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COASTAL AND OFFSHORE PRIMARY PRODUCTION ALONG THE WEST COAST OF THAILAND (ANDAMAN SEA) WITH NOTES ON PHYSICAL-CHEMICAL VARIABLES

by

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COASTAL AND OFFSHORE PRIMARY PRODUCTION ALONG THE WEST COAST OF THAILAND (ANDAMAN SEA) WITH NOTES ON PHYSICAL-CHEMICAL VARIABLES.

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ABSTRACT

Pelagic primary production (PP) data were obtained by the ^{14}C method. *In situ* incubations were made during March-April 1982 and January-February 1983 along the west coast of Thailand in coastal and offshore areas with depths from 8 to 77 m. PP was generally high in the northern area in 1983 compared to 1982 the opposite was found in the southern area. Mean PP was 821 mgC m^{-2} d^{-1} (range 305−2,440) in 1982, and 888 mgC m^{-2} d^{-1} (range 457−1,111) in 1983. Chlorophyll-*a* concentrations were slightly higher in the northern area in 1982 than in 1983 but much higher (> 50%) in the southern area during the same years.

Physical and chemical variables were measured but no correlation could be established at this stage with PP because of complicated, interrelated processes. Temperature-salinity relationships indicated a thermocline at 40 and 45 m depth in 1982 and 1983, respectively. Upwelling is suggested to be of importance for high levels of PP measured in the study area.

I. INTRODUCTION

During the past decades studies on coastal ecosystems have greatly intensified in temperate waters. In tropical waters, such as the Andaman Sea, knowledge accumulates at a more moderate speed in spite of the significance of these areas to marine fisheries.

The Andaman coast of Thailand is about 740 km long and the fishing area on the shelf is about 44,000 km^2, i.e. to a depth of 100 m where the edge of the shelf is located. The width of the

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shelf is approximately 90 km off the Ranong Province at the northern border to Burma; it narrows down to 30 km off Phuket Island and widens again to more than 240 km off the Satun Province at the southern border to Malaysia.

Wium-Andersen (1977) provided the only previous measurements of pelagic primary production (PP) in the waters around Surin Islands off Ranong. The results of a few measurements in April showed highly productive island waters but also a high offshore productivity of 690 mgC m^{-2} d^{-1}. The purpose of this study has been to expand the data base to encompass the whole fishing area on the shelf because fish production is a result of complicated, interrelated processes starting with PP. In the beginning of 1982 and 1983, physical-chemical parameters were measured, in addition to chlorophyll and PP, in order to study the suggested hypothesis of upwelling being responsible for a high PP (Wium-Andersen, 1977; Yesaki and Jantarapagdee, 1981). Concentrations of nutrients are generally low in clear tropical waters but upwelling (caused by wind displacement of surface water with deep water) can supply large quantities of nutrients. In spite of the importance of nutrients for the PP we are far from a full understanding of the processes responsible for inputs, outputs, and transformations that determine the concentrations of nutrients observed and few studies in shallow marine tropical environments have been carried out with a view to evaluate nutrient-productivity relationships. Testable hypotheses presuppose enough preliminary quantitative work to be able to ask interesting questions, for example, the relationship between PP and fish yield, or how much deep waters contribute to shallow water productivity in the Andaman Sea.

The present study has aimed at increasing knowledge of variation in nutrient concentrations and PP along the coast from Ranong to Satun in order to provide base-line information for future studies in this complex environment. In this respect the present study is along the line of the paper by Sundstrom *et al.* (1987). The data may be of interest to the Department of Fisheries and its ongoing work concerning management and resource utilization in the Andaman Sea.

II. MATERIALS AND METHODS

(a) THE STUDY AREA

Fisheries investigations in the study area take place within a grid consisting of 41 squares, each 15 × 15 square miles, along the Andaman coast from Burma to Malaysia. Measurements were made within this grid in March-April 1982 and January-February 1983 at 21 selected stations (Fig. 1, Table 1).

The study area has been divided into two sub-areas; a northern area with 12 stations from Ranong to the west coast of Phuket Island, and a southern area with 9 stations from the east coast of Phuket Island to Satun. Between Ranong and Phuket the stations 2, 4, 8 and 10 are referred to as deep offshore stations (65 to 77 m depth), and stations 1, 3, 5, 7, 9, 11, 13 and 16 as coastal stations (20 to 72 m depth; the depth increases gradually from north to south). Between Phuket and Satun the stations 17, 18, 23, 29, 32, 36 and 41 represent coastal stations (8 to 32 m depth) while stations 39 and 40 are referred to as shallow offshore stations (18 to 20 m depth).

The study area is influenced by distinct monsoons: dry season from November to March with winds from East-Northeast, and wet season from April to October with winds from West-Southwest (Yesaki and Jantarapagdee, 1981; Charuchinda and Hylleberg, 1984).

(b) METHODS

Measurements were made in accordance with Sundstrom *et al.* (1987). Each depth was sampled twice with a 1 litre fibreglass/stainless steel Ruttner sampler and mixed in a 2 litre plastic container before aliquots were used for incubations and analyses. Primary productivity

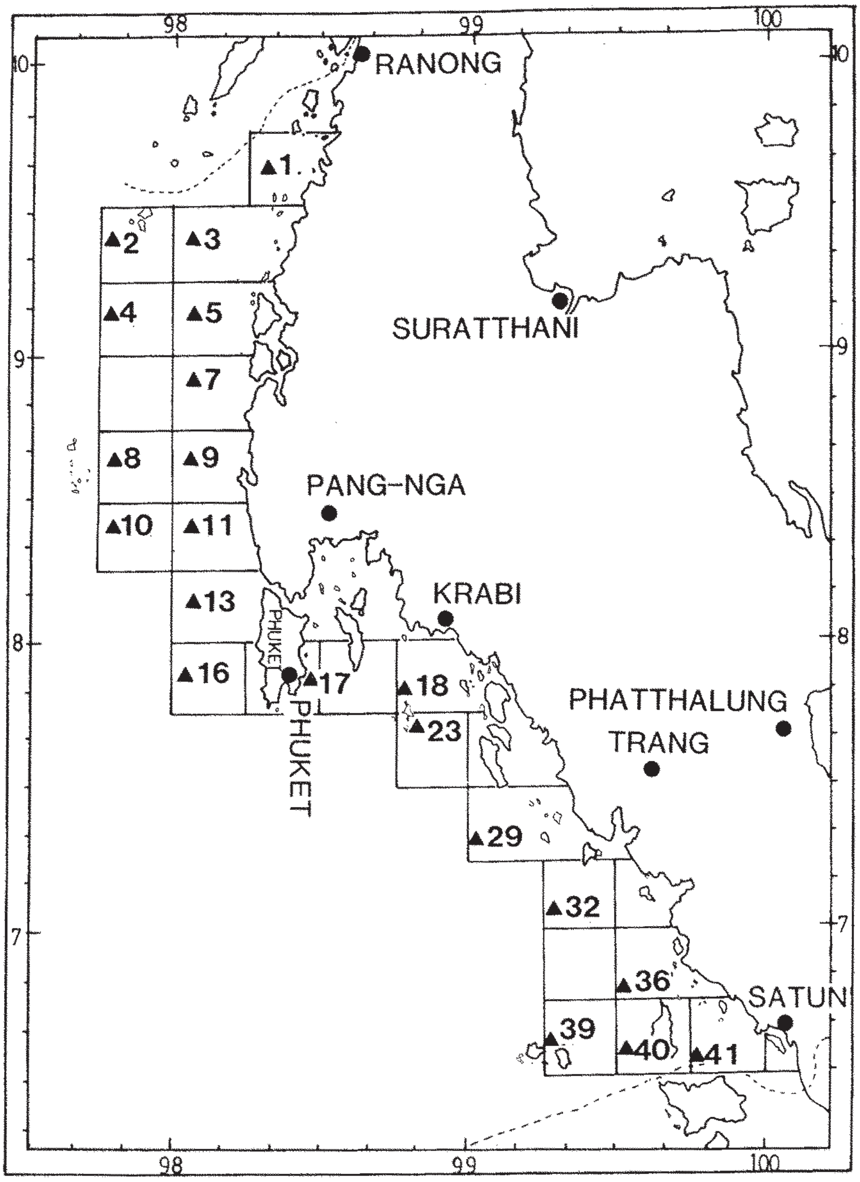

Fig. 1. The study area. Location of sampling sites. Twenty-one selected grids are located along the west coast of Thailand.

(PP) data were obtained by the C^{14} method. All experiments were carried out *in situ,* usually over a 4 hrs period around noon. Jena bottles (100 ml) were incubated at different levels according to the depth of the station. Dark bottles were placed at the 1 m depth and the deepest incubation depth. Approximately 4 µCi were added to each bottle (Ampoules from the ^{14}C-Center, Hørsholm, Denmark). After incubation the samples were filtered onto Sartorius membrane filters (0.2 µm pore size) and exposed to fumes of HCl and formalin before being dried. Activity counts were made by a Geiger-Müller counter. Selected filters were also

Table 1

Positions and depths of stations in the Andaman Sea included in the present study.

Station	Latitude (N)	Longtitude (E)	Mean depth (m)
1	9° 38′ 15″	98° 20′ 05″	20
2	9° 23′ 30″	97° 46′ 30″	73
3	9° 23′ 30″	98° 03′ 00″	38
4	9° 08′ 10″	97° 46′ 10″	75
5	9° 08′ 25″	98° 03′ 05″	48
7	8° 53′ 35″	98° 02′ 30″	42
8	8° 38′ 30″	97° 46′ 25″	65
9	8° 38′ 45″	98° 01′ 40″	50
10	8° 23′ 30″	97° 46′ 15″	77
11	8° 23′ 40″	98° 02′ 05″	60
13	8° 08′ 30″	98° 02′ 55″	66
16	7° 53′ 35″	98° 00′ 15″	72
17	7° 52′ 15″	98° 28′ 55″	26
18	7° 50′ 30″	98° 46′ 30″	23
23	7° 42′ 15″	98° 48′ 15″	24
29	7° 18′ 05″	99° 02′ 00″	21
32	7° 04′ 10″	99° 18′ 15″	32
36	6° 48′ 50″	99° 30′ 35″	17
39	6° 36′ 40″	99° 16′ 25″	20
40	6° 36′ 00″	99° 32′ 25″	18
41	6° 34′ 25″	99° 46′ 00″	8

counted in a liquid scintilation counter at the ^{14}C-Center for calibration. Calculation of hourly PP rates were made according to Strickland and Parsons (1968). Production per unit area (1 m^2) was calculated by integrating data from different depths. The transformation of hourly rates into daily production was made by multiplying the former with a factor expressed by the relation: daily irradiance/irradiance during incubation. Irradiance, as relative to the day maximum, was read every half an hour from 700 to sunset. Absolute values were not calculated.

For Chlorophyll-*a* determinations, 1000 ml aliquots were filtered onto Whatman GF/F or GF/C filters. A small amount of $MgCo_3$ in saturated aqueous solution was added during filtration. The filters were stored in a deep freezer and analyzed not later than 60 days after sampling. The filters were homogenized and pigments extracted in 90% acetone. Chlorophyll-*a* was determined spectrophotometrically following the equation of Jeffrey and Humphrey (1975).

Temperature, salinity and inorganic nutrient data (PO_4^{-3}, NO_3^{-1}, NO_2^{-1}) were collected at all sampling depths. Salinity was estimated by $AgNo_3$ titration, nutrients were measured spectrophotometrically according to Strickland and Parsons (1968) on a Spectronic 20 with 1 cm cells. Secchi disc readings were made at all stations and expressed as the average of the depths of disappearance and reappearance of the disc when lowered and hauled, respectively.

(c) ABBREVIATIONS

The following abbreviations are used:

- Pm^3 Primary productivity per m^3 and day ($mgC\ m^{-3}\ d^{-1}$)
- Pm^2 Primary productivity per day under a surface area of 1 m^2. Values were integrated from the surface to the bottom or to a designated depth ($mgC\ m^{-2}\ d^{-1}$)
- Pmax: Maximum primary productivity per m^3 and day during incubation ($mgC\ m^{-3}\ d^{-1}$)

III. RESULTS

(a) PHYSICAL AND CHEMICAL VARIABLES

(i) *Turbidity*

In the northern study area Secchi depth readings at coastal stations displayed small between year variation, although higher values were found at the deeper stations in 1983 (Fig. 2, Table 3). In 1982 readings ranged from 19 to 27 m, and in 1983 from 22.5 to 30 m with the exception of station 1 located near a river mouth. Here Secchi depth readings were 16.4 & 14 m in 1982 & 1983, respectively. At the off-shore stations Secchi depths were similar to coastal stations in 1982 (20.5 to 24 m) while readings in 1983 showed reduced transparency (18.5 to 21 m) compared with coastal stations at similar depth in this area.

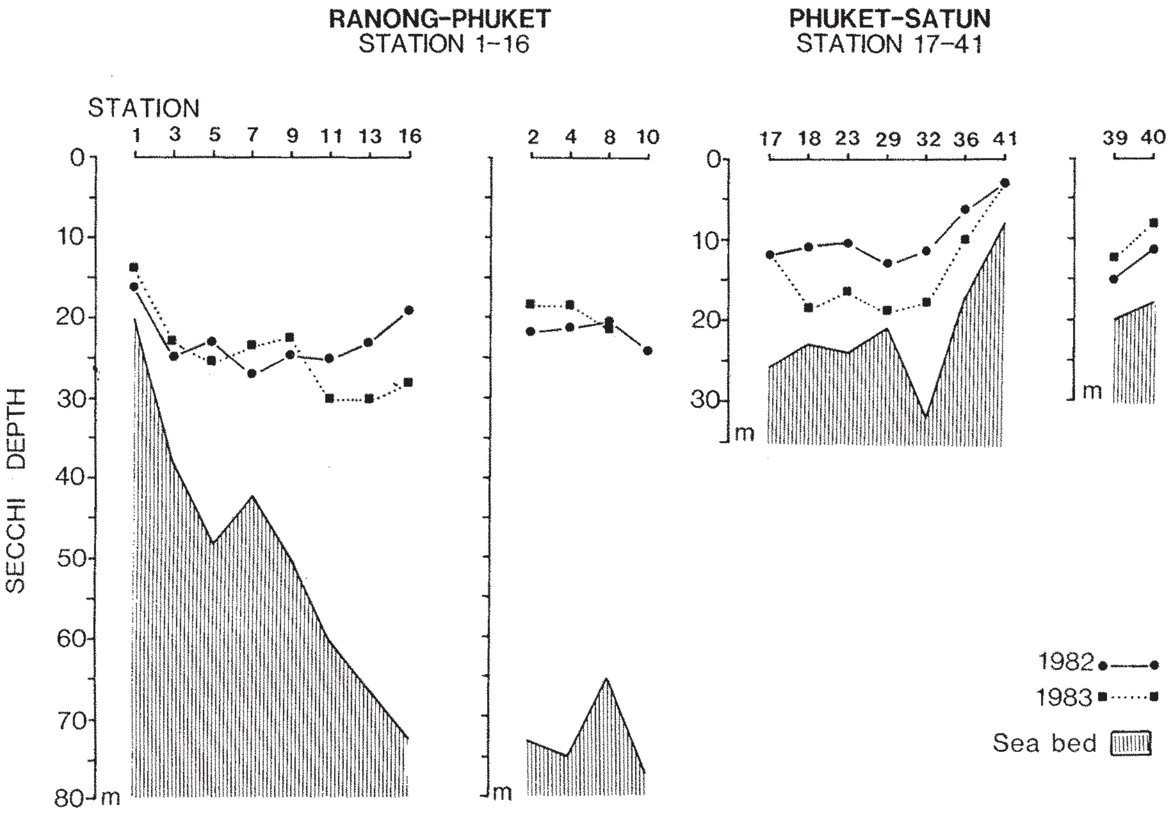

Fig. 2. Depths and Secchi depths from all stations in 1982 and 1983.

In the southern study area readings were generally lower at station 17 to 32 in 1982 compared with readings in 1983 (Fig. 2). The two shallow offshore stations 39 & 40 differed from the coastal stations in having slightly higher transparency in 1982 compared with 1983.

(ii) *Temperature*

Surface Water: In 1982 surface temperatures ranged from 27.6 to 28.9°C during March and April. In 1983 temperatures ranged from 25.6 to 27.2°C during January and February. Our values in 1982 were within the range reported by Yesaki and Jantarapagdee (1981) but the 1983 values were considerably lower than temperatures recorded in the same months in 1980 (Yesaki and Jantarapagdee, *op. cit.*).

It was characteristic for both cruises that differences between highest and lowest measurements only amounted to 1.3°C and 1.6°C, respectively.

Bottom water: In contrast to the surface, considerable variation was observed in bottom water temperatures. In 1982 the temperatures ranged from 20.0 to 21.8°C at depths between 60 and 77 m at the northern offshore stations (2, 4, 8, 10) and at some coastal stations (11, 13, 16). At depths between 38 and 50 m temperatures ranged from 22.4 to 26.7°C (St. 3, 5, 7, 9) while all other stations had warm bottom water ranging from 27.5 to 28.3°C (8 to 32 depth). In general, temperatures decreased with increasing depth. However, the northern coastal St. 13 was colder than should be expected from a depth-temperature relationship, indicating intrusion of deep water.

Bottom water temperatures displayed the same general tendency in 1983 as in 1982 although cold deep water was very pronounced at some stations. At depths from 65 to 75 m temperatures ranged from 18.4 to 19.6°C (St. 2, 4, 8, 13, 16). The depths from 38 to 60 m had temperatures from 20.8 to 24.0°C (St. 3, 5, 7, 9, 11) while the shallow stations between 8 and 32 m had temperatures from 24.6 to 26.4°C. The measurements indicated intrusion of deep water at St. 8 & 9 in the northern part of the study area.

(iii) *Salinity*

Surface water: In 1982 surface salinities ranged from 32.1 to 33.6‰ S, but the northern and southern areas differed markedly. North of Phuket Island salinities were 33‰, or higher, at coastal and offshore stations while salinities in the southern study area were lower than 33 ‰ S.

In 1983 this pattern was changed. Salinities higher than 33‰ (max. 33.5‰ S) were found at St. 1, 2, 4, 9 and 16 in the northern area and at St. 40 & 41 in the southern area. Salinities ranged from 32.1 to 32.9‰ at all other stations. In most cases the differences were small between samples from 1982 and 1983, except at St. 40 where salinities differed 1.2‰ between the two years.

Bottom water: In the northern area, salinities increased with depth in 1982 and 1983 with the exception of St. 1 & 5 where salinities in both years were 0.4 to 0.5‰ S lower at the bottom than at the surface. Lower salinities in bottom water were also found at St. 17 & 41 in both years, and St. 18 in 1982 and St. 40 in 1983.

In 1982 salinity profiles displayed less variation than in 1983, i.e. salinities increased or decreased more gradual with depth in 1982. In 1983 salinity profiles with maximum salinity at intermediate depths were recorded at St. 3, 5, 41 and 32, while St. 4, 7, 9, 11, 13 and 16 had minimum salinity at depths between 10 and 20 m.

(iv) *Temperature-salinity relationships*

Bottom water temperatures and salinities showed that two quite different water types characterized the photic zone above and below the thermocline.

In 1982 stations at bottom depths from 8 to 42 m had temperatures between 26.4 and 28.7°C and salinities between 32.4 and 33.6‰ S,

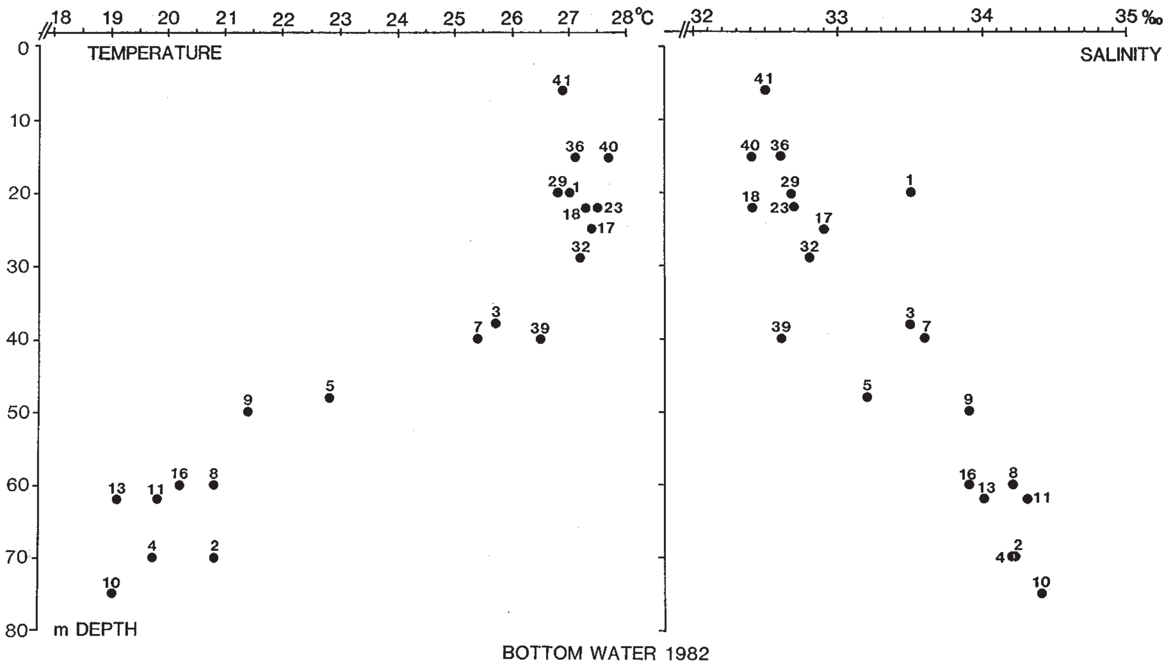

Fig. 3. Decreasing temperature and increasing salinity in bottom water from stations according to depths in 1982.

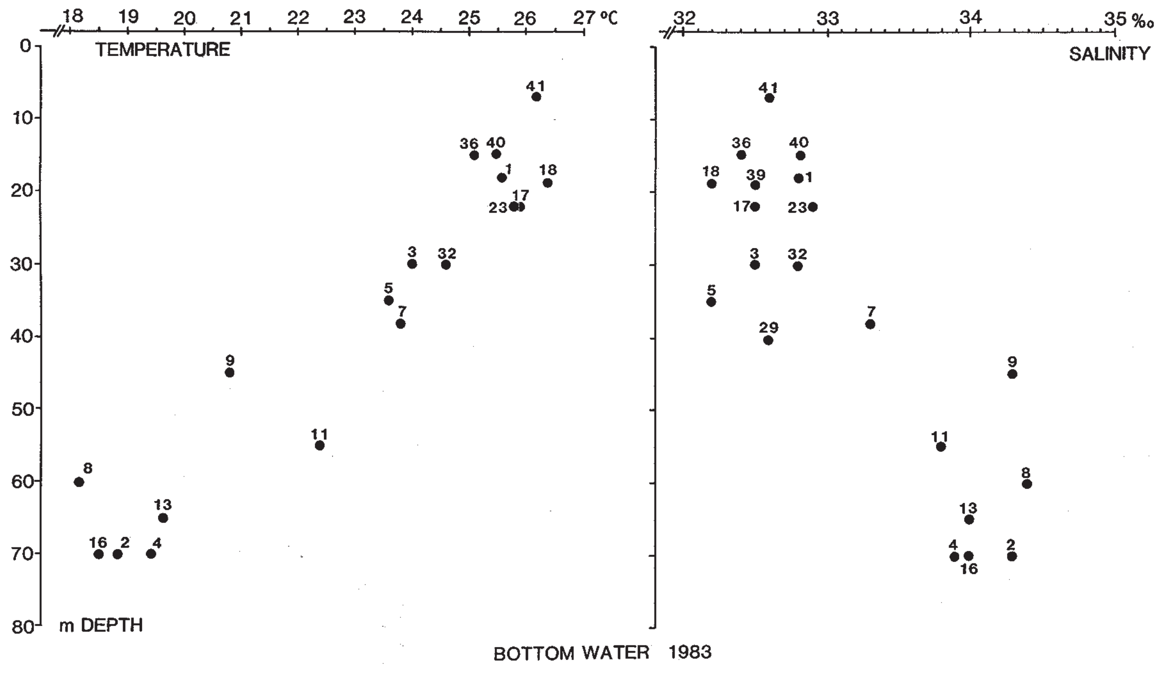

Fig. 4. Decreasing temperature and increasing salinity in bottom water from stations according to depths in 1983.

while stations at 48 to 75 m depth had temperatures between 20.0 and 23.8°C and sallinities between 32.2 and 34.4‰ S (Fig. 3). A similar pattern existed in 1983. Bottom depths of 8 to 40 m had water temperatures which ranged from 23.6 to 26.4°C and salinities from 32.2 to 33.3 ‰ S while bottom depths of more than 40 m had temperatures from 18.2 to 22.6°C and salinities from 33.8 to 34.4‰ S (Fig. 4).

In conclusion: warm, slightly brackish water was present at the bottom of shallow coastal stations while colder, more saline water characterized the bottom of offshore stations at depths exceeding 40–45 m.

(v) *Nutrients*

Inorganic nutrients are essential to the growth of primary producers. Where nutrients are found in low concentrations these elements are generally considered to limit the rate of growth. Low concentrations, sometimes below the level of detection, were commonly found in the present study. However, no correlation between PP and concentrations of nutrients could be established at individual stations or depths. Phosphate, nitrite and nitrate were measured in each sample.

Phosphate: The inorganic phosphorous concentrations varied from non-detectable to 5.68 µg-at P l^{-1} (Table 2). In 1982 relatively high concentrations were obtained in surface samples from 7 stations. At these stations values decreased to very low levels at depths between 3 and 30 m. Maximum concentrations were measured near the bottom (Fig. 5 & 6). This pattern of phosphate concentrations was mainly found at northern offshore and southern coastal stations. At 6 stations, concentrations were very low from the surface throughout the water column except in samples near the bottom. At 5 stations, concentrations increased from zero in the surface water to high values (max. 5.68 ug-at P l^{-1}) at depths between 5 and 10 m, then concentrations decreased, but high concentrations were again recorded in the bottom water. At 2 stations concentrations were rather uniform (0.2 to 0.4 µg-at P l^{-1}) throughout the profile while phosphate could not be detected at one station (St. 1). Similar variations, with respect to occurrence of high and low concentrations at specific depths, were measured in 1983. In conclusion, the analyses of inorganic phosphate showed that most stations had low concentrations in surface water and high concentrations near the bottom. Occasionally, concentrations were high at depths between 3 and 15 m. A few stations with non-detectable to very low concentrations from surface to bottom were encountered in shallow coastal areas (Table 2).

Nitrate: Concentrations of NO_3 ranged from non-detectable to 13.6 ug-at N l^{-1} in the study area. Similarly, considerable variation was found in the distribution of this nutrient at specific depths. In 1982 the most common pattern, shown in Fig. 5, was found at 18 stations. It was refound at station 16 in 1983 (Fig. 6) but otherwise there was much variation between profiles recorded in the two years.

In addition to the generally high bottom water concentrations (Figs. 5 & 6), high NO_3-N pool sizes were recorded in some surface samples (max. 6.36 µg-at N l^{-1} at 10 m depth). Generally, low concentrations were found at some shallow coastal stations in 1982 (St. 1, 3, 23) and in 1983 (St. 1, 17, 18, 23, 40) as shown in Table 2.

Nitrite: Concentrations of NO_2-N ranged from non-detectable to 0.8 µg-at N l^{-1} (St. 5 at 48 m depth, 1982). As for phosphate and nitrate the concentrations of nitrite varied considerably with depth and between the years 1982 and 1983. A general tendency was that high concentrations of nitrite were found in bottom water at offshore stations and to some extent correlated with high concentrations of nitrate and/or phosphate. However, this pattern had many exceptions. Samples with non-detectable levels of NO_3 could have up to 0.24 µg-at N l^{-1} of NO_2-N, and samples with high nitrate concentrations had low (even non-detectable) levels of

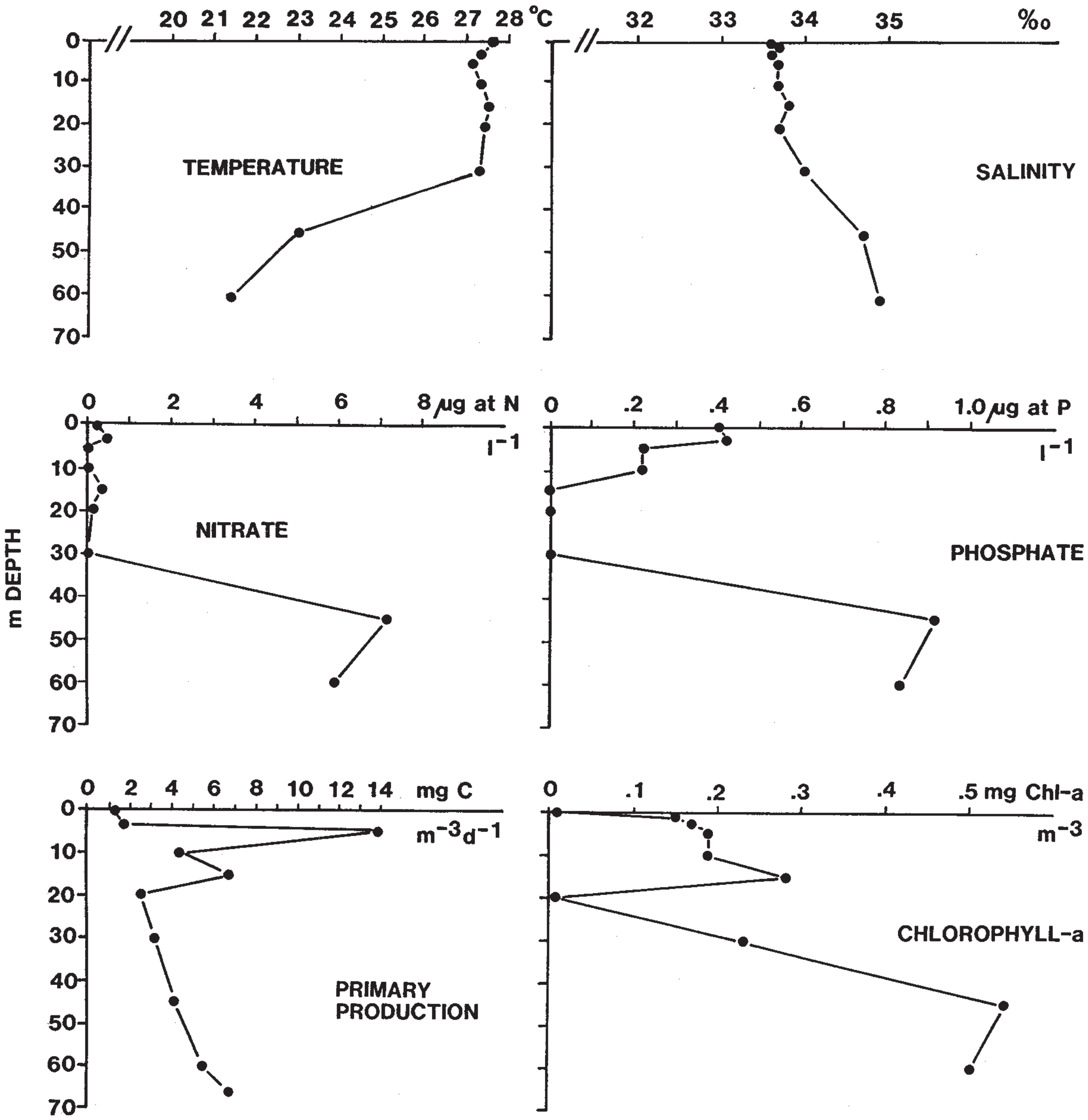

Fig. 5. Most common patterns of temperature, salinity, nitrate, phosphate, primary production and chlorophyll-*a* according to depths in 1982. (St. 16)

nitrite (Fig. 6). Shallow coastal stations, with the exception of St. 1, usually had concentrations of nitrite ranging from 0.1 to 0.4 µg-at N l^{-1} from surface to bottom.

(vi) *Carbonate carbon and pH*

Sundstrom *et al.*, (1987) estimated carbonate carbon at about 23,500 mgC m^{-3} in Phuket Island waters. This value was used in calculations of primary productivity in the present study. Limpsaichol *et al.*, (1987) measured pH during the two cruises. In 1982: pH averaged 8.08 ± 0.09, and in 1983: 8.18 ± 0.09. The pH values were highest in the surface and decreased with depth.

(b) PRIMARY PRODUCTION AND CHLOROPHYLL-A

(i) *Northern study area from Ranong to Phuket*

Primary production: At the offshore stations Pm^2 ranged from 441 to 695 mgC m^{-2} d^{-1} in 1982, and from 856 to 1,111 mgC m^{-2} d^{-1} in 1983 (Table

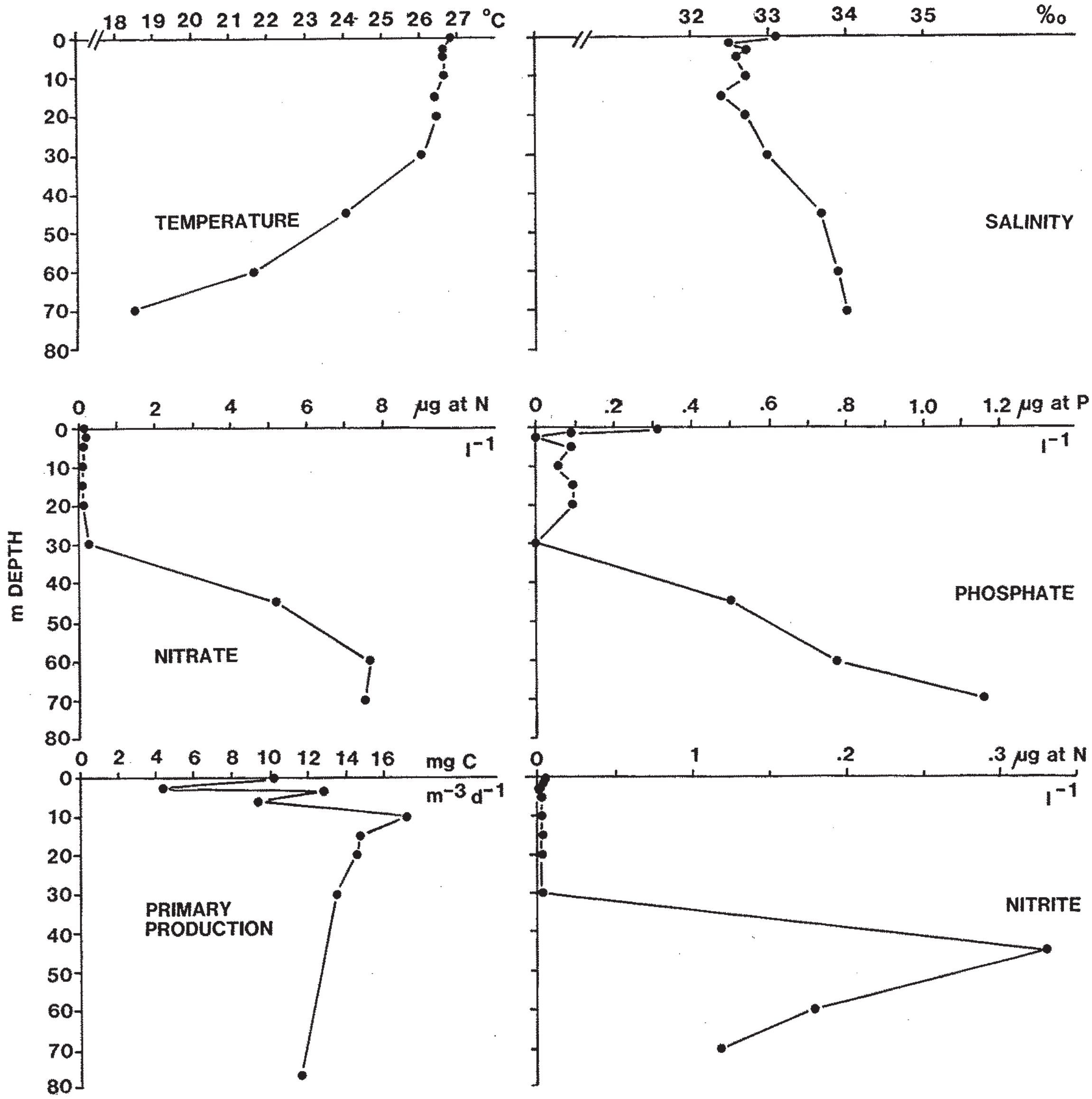

Fig. 6. Most common patterns of temperature, salinity, nitrate, phosphate, primary production and nitrite according to depths in 1983. (St. 16)

Table 2

Mean values and ranges of phosphate and nitrate concentrations estimated at offshore and coastal stations in 1982 and 1983. Date = year, month and day; $\bar{x}$ = mean; ND = non-detectable concentration.

STATION	DATE	PO_4^{-3} (µg at l^{-1})		NO_3^{-1} (µg at l^{-1})	
		$\bar{x}$	range	$\bar{x}$	range
Northern offshore					
2	820327	0.24	ND - 0.95	1.64	0.09 - 11.13
	830211	0.69	0.09 - 1.73	2.98	ND - 7.30
4	820328	0.21	ND - 1.25	2.31	ND - 13.65
	830213	0.49	0.18 - 0.96	2.35	0.33 - 6.47
8	820329	0.29	ND - 1.25	1.42	ND - 10.94
	830214	0.83	0.09 - 4.48	2.64	0.52 - 6.37
10	820330	0.39	ND - 1.32	3.63	0.02 - 13.60
Northern coastal					
1	820324	ND	ND	0.04	ND - 0.20
	830208	0.14	0.05 - 0.22	0.07	ND - 0.16
3	820308	0.06	ND - 0.22	0.09	ND - 0.19
	830207	0.31	0.05 - 0.62	0.74	ND - 0.77
5	820322	0.10	ND - 0.75	0.57	ND - 4.35
	830207	0.29	ND - 1.73	1.84	0.03 - 11.16
7	820320	0.15	0.05 - 0.86	0.16	ND - 0.74
	830206	0.19	ND - 0.71	0.95	0.02 - 3.84
9	820319	0.13	ND - 0.83	1.43	ND - 8.03
	830203	0.36	0.09 - 1.03	2.09	0.02 - 6.95
11	820318	0.21	ND - 1.25	1.60	ND - 10.62
	830203	0.32	ND - 1.16	1.51	0.03 - 7.33
13	820317	0.25	ND - 0.83	1.48	ND - 9.28
	830202	0.49	0.05 - 1.50	2.38	0.09 - 7.93
16	820316	0.34	ND - 0.91	1.41	ND - 7.07
	830201	0.29	ND - 1.16	1.96	0.07 - 7.60
Southern coastal					
17	820408	2.90	0.31 - 5.68	1.05	0.37 - 3.06
	830106	0.14	0.05 - 0.26	0.09	0.01 - 0.19
18	820423	0.36	0.22 - 0.54	0.34	0.01 - 1.67
	830107	0.10	ND - 0.22	0.07	ND - 0.14
23	820422	0.32	0.22 - 0.47	0.07	ND - 0.22
	830108	0.13	0.05 - 0.31	0.11	0.01 - 0.25
29	820409	0.83	0.42 - 1.57	2.88	0.57 - 7.31
	830109	0.23	ND - 1.12	0.93	0.02 - 6.89
32	820410	1.13	0.26 - 3.04	2.22	0.50 - 6.36
	830111	0.17	0.05 - 0.31	0.36	ND - 2.48
36	820411	0.79	0.26 - 1.87	0.31	0.06 - 0.72
	830112	0.28	0.14 - 0.58	0.41	0.21 - 1.05
41	820412	0.43	0.34 - 0.50	0.49	0.10 - 0.98
	830114	0.21	0.09 - 0.31	0.04	ND - 0.10
Southern shallow offshore					
39	820414	0.46	0.22 - 1.46	0.33	0.11 - 1.07
	830113	0.25	0.09 - 0.38	0.78	0.53 - 1.52
40	820414	0.48	0.30 - 1.12	0.52	0.08 - 2.65
	830113	0.24	0.14 - 0.34	0.55	0.45 - 0.71

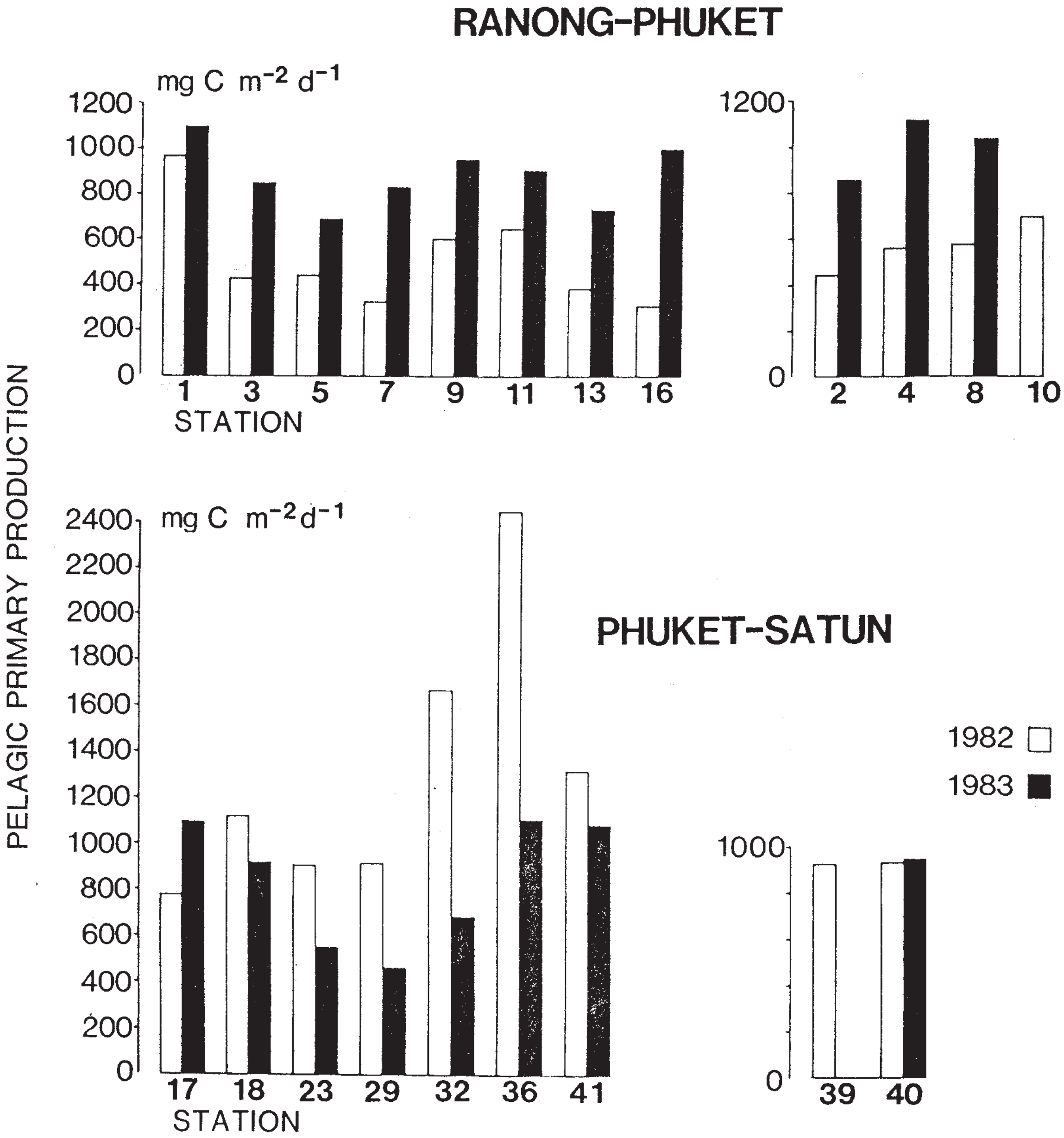

Fig. 7. Pelagic primary production (mgC) per day per unit area (m^2) to deepest depths from all stations in 1982 and 1983.

3). At the coastal stations Pm^2 ranged from 305 to 965 mgC m^{-2} d^{-1} in 1982, and from 682 to 1,091 mgC m^{-2} d^{-1} in 1983 (Fig. 7). Primary production measurements (Pm^3) at individual stations and depths are shown in Fig. 8.

Pmax: At the offshore stations Pmax ranged from 11.0 to 22.0 mgC m^{-3} d^{1} in 1982, and from 28.3 to 32.8 mgC m^{-3} d^{1} in 1983 (Table 3). At the coastal stations Pmax ranged from 11.6 to 103.8 mgC m^{-3} d^{-1} in 1982, and from 17.0 to 187.9 mgC

Table 3

Mean values and ranges of Chlorophyll-*a*, primary production (Pm^2), Pmax, and depth of Pmax estimated at offshore and coastal stations in 1982 and 1983, Date = year, month and day; $\bar{x}$ = mean: ND = non-detectable concentration.

STATION	DATE	Chlorophyll-*a* ($mg\ m^{-3}$) $\bar{x}$	Chlorophyll-*a* ($mg\ m^{-3}$) range	Pm^2 ($mgC\ m^{-2}\ d^{-1}$)	Pmax ($mgC\ m^{-3}\ d^{-1}$)	Pmax depth (m)	Secchi depth (m)
Northern offshore							
2	820327	0.12	0.03 – 0.34	441	11.0	20	21.9
	830211	0.17	0.04 – 0.13	856	28.3	3	18.5
4	820328	0.14	0.07 – 0.39	558	11.2	15	21.1
	830213	0.19	0.08 – 0.41	1111	29.8	15	18.5
8	820329	0.17	0.04 – 0.39	575	17.1	20	20.5
	830214	0.21	0.12 – 0.33	1032	32.8	15	21.5
10	820330	0.15	0.11 – 0.27	695	22.0	surf	24.0
Northern coastal							
1	820324	0.34	0.20 – 0.94	965	103.8	20	16.4
	830208	0.45	0.23 – 1.20	1091	187.9	19	14.0
3	820323	0.18	0.07 – 0.51	426	16.6	30	25.0
	830207	0.20	0.08 – 0.59	842	33.8	30	23.0
5	820322	0.17	0.03 – 0.59	438	17.8	48	23.0
	830207	0.14	0.03 – 0.27	682	22.2	20	25.5
7	820320	0.11	0.04 – 0.26	322	13.4	42	27.0
	830206	0.20	0.07 – 0.41	824	25.9	20	23.5
9	820319	0.29	0.04 – 1.16	599	22.7	40	24.5
	830203	0.23	0.04 – 0.58	948	37.0	15	22.5
11	820318	0.24	0.08 – 0.82	642	24.9	45	25.0
	830203	0.15	ND – 0.44	899	27.0	20	30.0
13	820317	0.18	0.04 – 0.51	382	11.6	45	23.0
	830202	0.16	ND – 0.60	725	18.6	20	30.0
16	820316	0.24	0.08 – 0.54	305	13.8	5	19.0
	830201	0.13	0.04 – 0.34	993	17.0	10	28.0
Southern coastal							
17	820408	0.26	0.15 – 0.34	776	45.6	10	12.0
	830106	0.49	0.04 – 0.56	1098	57.3	5	11.5
18	820423	0.54	0.36 – 0.79	1120	65.8	15	10.9
	830107	0.29	0.22 – 0.35	913	46.9	23	18.5
23	820422	0.28	0.20 – 0.37	903	58.3	1	10.4
	830108	0.26	0.17 – 0.40	548	33.9	surf	16.5
29	820409	0.63	0.17 – 2.68	911	138.0	21	13.0
	830109	0.19	0.11 – 0.37	457	24.8	5	18.8
32	820410	0.99	0.31 – 3.11	1665	83.5	15	11.3
	830111	0.26	0.19 – 0.47	680	33.2	5	17.8
36	820411	1.71	1.56 – 1.88	2440	239.6	5	6.3
	830112	0.85	0.66 – 1.17	1101	78.4	5	10.0
41	820412	1.67	1.44 – 1.92	1315	279.7	1	2.8
	830114	1.43	1.05 – 1.90	1080	156.3	2	3.0
Southern shallow offshore							
39	820414	0.24	0.08 – 0.91	–	–	–	15.0
	830113	0.33	0.31 – 0.36	926	70.8	3	12.3
40	820414	0.60	0.16 – 2.19	932	196.0	18	11.3
	830113	0.64	0.39 – 1.04	944	100.5	5	8.0

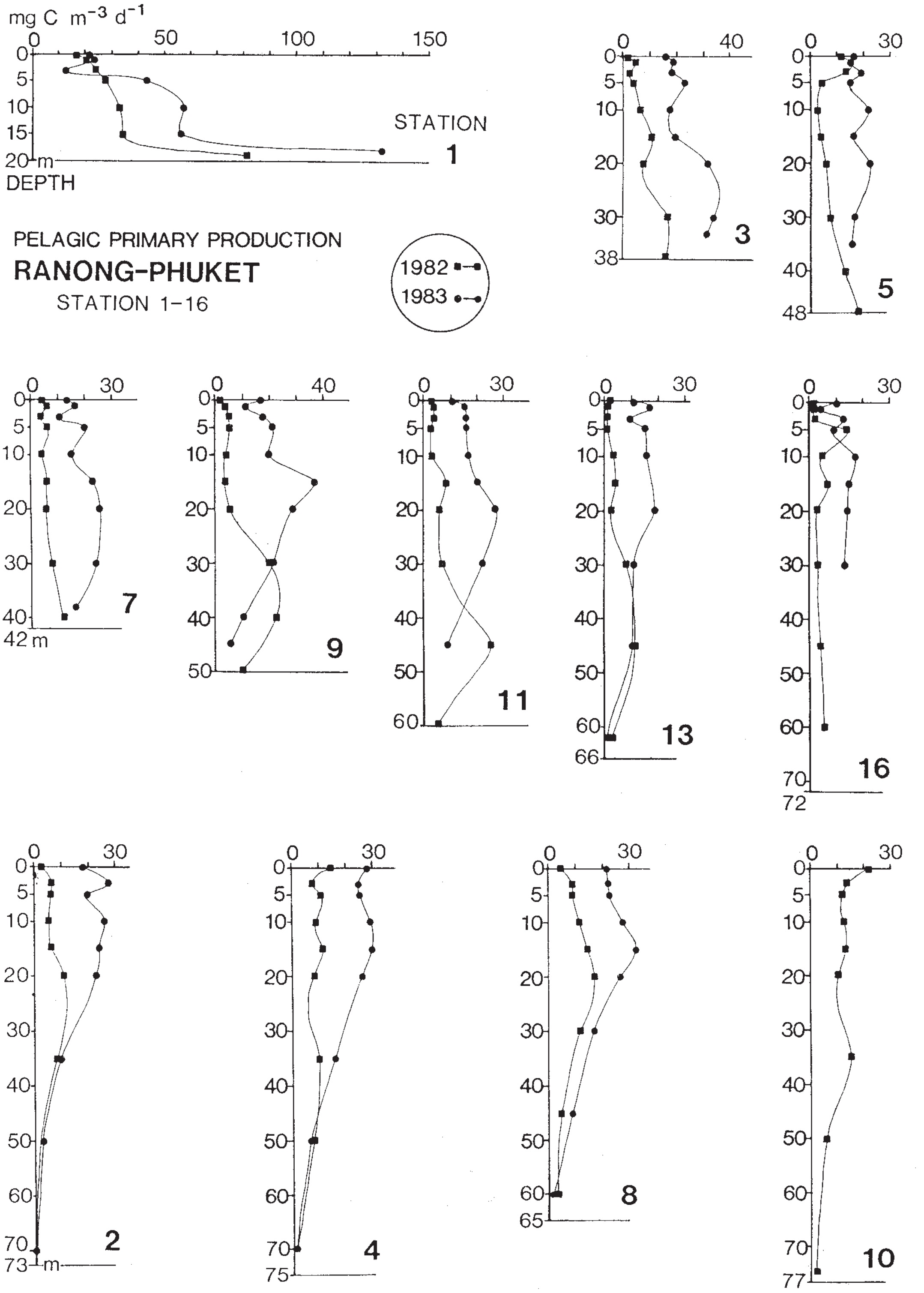

Fig. 8. Pelagic primary production (mgC m^{-3} d^{-1}) as a function of depth (m) from Ranong to Phuket (station 1–16) in 1982 and 1983.

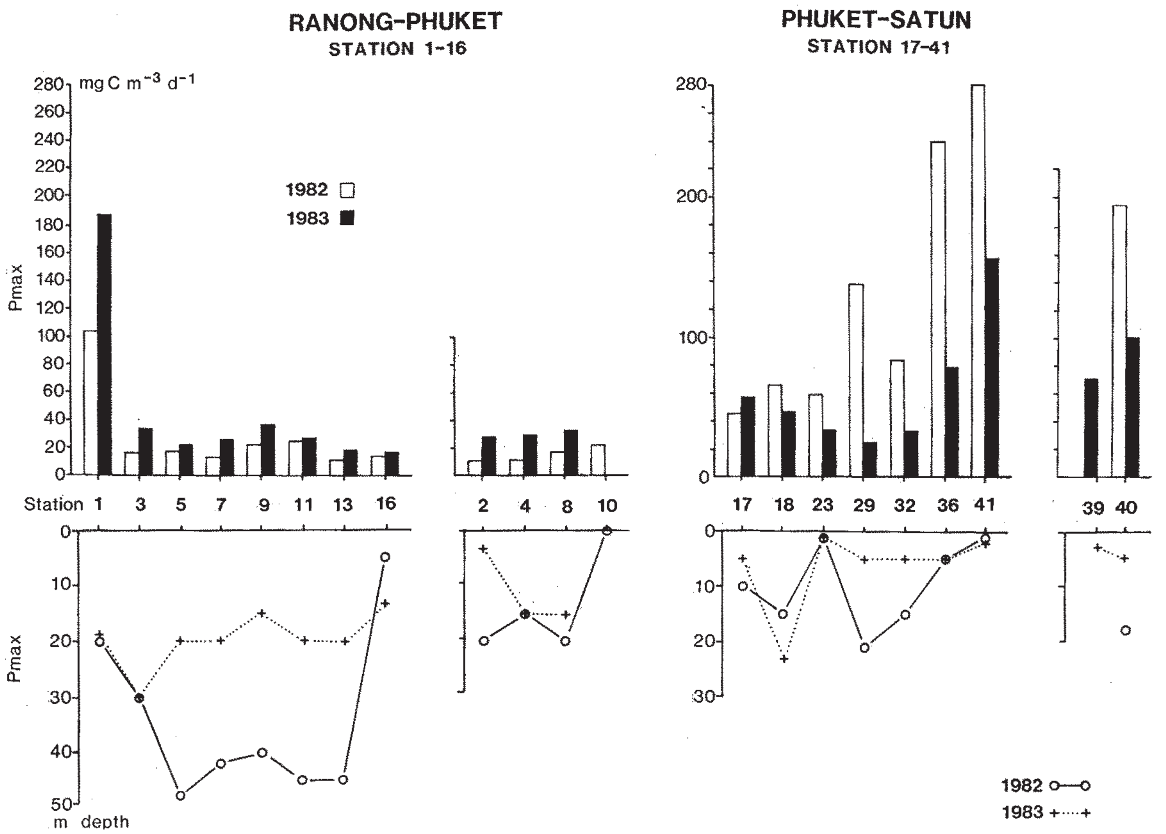

Fig. 9. Maximum primary production (Pmax: mgC m^{-3} d^{-1}) and its depth occurrence from all stations in 1982 and 1983.

m^{-3} d^{-1} in 1983. Depth of Pmax ranged from the surface to 45 m depth. The data are summarized in Fig. 9.

Chlorophyll-a (Chl_a): At the offshore stations Chl_a ranged from 0.03 to 0.39 mg m^{-3} in 1982, and from 0.04 to 0.41 mg m^{-3} in 1983 (Table 3). At the coastal stations Chl_a ranged from 0.03 to 1.16 mg m^{-3} in 1982 and from non-detectable to 1.20 mg m^{-3} in 1983. Chl_a concentrations measured at individual stations and depths are shown in Fig. 10.

(ii) *Southern study area from Phuket to Satun*

Primary production: At shallow offshore stations only one measurement of Pm^2 was obtained in 1982 (932 mgC m^{-2} d^{-1}). In 1983 the values ranged from 926 to 944 mgC m^{-2} d^{-1} (Table 3). At the coastal stations Pm^2 ranged from 776 to 2,440 mgC m^{-2} d^{-1} in 1982, and from 457 to 1,101 mgC m^{-2} d^{-1} in 1983 (Fig. 7). Primary production measurements (Pm^3) at individual stations and depths are shown in Fig. 11.

Pmax: At the shallow offshore stations a value of 196 mgC m^{-3} d^{-1} was recorded in 1982. In 1983 measurements ranged from 70.8 to 100.5 mgC m^{-3} d^{-1} in 1983. At the coastal stations Pmax ranged from 45.6 to 279.7 mgC m^{-3} d^{-1} in 1982, and from 24.8 to 156.3 mgC m^{-3} d^{-1} in 1983 (Table 3). Depth of Pmax ranged from 1 to 21 m in 1982, and from the surface to 23 m depth in 1983. Pmax and depth of Pmax at individual stations and depths are summarized in Fig. 9.

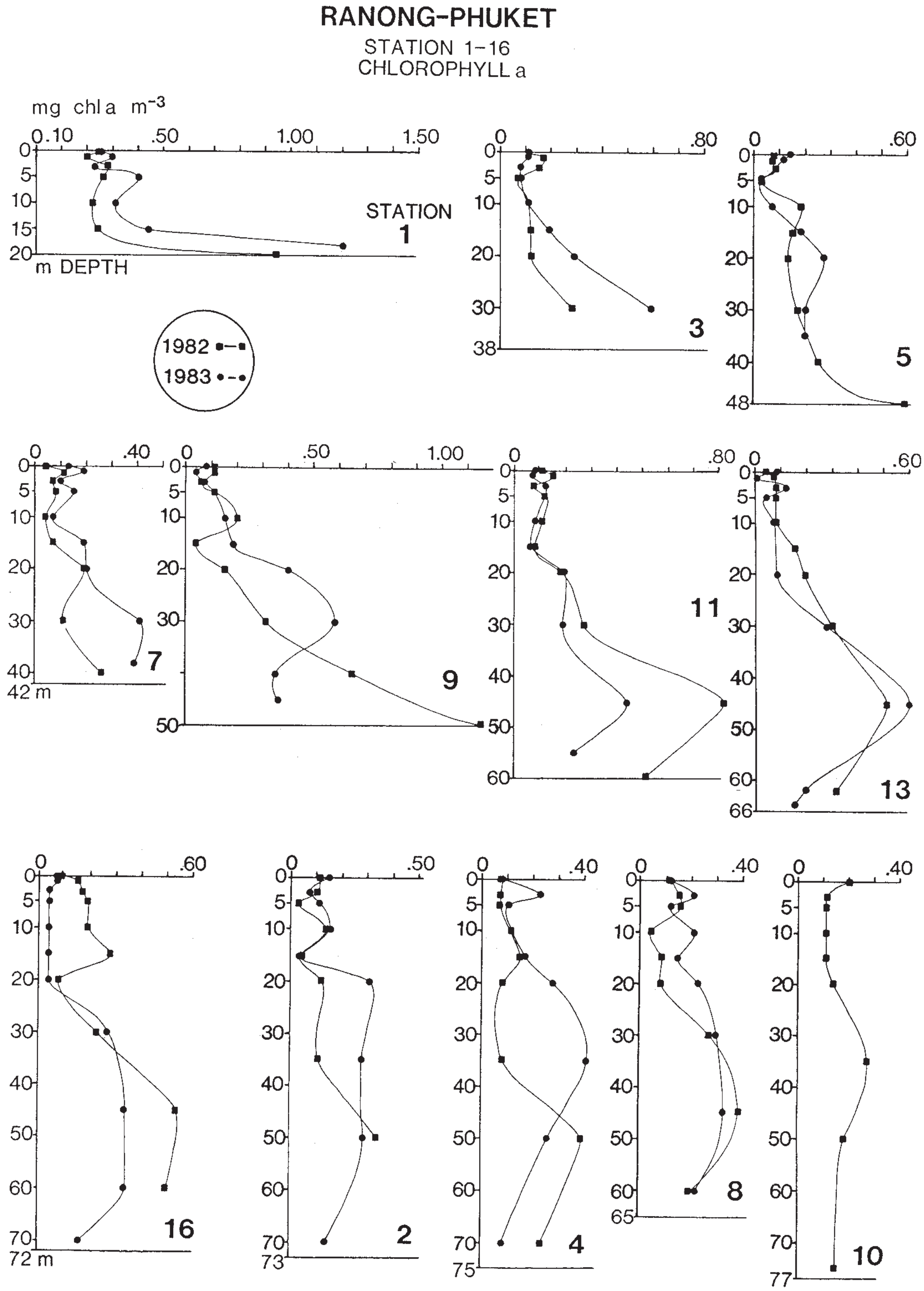

Fig. 10. Chlorophyll-*a* concentration ($mgChl_a\ m^{-3}$) as a function of depth (m) from Ranong to Phuket (station 1–16) in 1982 and 1983.

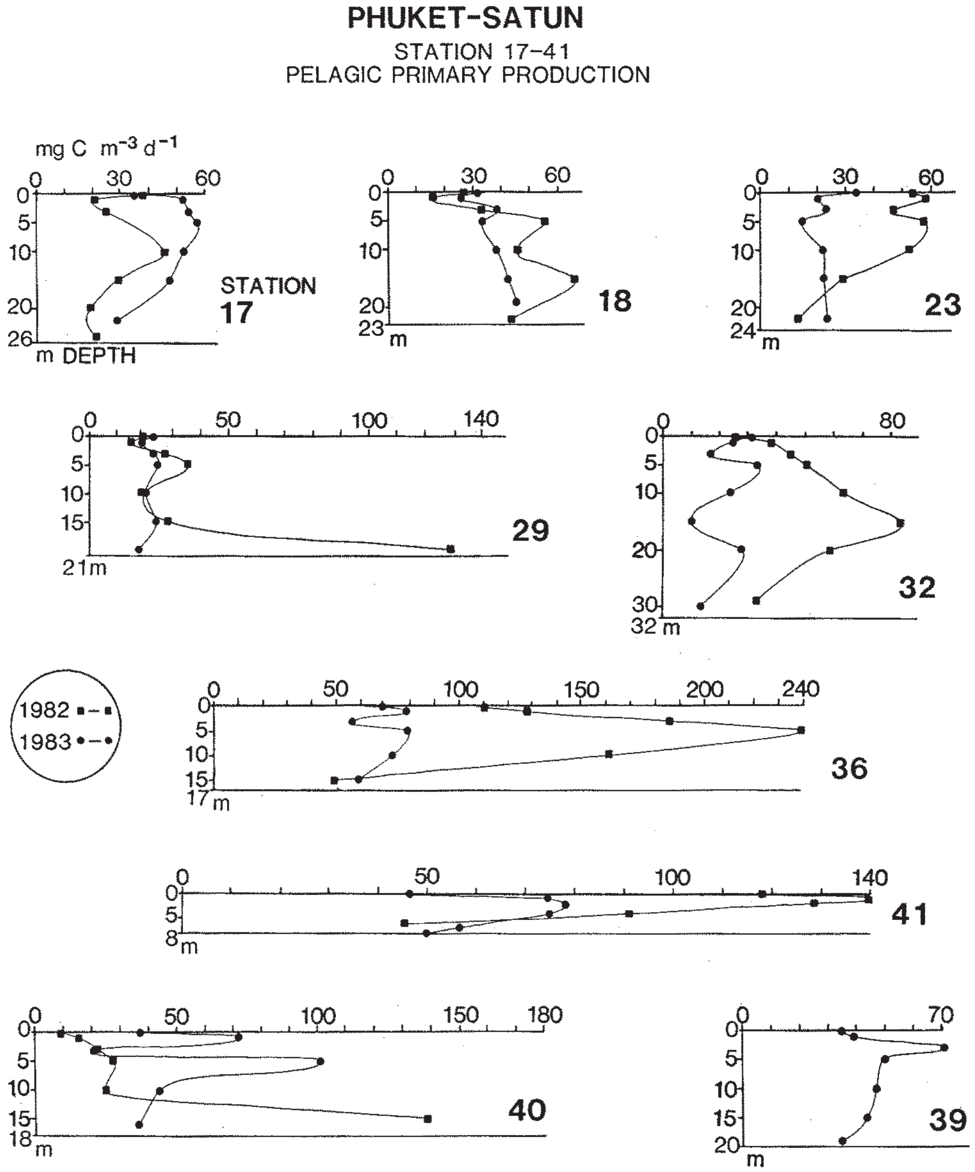

Fig. 11. Pelagic primary production (mgC m^{-3} d^{-1}) as a function of depth (m) from Phuket to Satun (station 17–41) in 1982 and 1983.

Chlorophyll-a (Chl_a): At the shallow coastal stations Chl_a ranged from 0.08 to 2.19 mg m^{-3} in 1982, and from 0.31 to 1.04 in 1983. At the coastal stations Chl_a ranged from 0.15 to 3.11 in 1982, and from 0.11 to 1.90 mg m^{-3} in 1983 (Table 3). Chl_a concentrations at individual stations and depths are shown in Fig. 12.

In summary, the measurements of primary production showed that Pm^2 was about two times higher in 1983 compared with 1982 in the northern study area from Ranong to Phuket. In the southern area from Phuket to Satun the opposite relationships were found when the two years are compared (Fig. 7). This pattern of difference with respect to year and area was also found in the Pmax values (Fig. 9). Pmax values were higher in 1983 in the northern study area and lower in the southern area compared with 1982. Regarding depth of Pmax the difference was less conspicuous. Generally, Pmax was found at greater depth in 1982 compared with 1983, especially in the northern area (Fig. 9). **The total Chl_a values do not match** the considerable difference in Pm^2 values. In

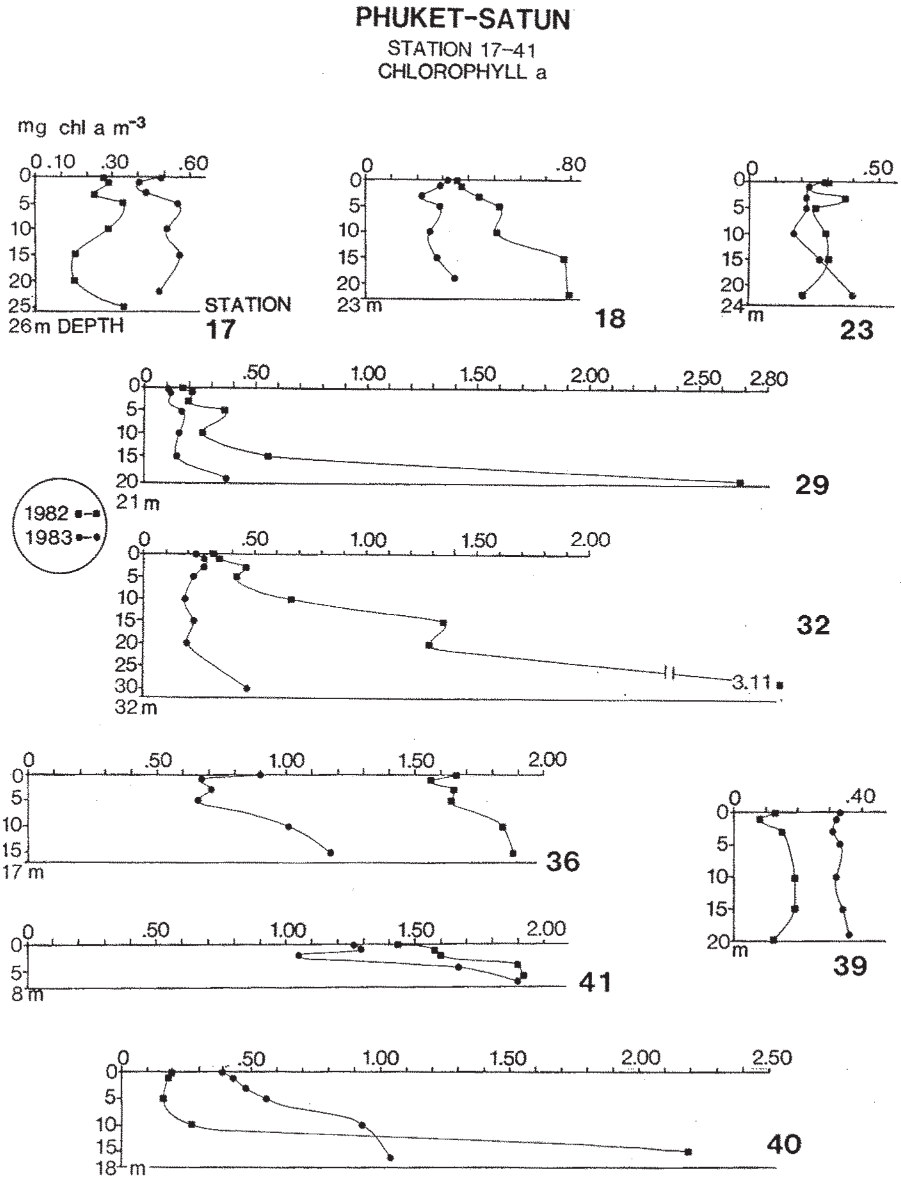

Fig. 12. Chlorophyll-*a* concentration (mgChl_a m^{-3}) as a function of depth (m) from Phuket to Satun (station 17–41) in 1982 and 1983.

1982 the average Chl_a concentrations were only slightly higher in the northern area compared to 1983. In contrast, the Chl_a values from southern area were about 50% higher in 1982 compared with 1983, in accordance with the higher Pm^2 measured in this area in 1982.

On account of the alternating nigh and low Pm^2 values in the northern and southern areas during 1982 and 1983, the average PP becomes nearly identical when calculated for the total Andaman coast from Ranong to Satun, *viz.* approximately 850 mgC m^{-2} d^{-1} equivalent to 300 gC m^{-2} per year. However, significant variation was found within the study area. In the northern part St. 1 had the highest Pm^2 in both years, on average 375 gC m^{-2} yr^{-1}, while St. 36 and 41 in the southern part were extremely productive with an average of 540 gC m^{-2} yr^{-1} during the two surveys.

IV. DISCUSSION

Production of organic matter in the sea is a result of complicated, interrelated processes. For the pelagic primary producers to flourish salinity, nutrient requirements, and physical factors such as light, temperature and water movement must be fulfilled.

In the present study we have considered total rate of primary production, transitory values of salinity and temperature, and actual pool sizes of Chl_a and nutrients, although it is clear that a better understanding of the processes would be possible if individual species participating in the PP and rates of nutrient transfer and regeneration had been studied. These aspects may be included in future investigations. Under the man-power and expenditure constraints of the Phuket Marine Biological Center we have been limited to carry out descriptive studies on hydrography and nutrient concentrations. Single stations, as we have been able to study them, do not yield data which are easy to interpret in terms of numerical explanations of the changes in time observed at these stations. The measurements themselves do not permit many conclusions in terms of cause and effect. However, the measurements have clearly demonstrated the patchiness of PP, and intriguing lack of correlation between nutrients, transparency and PP, in addition to the highly variable pool sizes of nutrients, spatially as well as with time.

In the following we will refer to some of the factors known to influence the physical-chemical environment and thereby the rate of primary production.

River runoff: Sub-surface water may be influenced by river runoff. Station 1 in the northern study area, and St. 36 & 41 in the southern area, are located near river mouths. Secchi disc readings were low at these stations when compared to other coastal stations (Fig. 2, Table 3). Part of the turbidity was caused by high levels of biomass (Table 3) and partly by output of silt-clay from the rivers. In spite of the low transparency these stations belong to the most productive in the study area. The Chl_a concentrations are also among the highest recorded during the two years of survey. The high PP at St. 36 is especially remarkable (Table 3). At this station measurements took place in front of a large mangrove swamp in shallow water close to the shore.

Characteristic for these productive stations is also the low concentrations of nitrate compared to phosphate, indicating conditions far from the optimal ratio of about 16:1 atoms N:P. Incidentally, nitrogen occurs to have limited the otherwise considerable PP.

Salinity-temperature: Vertical oscillations, usually referred to as internal waves, are present in all oceans. Internal waves cause cyclic changes in the position of the thermocline. Isotherms make vertical excursions of varying amounts (up to 15 m) which is important since the thermocline acts as an ecological boundary for many planktonic organisms. The complex motions associated with thermoclines play an important role in dispersing both nutrients and organisms in the sea.

Our measurements showed that a thermocline was found at 40 and 45 m depth in 1982 and 1983, respectively (Figs. 3 & 4). Some of the salinity-temperature variations recorded with depth at the offshore stations is probably due to internal waves.

Topography: Island promonteries, and spatial configuration of the shelf bottom, also influence the vertical and horizontal circulation of water in the Andaman Sea. When an island is in the path of a current, surface water tend to accumulate on the side of the island facing the current while localized upwelling of deep water occurs on the opposite side (down-current direction). A current.passing an island creates turbulence along its sides and eddies are formed in the wake. As a result, topographical features simultaneously influence the thermal structure, salinity and nutrient concentrations of the water, and thereby pelagic productivity.

Winds: One of the water motion processes considered most important to organic production is upwelling. It may occur anywhere the winds cause offshore displacement of surface water. To take its place, subsurface water upwells near shore, rising nutrient rich water to the surface layer. Furthermore, mechanical action of wind on the sea surface is important in terms of mixing the upper layers and bringing nutrients from the sub-surface to the surface layer.

The above transfer and mixing processes could be extended with convection currents, cyclonic eddies, tidal action and entrainment. We are unable to relate our data specifically to any of these processes. They have hardly been studied in the Andaman Sea. However, we realize that thermoclines in general constitute significant obstacles to upward transport of nutrients because of reduced turbulence and eddy diffusion. We conclude that powerful mechanisms must be in operation in order to maintain the high levels of PP and rather high concentrations of nutrients commonly recorded at 20−40 m depth above the thermocline especially during 1983. We suggest wind-driven upwelling and mixing as evidenced by Yesaki and Jantarapagdee (1981) to be the most important factors.

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