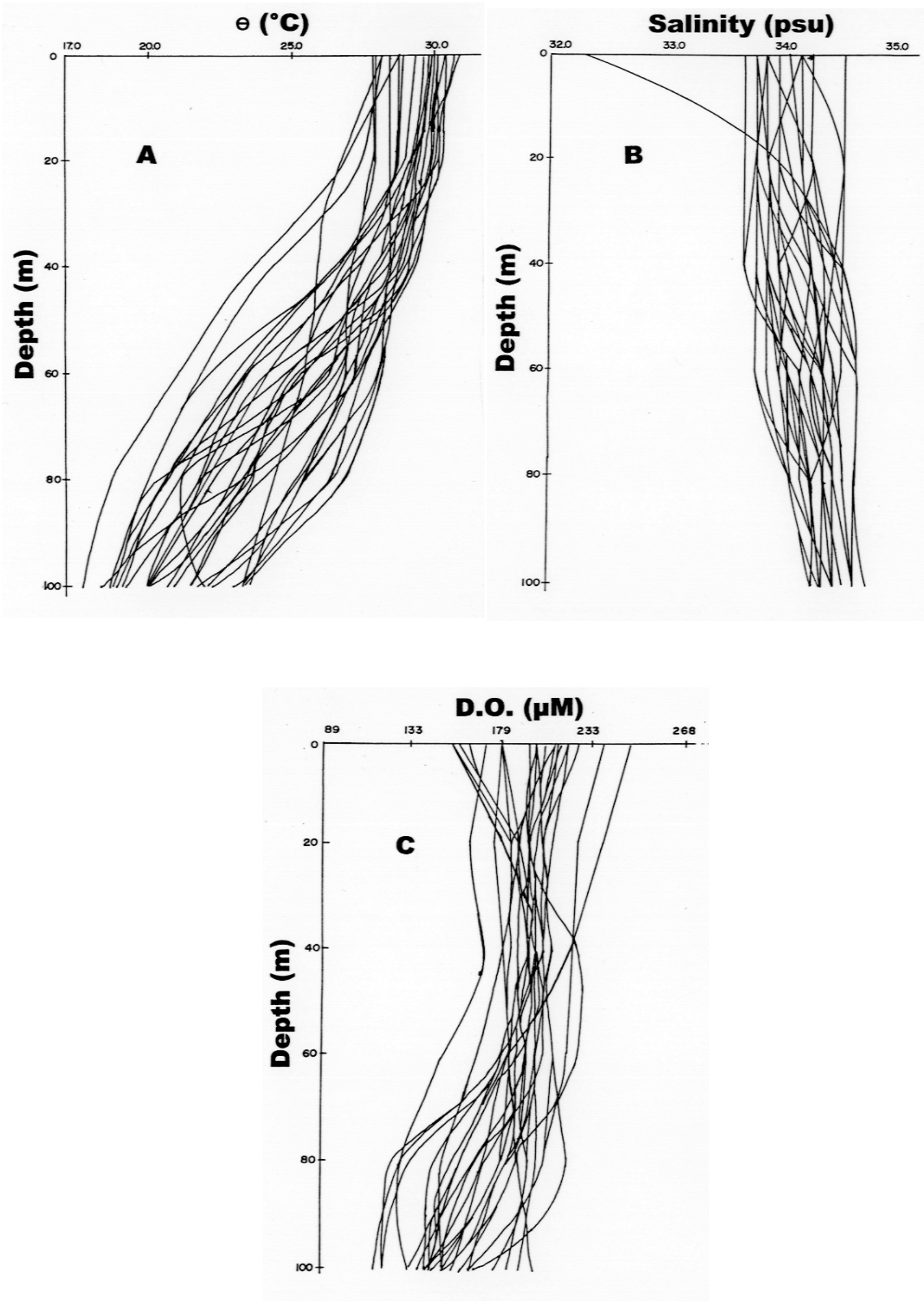

Fig. 2. Vertical profiles of (A) temperature, (B) salinity and (C) D.O. in Western Philippines, SCS from surface to 100 m depth.

m intervals from the surface down to 100 m.

Subsamples of 125 ml each were pressure filtered (< 1.0 atm) through Whatman GF/F glass fiber filters (nominal pore size: 0.7 µm) into previously acid-cleaned polyethylene tubes for dissolved nitrate, nitrite, phosphate and silicate determinations. Sample containers were rinsed twice with sample water before filling them with 125 ml of the subsample. Samples to be used for analysis were double packed with plastic bags and were frozen [IOC Manual Guide (1993)].

Nutrient analyses were undertaken using the standard colorimetric methods [Parsons and Strickland (1972)] at the Bureau of Fisheries and Aquatic Resources (BFAR) ocean laboratory in Manila. Isopleths and line graphs of nutrient concentration, temperature, D.O. and salinity at stations along 6 depths (20 m interval) were drawn. Comparative charts and scatter diagrams were plotted to illustrate the interrelations among the parameters under investigation. Statistical computations were done using the Strategic Application Software (SAS). '

Results

The concentrations of four nutrient parameters from the surface down to 100 m depth were as follows: nil-10.50 µM for NO3-N; nil-0.33 µM for NO2-N; nil-1.40 µM for PO4-P; and nil-38.00 µM for SiO3-Si.

Both the nutrient's horizontal and vertical profiles showed variations in their spatial distribution in the water column. Isolines clearly showed the concentration variations in the area, particularly in the northwestern Luzon and Mindoro Strait.

Hydrological Profile

Fig. 2A-C shows the vertical profiles of θ, S and D.O. in the first 100 m. The hydrological structure showed that the mixed layer was from 10 to 60 m in the survey area although according to Gong et al. (1992) it was at 15 to 30 m in December 1990. Vertical profiles of temperature demonstrated uniformity in the surface layer (s.d.: ±0.85), and greater variations at subsurface layers, particularly at 80 m, wherein the standard deviation (s.d.) was at its maximum value of ±2.18. Of all the locations surveyed, water temperature was generally lower at the entrance of Luzon Strait.

Except for Station 16, which is located 3 nautical miles from the Zambales coastline, salinity was more or less the same in the entire 100 m depth. The observed maximum salinity value range was less than 1 psu, whereas the s.d. value from the surface to 100 m depth ranged from ±0.12 to ±0.35 .

The D.O. profile was almost similar in all stations. The oxygen minimum concentration was recorded at 40 m depth with mean and s.d. values of 198.66±0.24 µM while maximum variations were located at 80 m depth with mean and s.d. values of 175.89 µM and ±0.55 µM, respectively. This variation in D.O. level was observed at northwestern Luzon and west of Mindoro Island.

The horizontal profiles in Fig. 3 illustrates a minimum surface water temperature that prevailed over the water mass at 15°N, 120°E and 18°-20°N, 119°E . This trend persisted up to 20 m with a slight increase in s.d. and mean value of ±0.94 and 29.18 °C. A warm tongue-like water mass was found at 40 m depth, 16° to 17°N, 119°E. The cooler water mass from the north converged with the relatively warmer waters that came from the outer zone extending downward at 12°N. The average water temperature for this layer was at 27.73±1.39 °C. At 60 m depth, the average water temperature was slightly lower at 25.40±1.97 °C with a warmer water mass now located at 15°-16°N, 117°E while cooler water mass still persisted at 18°N, 119°E. At 80 m

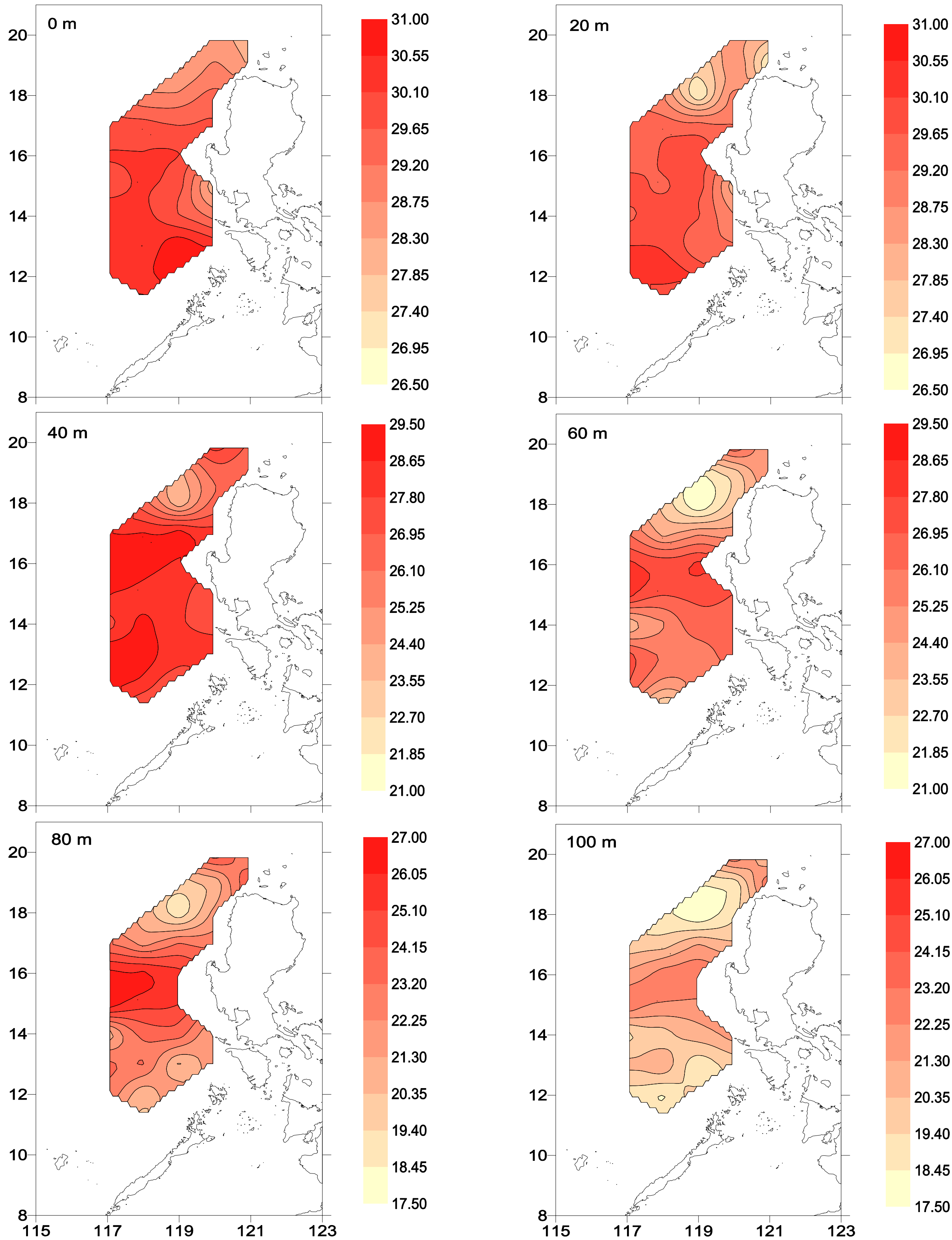

Fig. 3. Horizontal distribution of temperature in °C at various depths.

depth where the highest variation was recorded, moderately higher temperature continued to persist off Zambales coast with mean value of 22.76 °C in this water layer, while at 100 m depth, cooler water mass prevailed over the entire survey area (mean: 20.42 and s.d. ±1.72 °C).

The horizontal salinity profile shown in Fig. 4 demonstrated the surface water as an almost homogenous water mass (33.90±0.35 psu), except for slightly more saline water near the entrance of Luzon Strait and the Sulu Sea. At 20 m depth, the slightly saline condition of the water mass continued to prevail over northwestern Luzon up to 17°N and Mindoro Strait, with an average salinity of 33.97±0.23 psu. However, salinity level increased with an average value of 34.09±0.28 psu at 40 m depth. In this layer, water masses from outer zones converged with the lower salinity water mass off Lingayen Gulf, and the more saline water mass from the Sulu Sea. The same higher salinity level existed at 60 m depth (34.29±0.24 psu) situated over northwestern Luzon and northern Palawan and encompassed by a less saline water mass located, off Zambales and Pangasinan coasts. Water at 80 and 100 m had salinity that was almost uniform with mean values at 34.42±0.18 and 34.54±. 0.12 psu, respectively.

Fig. 5 shows the horizontal profile of D.O. at various depths. Generally, higher values were observed at the surface (198.66±45 µM), with maximum values at 13°N, 118°E and 11°N, 118°E. Lower concentrations were observed over the water mass originating from the north (17°-18°N, 119°-120°E), Zambales coast (15°N, 120°E) and at 14°N, 117°E. The trend persisted in different locations up to 20 m depth with a slightly lower mean value of 196.43±0.29 µM. There was a minimal increase of subsurface concentration of D.O. at 40 m depth with the maximum level observed at 12°-13°N, 118°-119°E. At 60 m depth, lower values persisted at 14°N, 117°E, and at 17°-18°N, 118°-119°E, a relatively higher concentration was evident at 13°N, 118°E. In this layer, the recorded mean value of 194.20±0.32 µM. At 80 m depth, significant reduction in D.O. level was established with an average of 175.89±0.55 µM. Similar to the shallower layers, low D.O. concentrations continued to persist at 14°, 117°E, 12°N, 118°E and 18°N, 118°E while higher concentrations were evident at northern Palawan, off central Luzon and Balintang Channel. There was a continuous reduction of D.O. level (mean : 153.12±0.50 µM), at 100 m depth .

Nutrient Profiles

Figs. 6A-D shows the vertical profile of NO_3-N, NO_2-N, PO_4-P and SiO_3-Si. Except for nitrite, the three nutrients demonstrated abrupt increases in concentration below the mixed layer. The homogeneous water mass was almost devoid of nutrients particularly with nitrate, nitrite and phosphate. Of the 31 stations surveyed, nitrate values can be grouped into four sets namely: stations with significant increase at 60 m, 80 m, 100 m and those with insignificant changes in concentration level. Phosphate profiles were similar to nitrate, except in Station 7. Silicate, on the other hand, showed a localized increased in concentration at various depths in different stations. The maximum increase in concentration was noted in stations located near Luzon Strait and the Sulu Sea entrance.

The horizontal profiles of nitrate in Fig. 7 show the surface water to have a relatively low nitrate concentration (range 0.84, mean: 0.11 µM). However, this nutrient was present at offshore waters (117°-118°E, 14°- 15°N) and near the Zambales coast, while below detection limit for the rest of the stations. Nitrate was also prevalent at 20 m off Cape Bolinao (16°N, 119°E) and near the entrance of Manila Bay (Station 23), but practically nil value was observed from 17° to 20°N latitude. It was also present at 40 m along the latitudinal zones (13°, 14°N), perpendicular to Manila Bay, followed by an abrupt increase in concentration on the northwestern Luzon at 60 m (range: 6.85, mean: 0.64 µM). Waters coming from Sulu Sea was observed to have a relatively

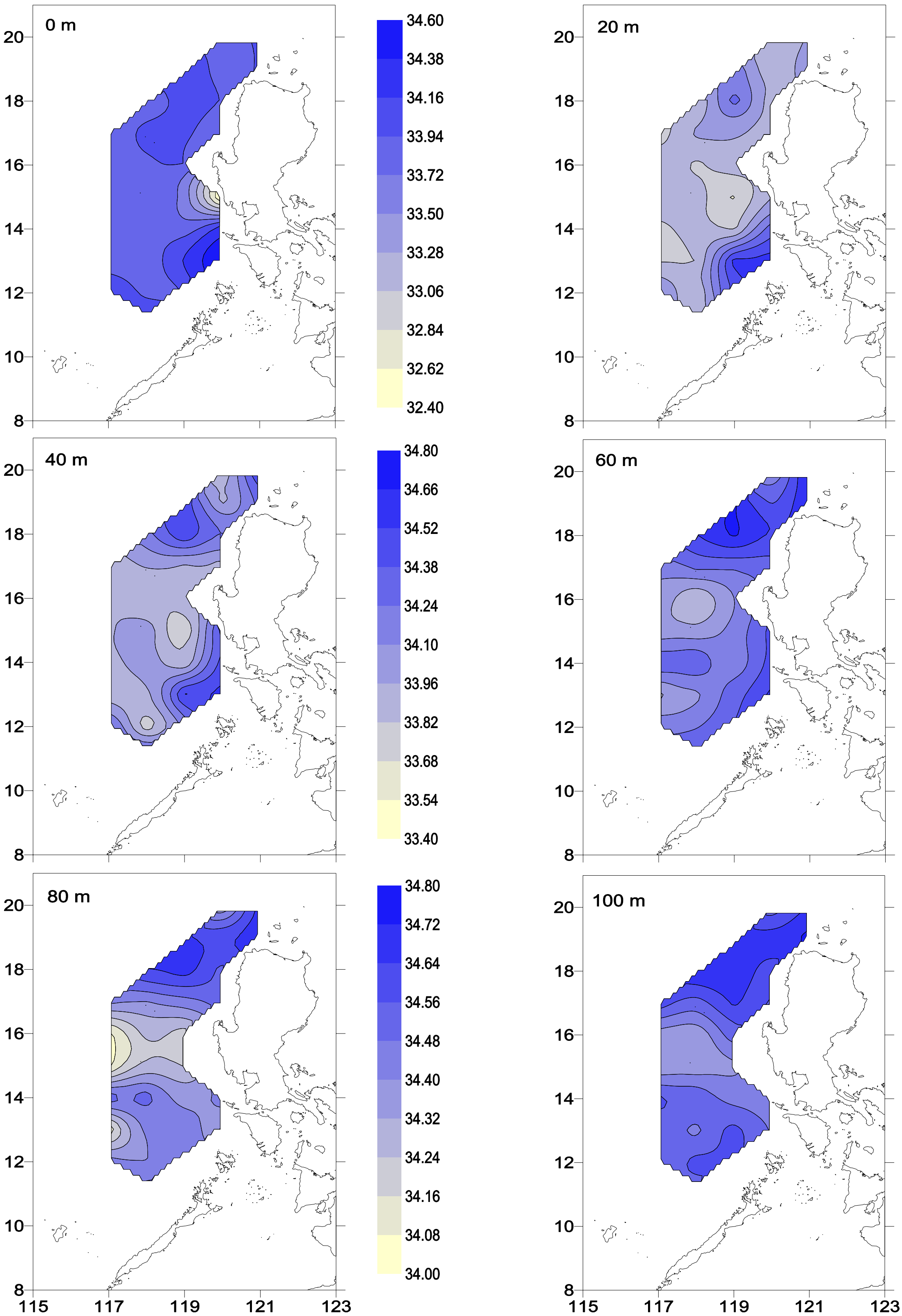

Fig. 4. Horizontal distribution of salinity in psu at various depths.

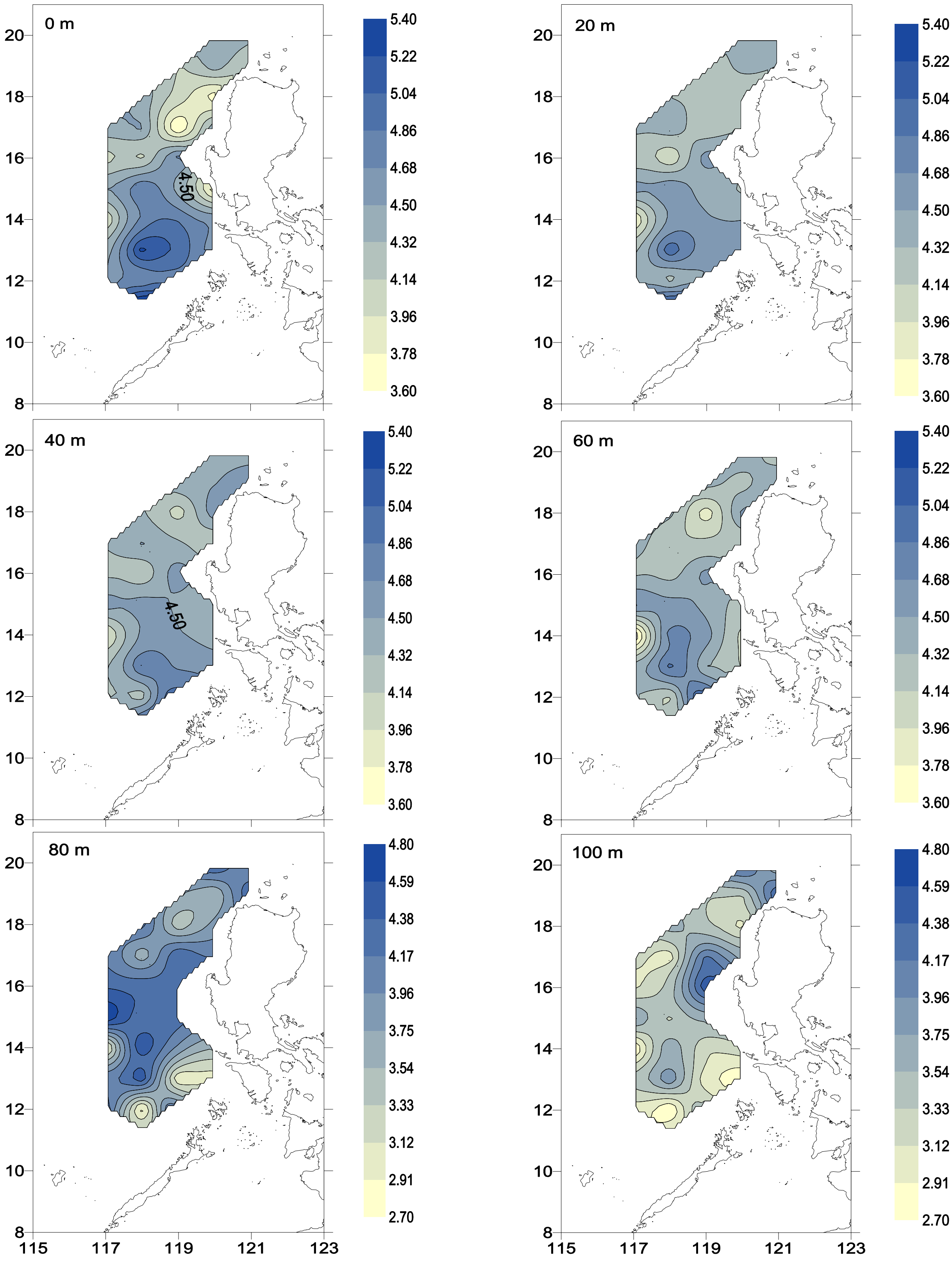

Fig. 5. Horizontal distribution of D.O. in µM at various depths.

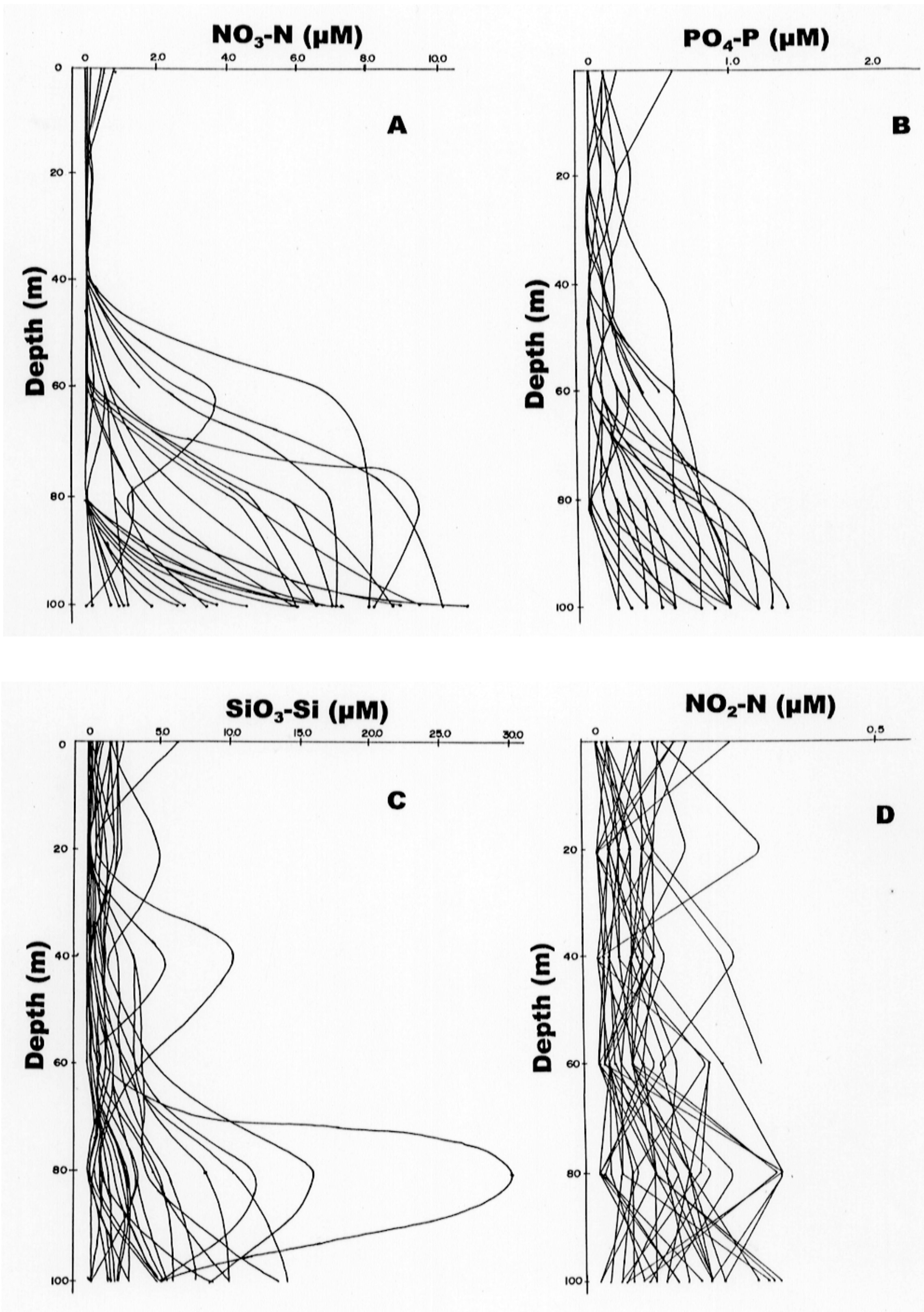

Fig. 6. Vertical profiles of (A) NO_3-N, (B) NO_2-N, (C) PO_4-P and (D) SiO_3-Si in Western Philippines.

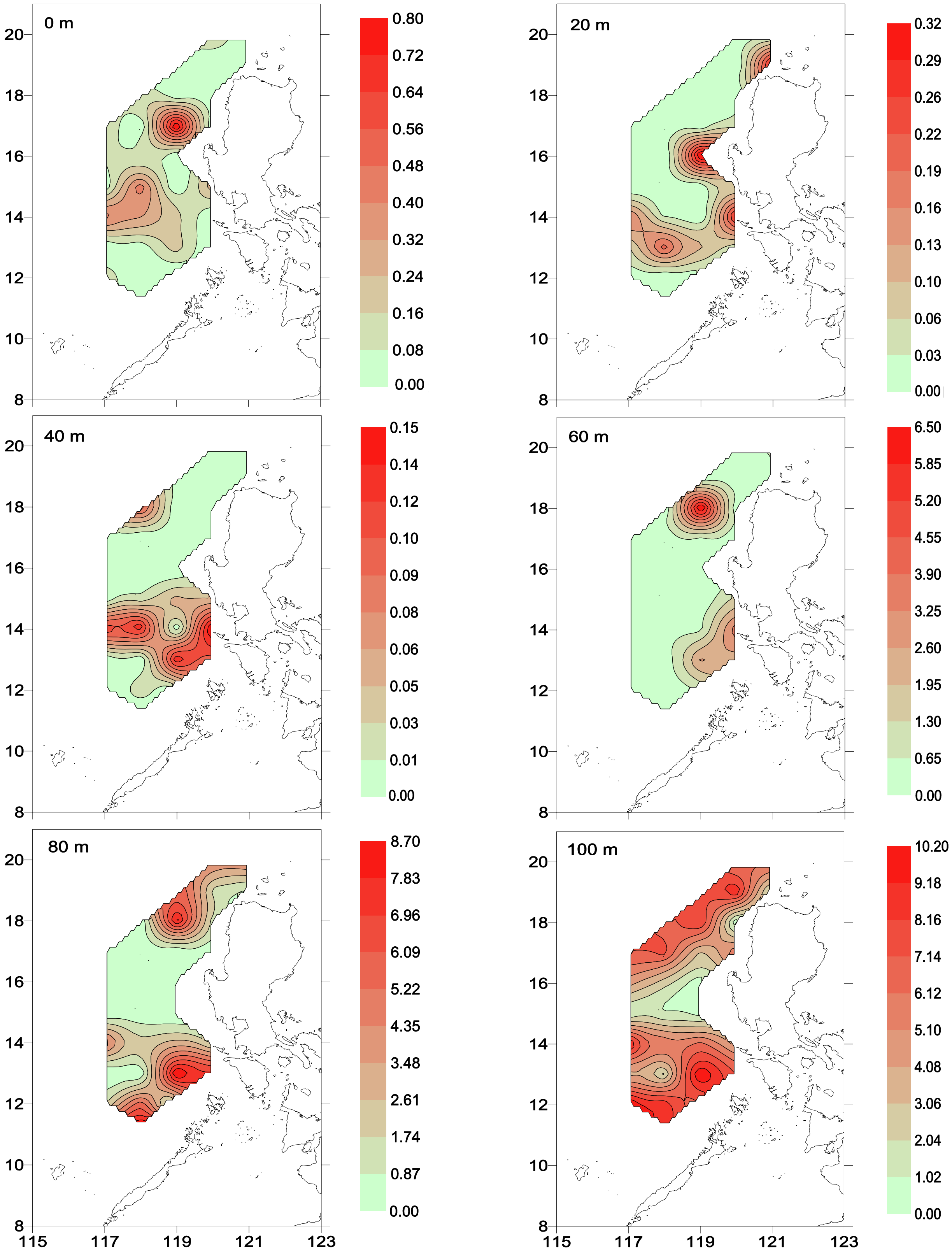

Fig.7. Horizontal distribution of NO_3-N in μM at various depths.

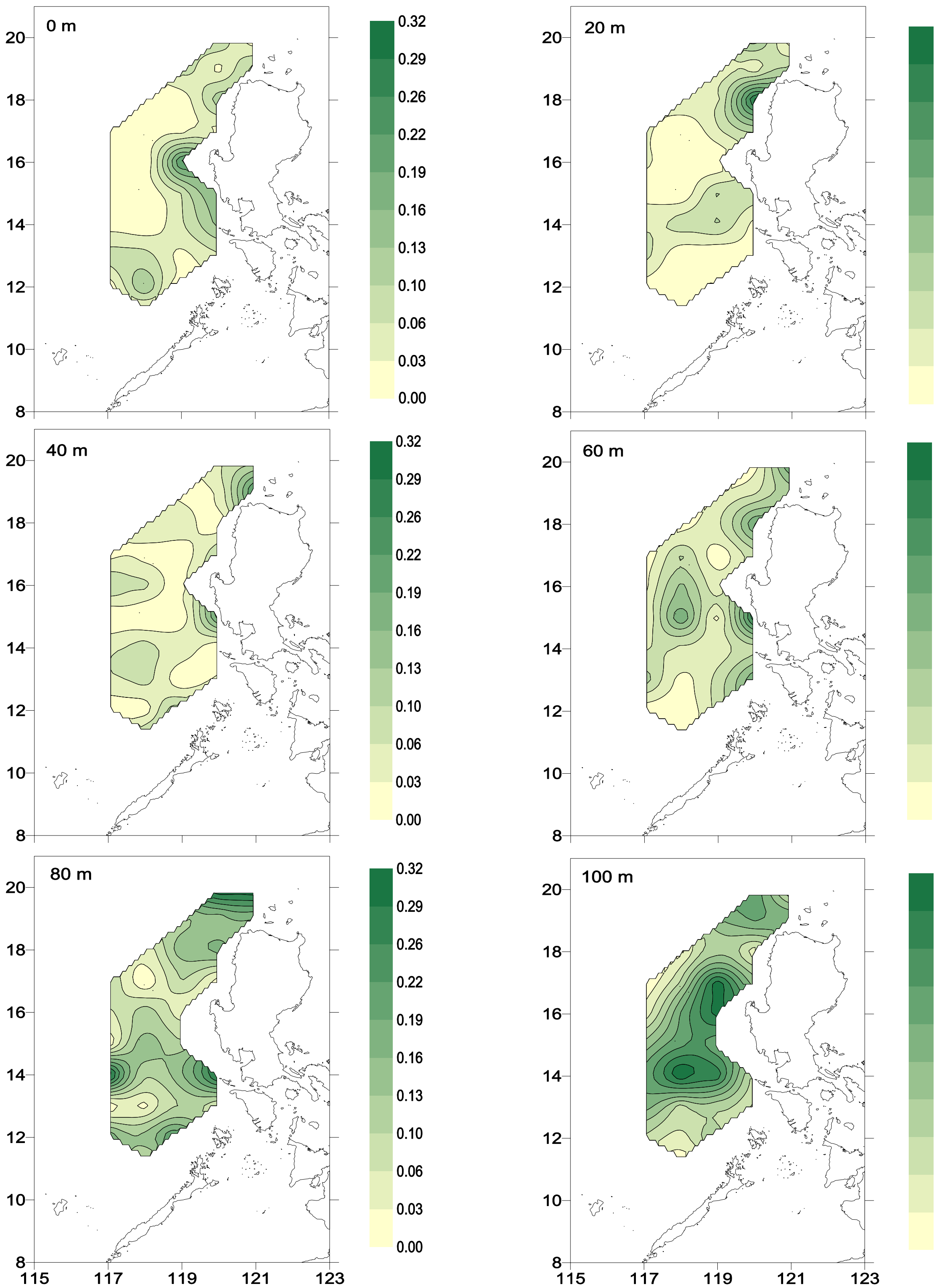

Fig. 8. Horizontal distribution of NO_2-N in μM at various depths.

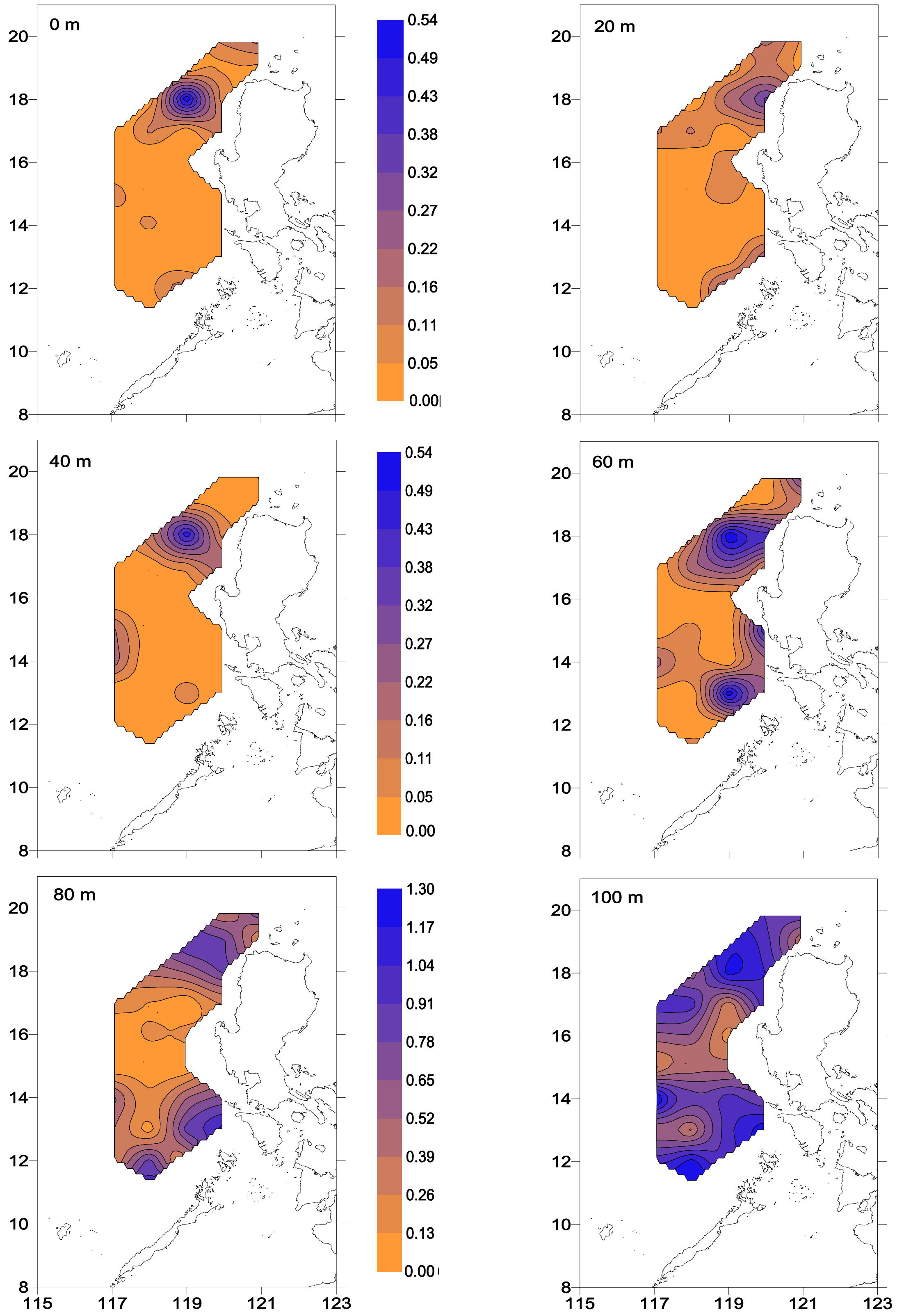

Fig. 9. Horizontal distribution of PO_4-P in µM at various depths.

higher in nitrates. Consequently, the 80 m depth, nitrate-rich northwest excursion from Sulu Sea and Luzon Strait continued to persist (range: 8.96, mean: 2.32 µM), while the middle part of this layer (15° to 17°N, 117° to 120°E) has a concentration below detection limit for said nutrient. At 100 m depth, dissolved nitrate had a mean value of 5.15 µM and a range of 10.32 µM.

Nitrite ion [Fig. 8] was almost uniformly distributed from the surface up to 100 m depth. In the surface layer, dissolved nitrite near the shore area had a range of 0.24 µM and a mean of 0.05 µM. At 40 m depth, it had only minimal values in all the stations surveyed (range: 0.25, mean: 0.03 µM). The range and mean nitrite values at various depths were as follows: 0.30 and 0.06 µM at 20 m, 0.22 and 0.07 µM at 60 m, 0.33 and 0.13 µM at 80 m and 0.32 and 0.14 µM at 100 m depth.

Similar to nitrate, phosphate ion concentrations, as shown in Fig. 9, were relatively higher in the water mass off northwestern Luzon at all depths investigated while the rest of the stations in the surface layer, 20 m, and 40 m depths were almost devoid of this nutrient. The range and mean values obtained were: 0.55 and 0.05 µM at the surface, 0.34 and 0.06 µM at 20 m depth, and 0.48 and 0.05 µM at 40 m depth. Phosphate concentrations significantly increased at 60 m depth (range: 0.55, mean: 0.12 µM) with three diverging zones, 18°N, 119°E, at 14°N, 117°E and 13°N, 119°E, respectively. Moreover, at 80 and 100 m depth, the phosphate concentration continued to increase with maximum values of 1.08 and 1.40 µM and mean values of 0.42 and 0.82 µM, respectively.

Fig.10 shows dissolved silicate profiles in the study area. Surface layer water mass demonstrated relatively high values (range: 6.31, mean: 0.72 µM), particularly at 19°N, 119°E extending longitudinally southward up to 15°N, converging with water mass containing minimum silicate from the center and at 13°N, 119°E as well as at 14°N, 117°E. The same trend was observed at 20 m depth, specifically, at the northwestern part of Mindoro Island and nearshore of northwestern Luzon (range: 5.04, mean: 0.67 µM). Meanwhile, at 40 m depth, silicate levels in areas off northwestern Luzon and the Sulu Sea entrance remained higher (range: 1.35, mean: 1.20 µM). At 60 m, silicate–rich water (range: 4.65, mean: 1.34 µM) were observed (15°N, 119°E and 117°E, 14°N together with 16°N-18°N, 119°E). At deeper waters, silicate level significantly increased with range and mean values of 38.85 and 4.43 µM at 80 m depth, and 14.19 and 5.04 µM at 100 m depth respectively.

Figs. 11-15 shows the average nutrient as well as the hydrological profiles (continuous line) of the 1998 survey compared to the data from the previous investigations of Gong et al. (1992) and Watts, (1970). The first was the result of the oceanographic cruise in the SCS on December 1990, while the later data were obtained from 19° to 20°N and 113° to 116°E during the summer of 1967-68 [Watts (1970)].

θ - Nutrient Relationship

Fig. 11A-D shows the nutrient concentration as a function of temperature. In Fig. 11A, nitrate results in the 1998 survey obtained minimal values of ≤ 0.05 µM from 31°C to 27.0°C. An inverse relationship was observed below this temperature as both previous data demonstrated a significant increase in nitrate concentration as temperature decreases. At initial temperature range, no correlation was established by Watt while the same temperature range was absent in the water mass investigated by Gong et al. (1992). But for the 1990 northeast monsoon data, a very high concentration gradient from 27° to 24.5 °C, from this point until 17 °C, minimum change in concentration was observed.

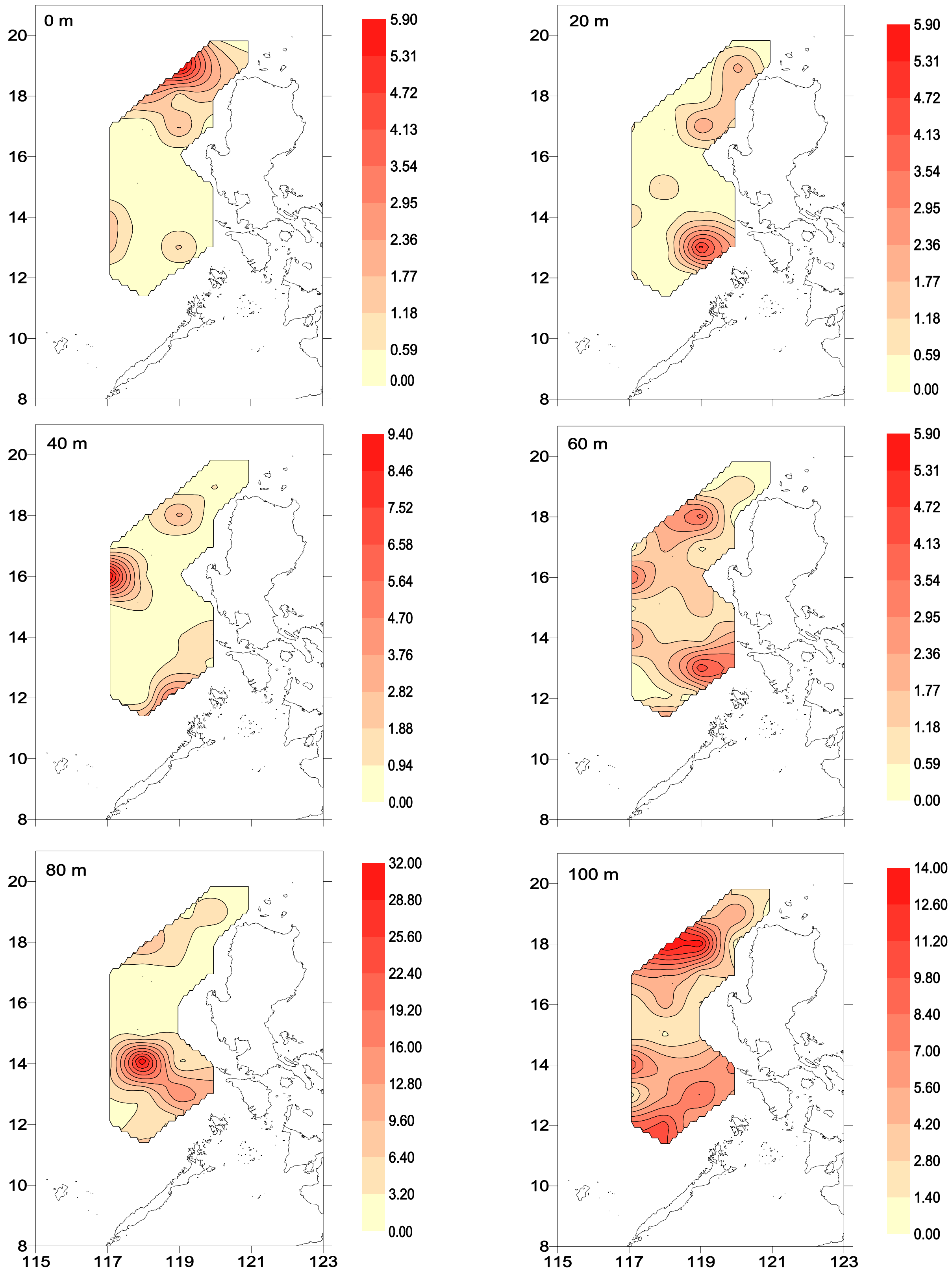

Fig. 10. Horizontal distribution of SiO_3-Si in µM at various depths.

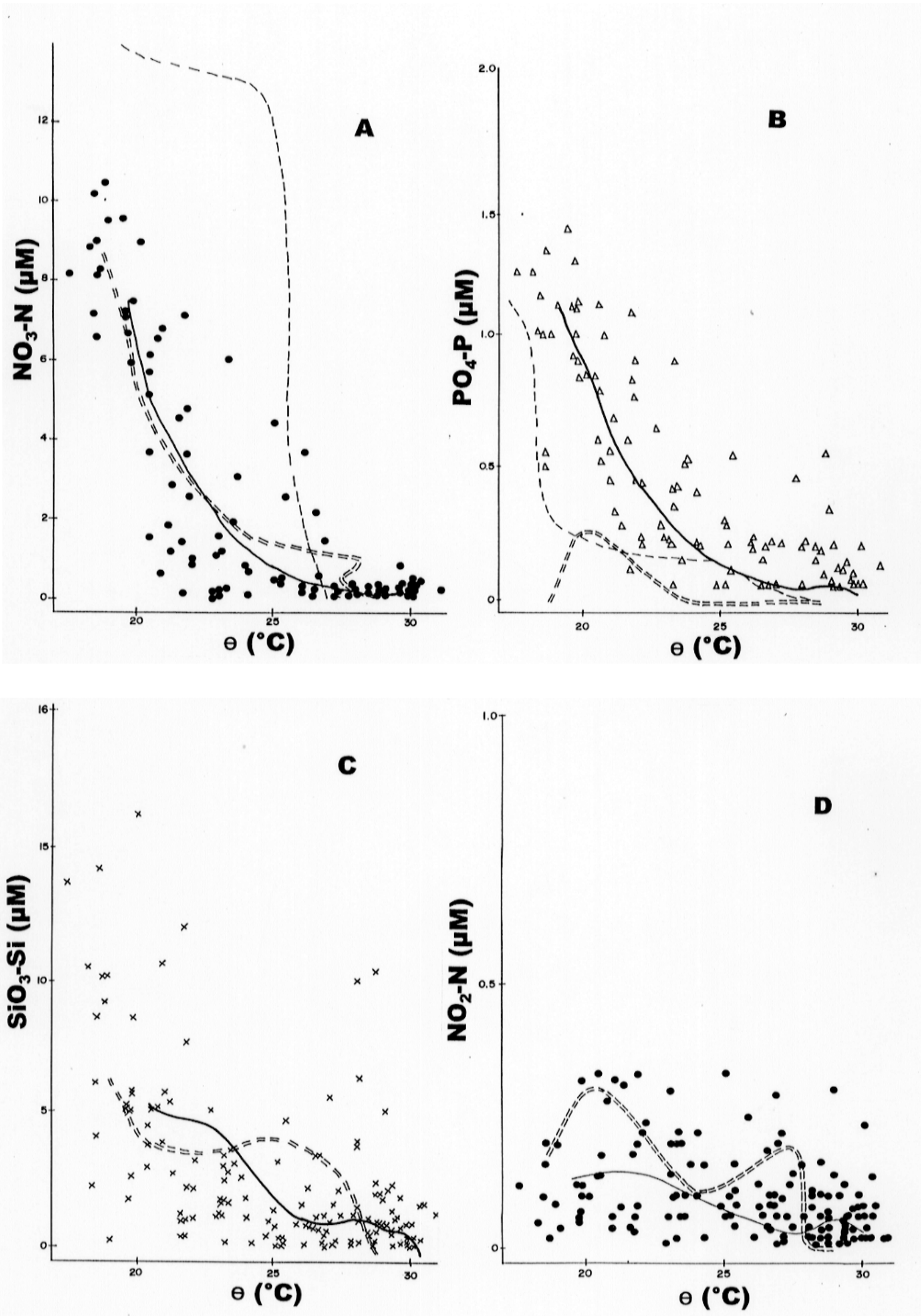

Fig. 11. Comparative profiles of o-nutrient relationships: (A) θ- NO_3-N, (B) θ-PO_4-P, (C) θ-SiO_3-Si and (D) θ-NO_2-N. (—) refer to 1998 summer average result, (- -) refer to December 1990 and (= =) for summer of 1967-68.

The θ - phosphate relationship in Fig. 11B shows a relation that is inversely proportional. This trend was similar to what Gong et al. (1992) established in the 1990 data.

The θ - silicate relationship [Fig. 11C] shows a multi-modal peak for both lines presented. This profile demonstrated an absence of a direct relationship for this nutrient with temperature in the first 100 m depth. The θ-nitrite plot in Figure 11D followed the same trend.

Salinity-Nutrient Relation

Fig.12a-d shows salinity as a function of nutrient concentration. The nitrate profile [Fig. 12A) shows a similar line structure for the three surveys, except for the summer data, wherein a minor peak was evident in nitrate concentration of <1.0 μM at corresponding salinity values of 33.7 to 34.0 psu. Gong et al. (1992) obtained relatively higher nitrate concentrations at this salinity range. A similar increase in concentration (from 1.0 μM and above) was observed at 33.75 psu (NE monsoon) and 34.58 psu (summer data).

The 1998 and 1990 surveys show similar salinity-phosphate profile [Fig.12B], while the 1967-68 results demonstrated an almost nil value at 34.5 psu.

For salinity and silicate relationship [Figure 12C], a lesser degree of association was obtained based on the two summer results, but in general, the concentration of silicate ion increased with salinity. The nitrite-salinity profile [Figure 12D] shows an almost insignificant correlation.

D.O.-Nutrient Relationship

D.O.-nitrate relationship in Fig.13A, shows a nearly uniform initial concentration of nitrate (≤05 μM) at 192.0 to 205.0 μM of D.O. in all the three surveys conducted. The present average data demonstrated a constant increase in nitrate concentration with decreasing D.O. level. The December 1990 data showed significant increase in nitrate concentration at 205.0 μM in relation to a much lower D.O. level of 174.0 μM. Watts (1970) obtained no trend for NO3-N concentration at a relatively higher D.O. level (190 to 205 μM). Lower than this value a constant increase in nitrate concentration was observed.

The D.O.-phosphate plot [Fig. 13B] was almost similar to nitrate. There was a uniform increase in phosphate level with decreasing D.O. level. There was a single-broken line that shows a curvilinear behavior contrary to the data obtained by Watts (1990) with almost no relationship.

Based on the silicate and nitrite-D.O. graph [Fig. 13C-D], both nutrients showed no direct correlation in the two studies made. However, silicate concentration generally increased with depth.

Discussion

SEAFDEC's 1998 survey of the Western Philippines, SCS, established similarities in the physico-chemical profile but also demonstrated differences in seasonal and spatial values relative to the previous studies conducted.

Figs.14A-D shows the comparative profile of temperature, salinity and D.O in different occasions in the SCS and the eastern Philippine waters. The temperature profile [Figure 14A] of SCS showed parallelism compared to the Pacific side with average values that were generally higher compared to previous results. Only at 40 and 100 m depths , the results obtained by Watts (1970), were close to the average values and were within the s.d. range of the present study. The profile obtained in the first 40 m depth was almost similar with the eastern Philippines'

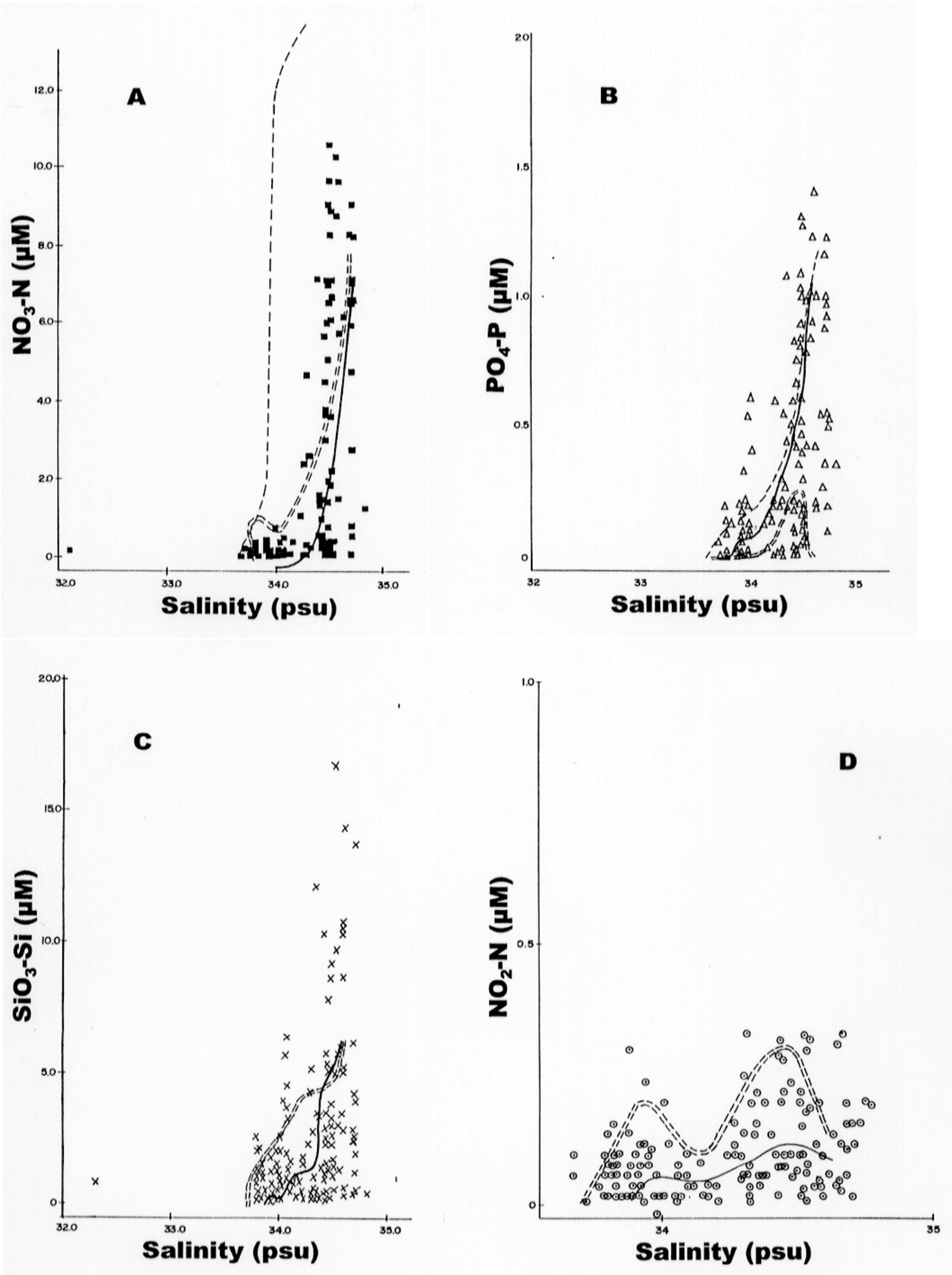

Fig. 12. Comparative profiles of S-nutrient relationships: (A) S-NO_3-N, (B) S-PO_4-P, (C) S-SiO_3-Si and (D) NO_2-N. (—) refer to 1998 summer average results, (- -) refer to December 1990 and (= =) for summer of 1967-68.

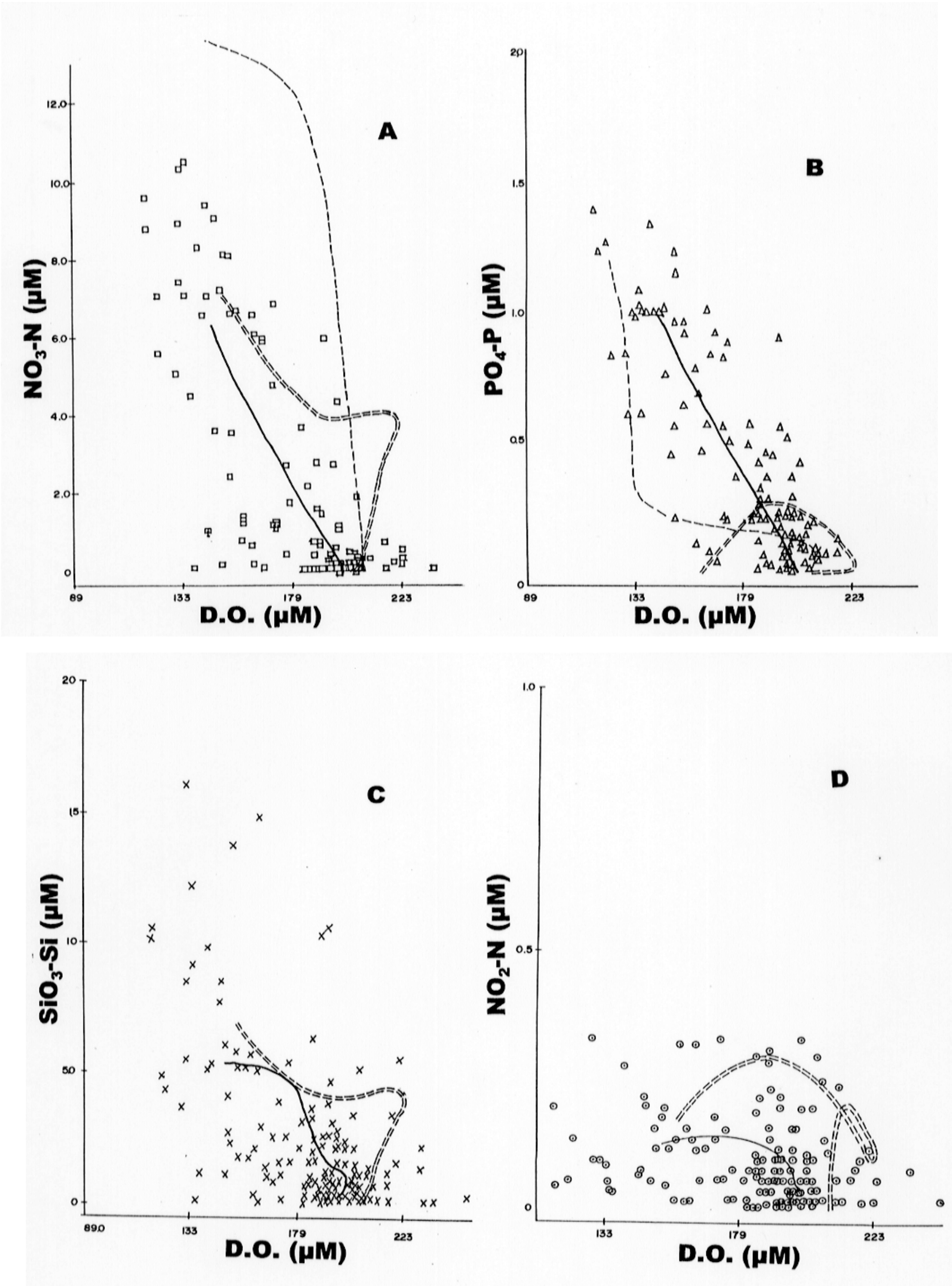

Fig. 13. Comparative profiles of D.O.-nutrient relationships: (A) D.O.-NO_3-N, (B) D.O.-PO_4-P, (C) D.O.-SiO_3-Si and (D) D.O.-NO_2-N. (—) refer to 1998 summer average results, (- -) refer to December 1990 and (= =) for summer of 1967-68.

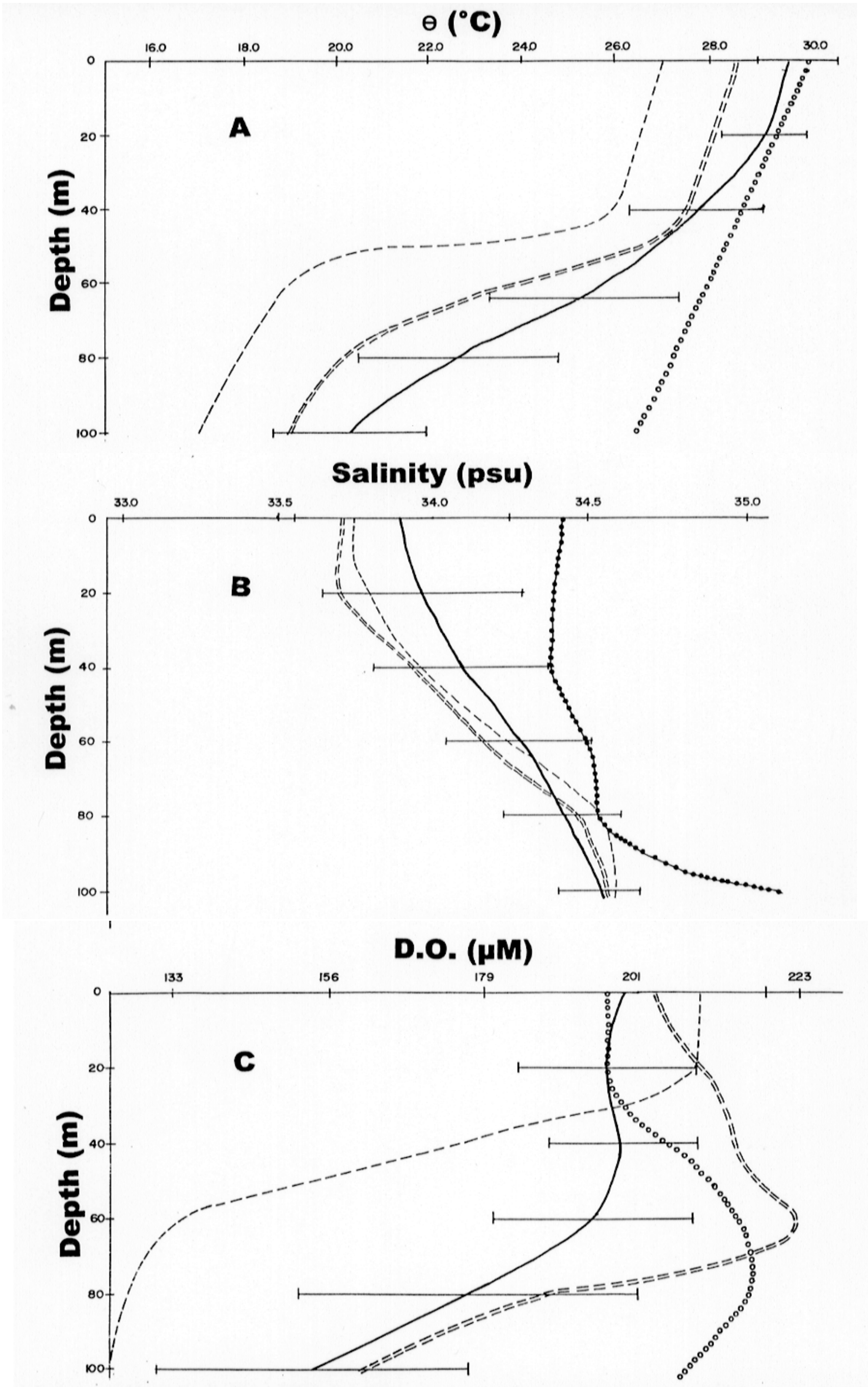

Fig. 14. The vertical profiles of (A) θ, (B) S and (C) D.O. in different occasions. (—) refer to 1998 summer average results, (- -) refer to December 1990, (= =) refer to summer 1967-68 and (….) refer to Eastern Luzon Waters. The horizontal bars represent the s.d. range of the latest data.

temperature structure from 10° to 20°N Manansala (1970). The higher temperature values obtained in the latest survey as compared to historical data being considered in this study was probably due to the global warming brought about by the 1998 El Niño phenomenon as well as a reflection of local and seasonal variations [(Gong et al. (1992)].

Salinity [Fig. 14B] on the other hand, demonstrated a slight variation but were still within the range of values of the SCS data. However, the SCS profiles were different compared to the more saline Pacific waters. During the survey, the higher salinity level of the surface water may be due to higher evaporation rate in the area during the summer season [Wyrtki (1961)]. Gong et al. (1992) suggested that there was no significant surface water mass intrusion coming from the Pacific Ocean due to extreme values in salinity.

For D.O. [Fig. 14C], average values at the first 20 meters were almost similar; however, there were significant differences observed below this depth level. There was reduction in D.O. level along SCS at lower depths compared with the Pacific profile. These difference at the subsurface layers can be due to subsurface water currents as reported by Watts (1970).

The nutrient levels in the area were also quantified and compared to previous studies [Fig.15]. The nitrate and phosphate data demonstrated similar trends while the point for comparison for nitrite and silicate profile cannot be established except with depth. The profile of nutrients particularly for N and P in the first 100 m depth was a function of the mixed layer in which abrupt increased in concentration was observed, usually from 10 to 60 m depth. Except for P, the 1998 cruise obtained the lowest stocks of nutrients in the area.

The tropical oceanic waters such as the SCS generally have a deficiency in nutrients especially during summer time [Furnas ,1992]. This concept was demonstrated clearly by the present results in comparison with Gong et al, (1992), who made the survey during the northeast monsoon. The latter survey obtained a significant level of nitrate at shallower mixed layer compared to the present and 1967-68 summer data. Nitrite and silicate ions increased with depth but no specific trends were obtained [Fig. 15C-D].

In comparison to other studies, Zhiging and Feiyong (1983) reported that the central waters of SCS (110°-118°E, 12°-15°N) demonstrated a tropical behavior [Furnas, (1992]. The horizontal distribution of dissolved Si and P were more or less uniform, with decreasing trends in concentration from SE to NW. The vertical profile on the other hand, from surface down to 1000 m depth was similar to that of the Pacific Ocean. The range was from nil to 3.1 µM for P and nil to 182.14 µM for Si. There were higher values at 100 m and 1000 m with homogenous water mass beyond 1000 m depth [Han (1982)].

In the southwestern part of SCS, values obtained [Toshihiro et al., 1987] for nitrate and nitrite were generally lower in comparison with the current results. P on the other hand, was higher compared to the present value. In Sarawak waters [Saleh et al. (1986)], the average nitrate concentration was 200 % greater than the present values and nitrate was slightly higher at 0.37 µM. Further SW in western peninsular Thailand (97°E, 9°N), both N and P values were lower compared to Area III, with nitrite registered a nil value [Limpsaicol (1978)].

Horizontal distribution of nutrients showed a relatively higher concentration which was evident off northwestern Luzon (17°-20°N, 118°-120°E) and off western Mindoro Is (12°-14°N, 117°-120°E). This phenomenon was attributed to the seasonal oceanic regimes typical in tropical areas like the South China Sea. In the first location, there was significant level of nutrients through eddy formation caused by the turbulence from the Pacific Ocean in the north [Takenoute (1970)] and converging with the northward longitudinal current of the SCS [O'Niel and Eason (1982)] during the month of April. O'Neil and Eason (1982) further discussed that in the month of May, this concurrent water mass displacement from Mindoro Strait as well as from the

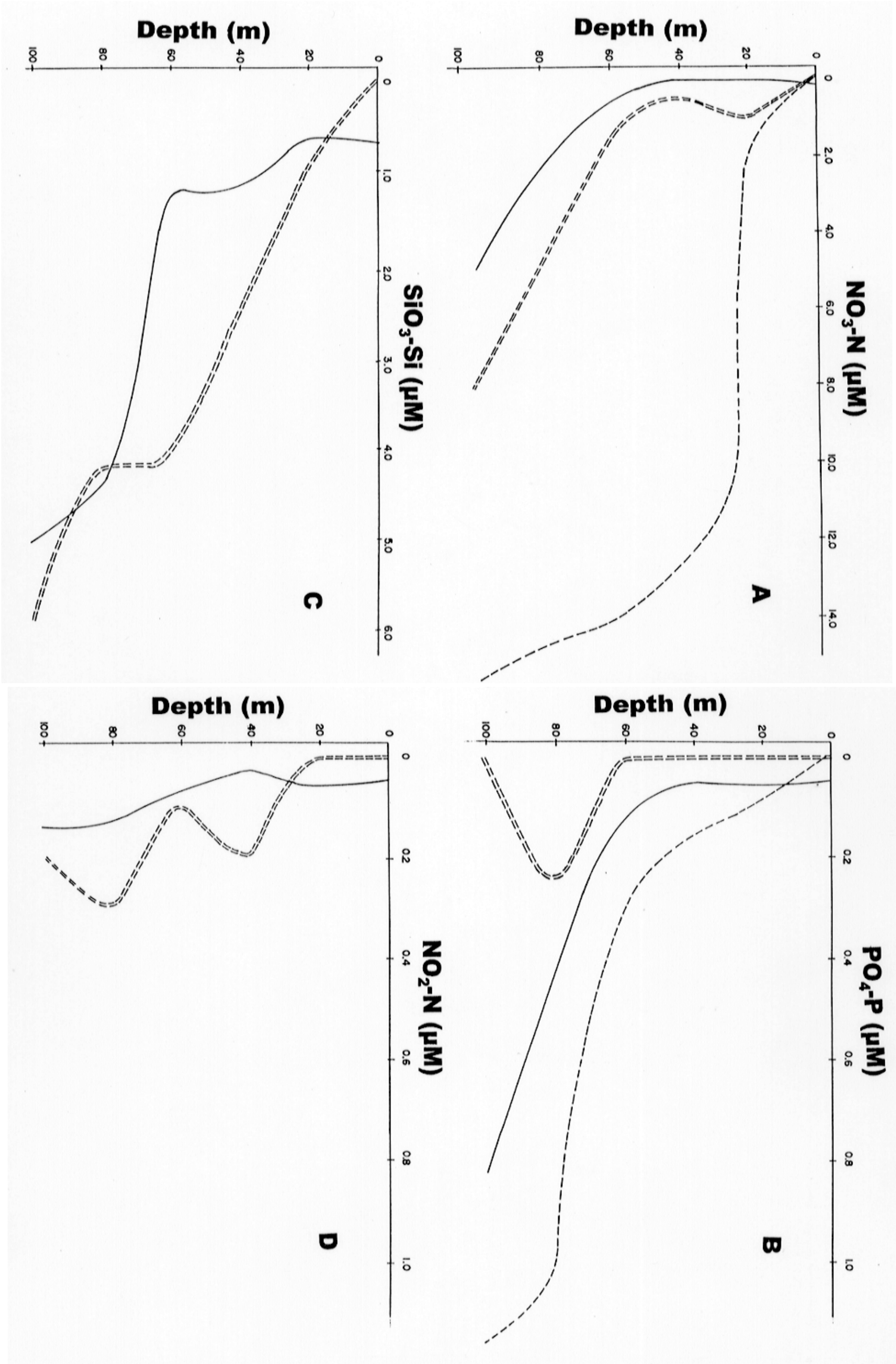

Fig. 15. The vertical profiles of (A) NO_3-N, (B) PO_4-P, (C) SiO_3-Si and (D) NO_2-N, in different occasions. (—) refer to 1998 summer average results, (- -) refer to December 1990 and (= =) for summer of 1967-68.

southern part of SCS, induced water circulation.

However, the absence of water circulation, off Zambales coast (15° and 16°N latitude) was the reason for the minimum nutrient and salinity (32.0 psu) levels, which could be a reason for its different water mass as reported by Uda et al. (1972).

Finally, the chemical hydrography from 11°-20°N and 117°-121°E, within 100 m confirmed similarities in hydrological structure though the values obtained were different as a result of different mixed layers due to current regimes, seasonal changes as well as the El Niño phenomenon. The present study also observed contrasts and similarities in temperature, salinity and D.O. between SCS and the Pacific side of the Philippine waters. Their hydrological profiles were different except for the surface D.O and temperature which were most likely due to the above cited phenomenon. The spatial and seasonal variability in the mixed layer area was attributed to fact that the SCS, particularly in the northeastern Luzon and northern Palawan are the converging zones of multi current system [Wyrtki (1961), Takenuoti (1970), and O'Niel and Eason (1982)]. The comparison made by Gong et al. (1992) confirmed that during NE monsoon, the area has a shallower mixed layer. At the same time, the area had relatively high nutrient stocks. Nutrient distribution was also dependent with hydrology particularly the nitrate and phosphate ion concentrations. These ions showed a direct relationship with hydrology based on several studies while silicate and nitrite failed to demonstrate direct relationship except with depth for silicates.

Also, it is possible that upwelling occurs in the location off northwestern Luzon, based on the hydro-chemical characteristics cited above. However, the finding is not yet conclusive and needs further verification to elucidate the seasonal water dynamics in the area.

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