Sub-Thermocline Chlorophyll Maximum in the South China Sea, Area IV : Vietnamese Waters

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ABSTRACT

Shipboard measurement of chlorophyll a and b by HPLC system were carried out on the M.V. SEAFDEC Cruise No. 57/3-1999 from 21 April to 5 June 1999, in the South China Sea, Vietnamese waters. Chlorophyll a and b in surface water (2 m), seasonal thermocline below the mixed layer, chlorophyll maximum depth and sub-chlorophyll maximum depth from 58 stations in the studied area were investigated. Chlorophyll maximum depth ranged 7-90m and the concentration of chlorophyll a and b in this layer were 0.07-1.75 mg/m^3 and 0.003-0.31 mg/m^3 respectively. High concentration of chlorophyll a and b were observed in nearshore water which may reflected the effect of run off from the coastal cities and lower Maekong delta. Observed chlorophyll concentrations in this area agreed well with other values reported for tropical seas.

Key words: Primary production, Sub-thermocline, Chlorophyll maximum, South China Sea

Introduction

The phytoplankton provide the food base which supports directly or indirectly the entire animal population of the open oceans and they contribute significantly to climatic processes. Chlorophyll is the principal photosynthetic pigment of phytoplankton in the oceans. Measurement of chlorophyll have been used as indicator of biomass and productivity in marine environment for over 40 years. Chlorophyll a is a summarizing parameter of the pigment from several phytoplankton groups while chlorophyll b represents fewer phytoplankton groups [Jeffrey and Montura (1997)]. It has been assumed that concentration of chlorophyll b relative to chlorophyll a were low in marine system [Lorenzen (1981)].

Sub-thermocline chlorophyll maxima (SCM) are a well documented phenomena in tropic, subtropic and temperate seas. Many regions of the world's oceans show oligotrophic conditions during the period of vertical stratification and a deep chlorophyll maximum is frequently observed below the thermocline [Varela *et al.* (1992)]. Usually, SCM develops in water where or when the upper layer is stratified, primary production in the surface layer is limited by the availability of nutrients and photosynthetically active radiation penetrates into the nutrient- enriched water layer beyond the pycnocline. Lokman *et al*. (1988) studied the chlorophyll a content off the Sarawak waters of the South China Sea during the Matahari Expedition in 1987 and reported the range of chlorophyll a as 0.006-0.257 mg/m^3 and the SCM was observed at 60 m.

Ichikawa (1990) found that SCM in the South China Sea off Sabah occurred at 50 m and chlorophyll a ranged 0.14-0.43 mg/m^3. In the Gulf of Thailand, Musikasang (1999) also mentioned the occurrence of SCM. Strass and Woods (1991) have shown that the seasonal onset of oligotrophy after the spring bloom results in a poleward elevation of the SCM from a depth of about 60 m in the subtropic until it becomes an almost homogenous mixed layers in the subarctic.

The formation and maintenance of SCM have been regulated by many processes. In oligotrophic areas an approximate steady state requires balance between nutrient supply through vertical cross isopycnal mixing and export through sedimentation. Upwelled nutrient–rich coastal water often spreads at pycnocline depth and horizontal advection and isopycnal mixing enters the balance as well. Good growth conditions in a layer with both light and nutrients should favour phytoplankton species capable of regulating sink to avoid starvation in a nutrient–depleted surface layer and swimming to avoid the darkness deeper down [Djurfeldt (1994)].

There has been much debate concerning the SCM and a maximum in production/bio mass. In the Gulf of Mexico, Steele (1964) found that SCM did not correspond to a maximum in biomass but reflected the shade adaptation to lower light levels of the slowly sinking cells. Anderson (1969) on the other hand described a SCM made up of actively growing cells. Keifer and Kremer (1981) hypothesized that plankton community is locked in the developing stratification during the formation of the thermocline. In modern models, Varela *et al*. (1992) used physical–biological approach to study SCM. They concluded that the SCM depth and magnitudes is mainly determined by the vertical eddy diffusion and light extinction. The grazing parameters mainly affect the intensity of the SCM. They suggested that SCM is primarily the results of a balance between upward nutrient flux and light field characteristics. Regenerated production only plays a secondary role.

The objective of the present study is to collect information on the distribution of chlorophyll a and b in the South China Sea (Vietnamese waters) and attempt to elucidate the over all chlorophyll distributions in relation to marine fishery resources survey conducted by SEAFDEC member countries.

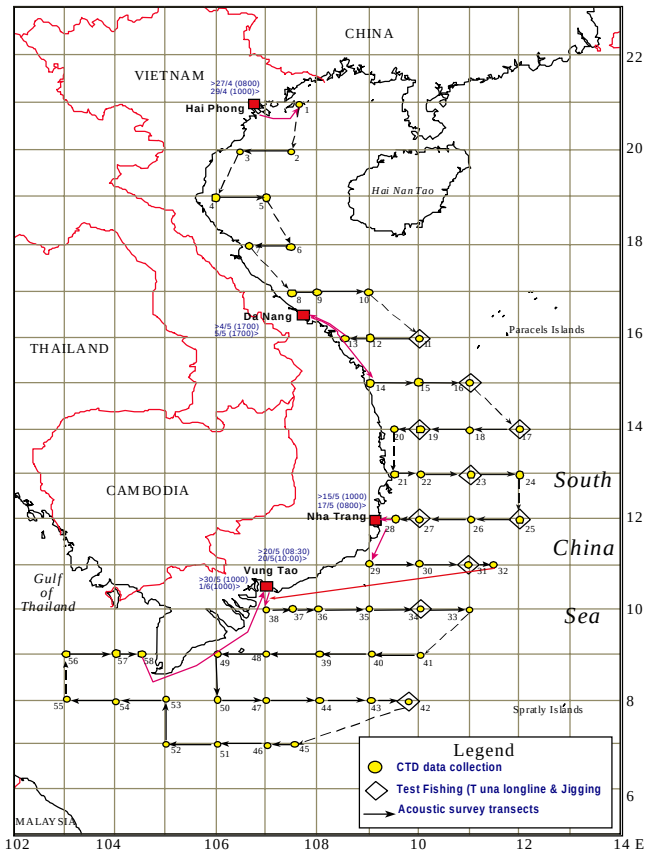


Fig. 1. Survey stations for M.V. SEAFDEC cruise No. 57/3-99 from 21 April-5 June 1999.

Materials and Methods

Sample collection. The present study is based on an oceanographic cruise of M.V. SEAFDEC conducted a survey between 21^0 00N, 107^0 55E and 8^0 95N 104^0 30E.[Fig.1] during 21 April to 5 June, 1999. Water samples from 58 stations were taken by 10 liters Vandorn water sampler at surface (2 m), seasonal thermocline (below the mixed layer), chlorophyll maximum depth and sub-chlorophyll maximum depth. The sampling depths were monitored through ICTD record at each station. The chlorophyll maximum depth for all stations were well below seasonal thermocline depths. The water samples of 2–5 liters were collected and prefiltered with plankton net of 300 mm mesh size then vacuum filtered through GF/F filters with 47 mm diameter under 10 inch of Hg in the dark place. Then the GF/F filters were blotted with tissue paper and wrapped with aluminium foil before keeping in glass vials and stored in freezer.

Sample extraction. Shipboard extraction of the collected samples were performed after filtration. The thawed GF/F filters were blotted dry with tissue paper and cut into small pieces. Then the filters were added with 2.5 ml Dimethylformamide [Furuya *et al*. (1998)] and ground with glass-Teflon homogenizer and kept in refrigerator for 30 minutes. Homogenates were centrifuged for 6 minutes and filtered with PTFE filters (Sartorius) with pore size of 0.2 mm. The filtrated DMF were kept in amber vials and stored in freezer for 1-3 days before commencing the analysis.

Sample analysis. The extracted samples were run by a Thermoseparation HPLC systems (a binary gradient pump, autosampler, UV detector, and degasser) filled with a 5 mm HiCHROM S5ODS (4.6x250 mm). HPLC grade reagents were used for all analysis. The pigment separated were identified on retention time of commercially available pigment (Chl a and b: Sigma USA.). Chlorophyll were quantified by peak area calibrated against that of the standard solution [Fig. 4]. The solvent programs of step-isocratic elution were as follow: Mobile phase, solvent A (MeOH: 0.5 M Ammonium Acetate; 80:20) and solvent B (MeOH:Acetone; 90:10). The first 3 minutes 100% solvent A got into the system followed by 100% solvent B for 15 minutes and again with solvent A for 5 minutes to equilibrate the system for the next sample. The flow rate was controlled at 1 ml/min and sample injection volume is 100 ml. The total running time of each sample was about 23 minutes.

Results

The concentration of chlorophyll a and b in this study were summarized in Table 1 and showed in Fig. 2 and Fig. 3 while bottom depth and sampling depth were reported in Table 2. The others physical parameter e.g. pH, dissolved oxygen, salinity and temperature were shown in Fig. 6, 7, 8, 9 respectively.

The surface layer. Concentration of chlorophyll a and b in the surface layer were shown in Fig. 2 and Fig. 3. In this layer, chlorophyll a and b ranged 0.006-1.75 mg/m^3 and 0.005-0.16 mg/m^3 respectively. Fig. 2 showed the spatial distribution of chlorophyll a in the surface water. It was cleared that near shore water had higher chlorophyll a than the off shore. Localized high chlorophyll a were observed at all major city along the coast of Vietnamese waters, among those cities, Vung Tao had the highest chlorophyll a concentration of 1.75 mg/m^3. Chlorophyll b also reflected the similar general patterns.

The thermocline layer. Chlorophyll a and b in this layer ranged 0.061-0.922 mg/m^3 and 0.002-0.103 mg/m^3 respectively. The spatial distribution of chlorophyll a and b were shown in Fig. 2 and Fig. 3. The general distribution is similar to those of surface layer. The thermoclines layer ranged 12-52 m.

The chlorophyll maximum layer. Chlorophyll a and b in this layer ranged 0.07-1.7 mg/m^3

and 0.003-0.31 mg/m^3 respectively. All chlorophyll a maximum concentration except at stations 10,13,14,16 had higher concentrations than the surface layer. Most of the chlorophyll b maximum in this layer had higher concentration than the surface layer. The spatial distribution of chlorophyll a and b in this layer were shown in Fig. 2 and Fig. 3. The depth of this layer ranged 7-90 m.

The sub-chlorophyll maximum layer. Concentration of chlorophyll a and b in this layer ranged 0.02-1.48 mg/m^3 and 0.01-0.195 mg/m^3 respectively. Their spatial distribution were shown in Fig. 2 and Fig. 3. The depth of this layer ranged 14-125 m but mostly exceed 100 m.

The magnitude of chlorophyll spatial distributions at various depths under this investigation were well within those values reported for the world oceans. Jeffrey and Montoura (1997) summarized that in the oligotrophic ocean gyres in surface water concentrations of chlorophyll was low (<0.05 mg/m^3) and their characteristic maxima at depth 100-150 m were 0.1-0.5 mg/m^3 but in the upwelling areas along continental shelf fronts and coastal sea and estuaries chlorophyll values ranged 1-10 mg/m^3.

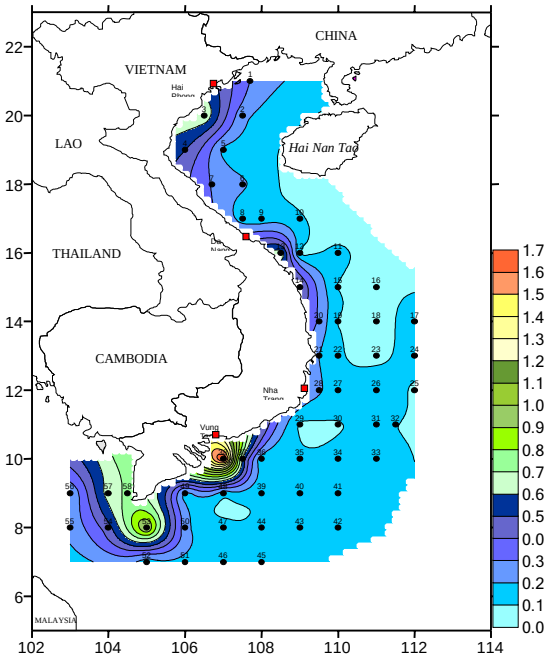
Spatial distributions of chlorophyll a and b in the South China Sea off Vietnamese Coast lead us to suggest the preliminary conclusion as the following:-

Conclusions

- Chlorophyll a and b reached their maximum value in the chlorophyll maximum layer, which observed mostly in the sub-thermocline layer.
- High concentration of chlorophyll a and b were observed in near shore water especially at station 38 (Vung Tao) which may reflected the effect of run off from the city and lower Maekong Delta.
- Chlorophyll a and b appeared to show no close correlation but chlorophyll b had much smaller concentration than chlorophyll a as had been reported.
- HPLC Chromatograms of the chlorophyll maximum samples had more pigments distribution than other investigated layers. This may indirectly attributed to the much higher phytoplankton diversity in this layer. Furthermore, HPLC technique may use as alternative approaches to identify phytoplankton groups. [Fig. 5 and Table 3].

Chlorophyll a in some tropical waters.

Area	Chlorophyll a (mg/m^3)	References
South China Sea	0.11-0.16	Marumo (1972)
Indian Ocean	0.16	Marumo (1972)
Philippine Sea	0.10-0.17	Marumo (1972)
Celebes Sea	0.10-0.27	Marumo (1972)
North of New Guinea	0.10-0.40	Wauthy (1972)
Off Southern Makassar Strait, Indonesia	0.4-0.7	Ilahude (1978)
Off Sarawak : SCS	0.006-0.257	Lokman *et al*. (1988)
Off Sabah : SCS	0.14-0.43	Ichikawa (1990)
Western Phillipines : SCS	0.10-0.18	Bajarias (2000)
Vietnamese Water : SCS	0.06-1.75	This Study



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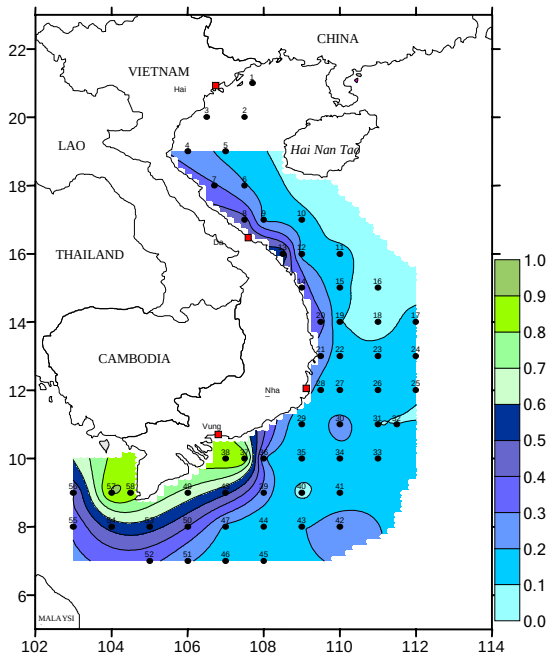
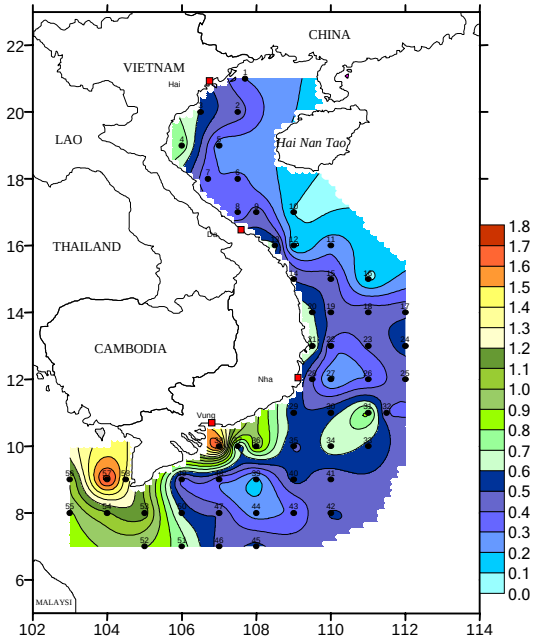
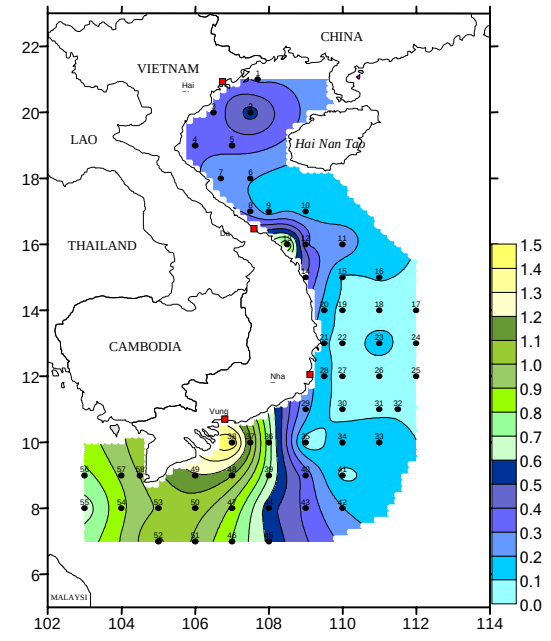


Thermocline

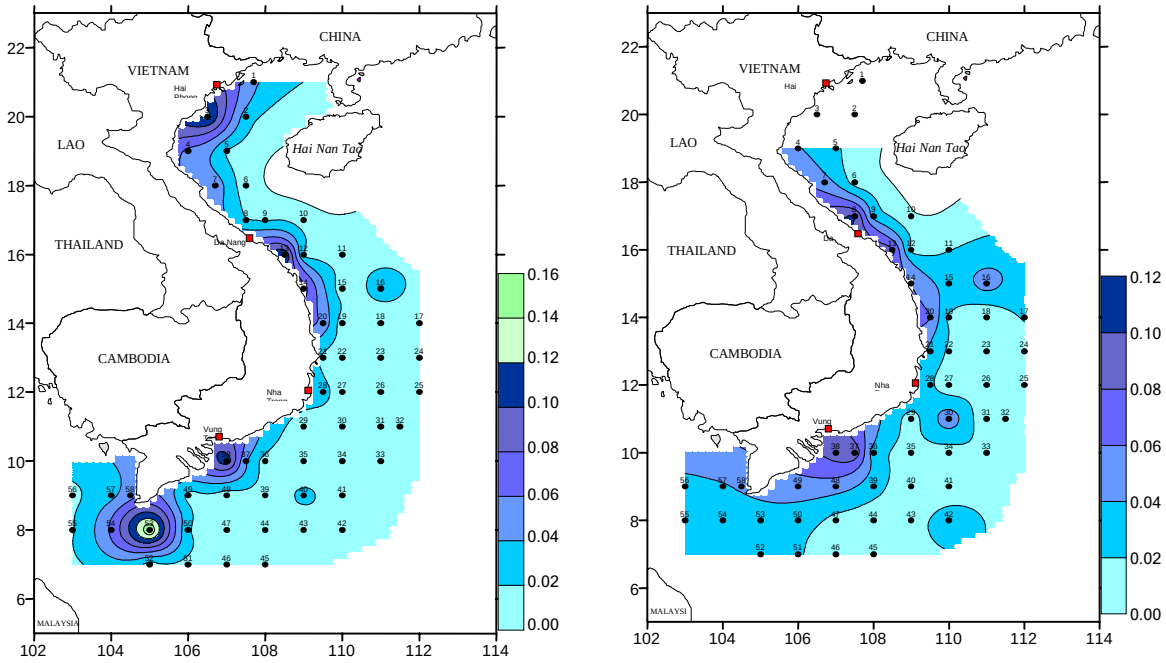


Chlorophyll maximum



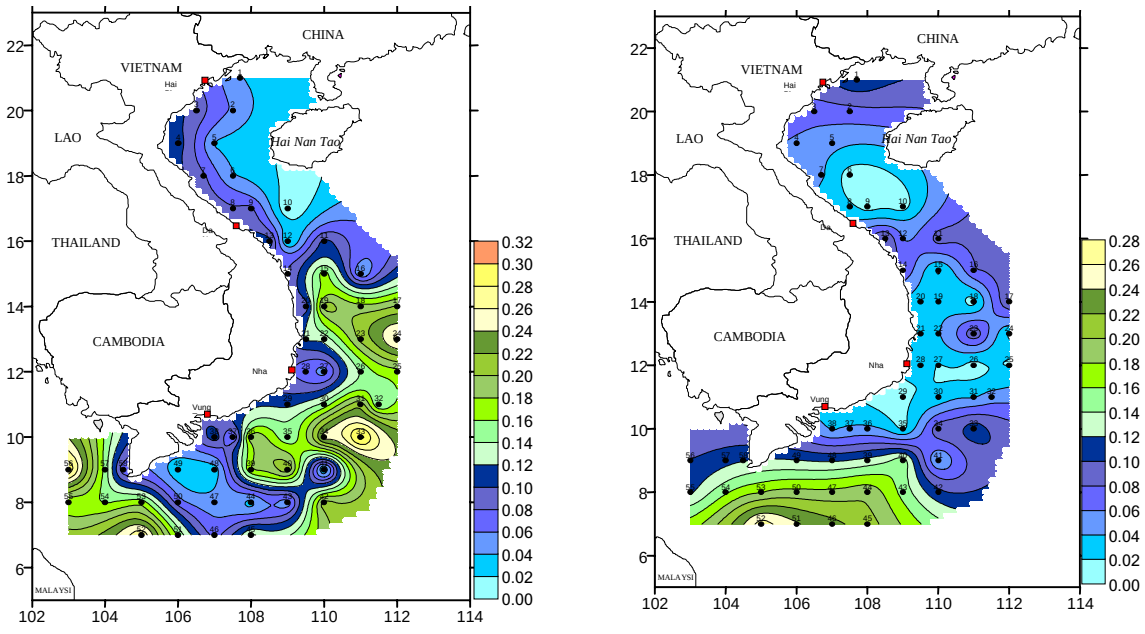
Sub-chlorophyll maximum

Fig. 2. Concentration of chlorophyll a (mg/m^3) at various sampling depths.



Surface

Thermocline



Chlorophyll maximum

Sub-chlorophyll maximum

Fig. 3. Concentration of chlorophyll b (mg/m^3) at various sampling depths.

Table 1. Concentrations of chlorophyll a and b (mg/m^3) at various depths.

Station	Surface		Thermocline		Chlorophyll maximum		Sub-chlorophyll maximum	
	Chl a	Chl b	Chl a	Chl b	Chl a	Chl b	Chl a	Chl b
1	0.297	0.044	-	-	0.297	0.041	0.278	0.116
2	0.234	0.029	-	-	0.456	0.058	0.548	0.072
3	0.692	0.127	-	-	0.591	0.093	0.348	0.069
4	0.502	0.054	-	-	0.777	0.109	-	-
5	0.172	0.018	0.167	0.024	0.233	0.038	-	-
6	0.224	0.008	0.208	0.011	0.332	0.042	0.210	0.011
7	0.293	0.054	-	-	0.316	0.083	0.227	0.044
8	0.146	0.020	0.445	0.103	0.293	0.082	-	-
9	0.144	0.017	0.177	0.031	0.460	0.085	0.136	0.011
10	0.116	0.009	0.134	0.002	0.088	0.003	0.144	0.012
11	0.126	0.014	0.123	0.020	0.293	0.107	0.267	0.089
12	0.079	0.015	0.141	0.015	0.082	0.015	0.320	0.057
13	0.672	0.121	0.580	0.086	0.647	0.113	0.905	0.103
14	0.504	0.088	-	-	0.487	0.080	0.403	0.077
15	0.091	0.008	0.122	0.033	0.460	0.170	0.090	0.017
16	0.087	0.032	0.085	0.050	0.071	0.040	0.110	0.078
17	0.142	0.008	0.127	0.022	0.487	0.203	0.083	0.100
18	0.062	0.005	0.061	0.002	0.474	0.188	0.045	0.010
19	0.088	0.009	0.104	0.014	0.452	0.212	0.065	0.033
20	0.289	0.056	0.346	0.063	0.612	0.082	0.168	0.029
21	0.197	0.015	0.246	0.037	0.728	0.124	0.120	0.024
22	0.116	0.009	0.157	0.016	0.327	0.126	0.060	0.039
23	0.074	0.005	0.128	0.001	0.425	0.207	0.155	0.098
24	0.132	0.008	0.162	0.018	0.537	0.269	0.025	0.017
25	0.086	0.000	0.103	0.016	0.452	0.172	0.032	0.019
26	0.176	0.014	0.134	0.013	0.304	0.142	0.038	0.013
27	0.104	0.008	0.107	0.008	0.179	0.049	0.064	0.019
28	0.226	0.027	-	-	0.413	0.070	0.133	0.030
29	0.084	0.006	0.109	0.013	0.528	0.114	-	-
30	0.098	0.018	0.249	0.056	0.562	0.146	0.064	0.026
31	0.102	0.007	0.100	0.005	0.853	0.215	0.080	0.038
32	0.101	0.006	0.100	0.008	0.389	0.135	0.086	0.051
33	0.131	0.012	0.160	0.017	0.570	0.311	0.163	0.113
34	0.133	0.010	0.184	0.011	0.662	0.249	0.188	0.095
35	0.121	0.011	0.149	0.015	0.480	0.139	0.032	0.014
36	0.137	0.012	0.201	0.028	0.996	0.198	-	-
37	0.552	0.041	0.904	0.096	0.505	0.051	-	-
38	1.750	0.113	-	-	1.750	0.113	1.485	0.037
39	0.118	0.014	-	-	0.154	0.181	-	-
40	0.196	0.024	0.079	0.011	0.542	0.219	0.358	0.154
41	0.108	0.014	0.141	0.014	0.421	0.011	0.079	0.035
42	0.178	0.013	0.259	0.025	0.510	0.212	0.203	0.105
43	0.155	0.011	0.195	0.017	0.311	0.046	0.376	0.152
44	0.124	0.009	0.103	0.008	0.250	0.031	0.538	0.195
45	0.122	0.008	0.141	0.011	0.536	0.146	-	-
46	0.129	0.008	0.140	0.003	0.465	0.071	-	-
47	0.132	0.010	0.179	0.014	0.498	0.051	-	-
48	0.127	0.009	-	-	0.321	0.028	-	-
49	0.151	0.013	-	-	0.344	0.025	-	-
50	0.241	0.022	-	-	0.584	0.069	-	-
51	0.160	0.013	0.211	0.023	0.748	0.155	-	-
52	0.125	0.010	-	-	0.909	0.279	1.115	0.272
53	1.029	0.162	-	-	1.157	0.173	1.006	0.179
54	0.454	0.064	-	-	1.078	0.157	-	-
55	0.230	0.018	0.313	0.025	0.872	0.162	0.642	0.116
56	0.200	0.015	0.396	0.035	0.991	0.300	-	-
57	0.648	0.034	0.923	0.038	1.702	0.153	-	-
58	0.712	0.052	-	-	1.350	0.064	-	-

Table 2. Bottom depth (m) and sampling depths (m) of chlorophyll samples.

St. No.	Bottom Depth	Thermocline	Chlorophyll maximum	Sub-chlorophyll maximum
1	34	-	22	30
2	29	-	20	25
3	28	-	7	20
4	26	-	20	-
5	58	25	54	-
6	80	30	45	70
7	40	-	25	35
8	45	25	40	-
9	75	29	45	70
10	107	45	72	100
11	847	52	90	125
12	105	40	65	90
13	42	-	15	30
14	36	-	10	30
15	462	42	75	100
16	1,230	40	88	125
17	2,100	20	80	120
18	2,200	20	60	100
19	653	32	82	125
20	143	-	40	100
21	134	-	45	100
22	1,910	35	88	125
23	2,703	20	70	125
24	3,332	20	65	125
25	4,117	20	70	125
26	2,889	15	84	125
27	1,734	20	75	125
28	110	-	45	100
29	72	-	60	-
30	648	35	50	125
31	2,940	12	62	125
32	3,897	14	73	125
33	3,385	26	80	125
34	1,614	25	90	125
35	156	42	80	125
36	45	-	40	-
37	32	-	27	-
38	21	-	2	14
39	62	-	55	-
40	129	25	82	100
41	1,250	22	75	125
42	654	25	85	125
43	147	20	75	-
44	79	25	50	75
45	61	-	55	-
46	51	-	46	-
47	42	-	38	-
48	32	-	26	-
49	20	-	16	-
50	33	-	28	-
51	44	-	39	-
52	51	-	35	46
53	34	-	16	28
54	26	-	22	-
55	70	25	48	65
56	57	-	50	-
57	34	-	29	-
58	23	-	19	-

Table 3. Classification of some phytoplankton groups by pigments.

Peak	Pigment	Occurrence	Colour
1	Chlorophyll $c_1+c_2+c_3$	Chromophyte algae, Prymnesiophytes, Chrysophytes	Light green
2	Divinyl chlorophyll b	*Prochlorococcus marinus*	Brown-green
3	Fucoxanthin	Diatoms, Prymnesiophytes,	Orange
4	Carotene	Cryptomonads, Chromophyte	Yellow-orange

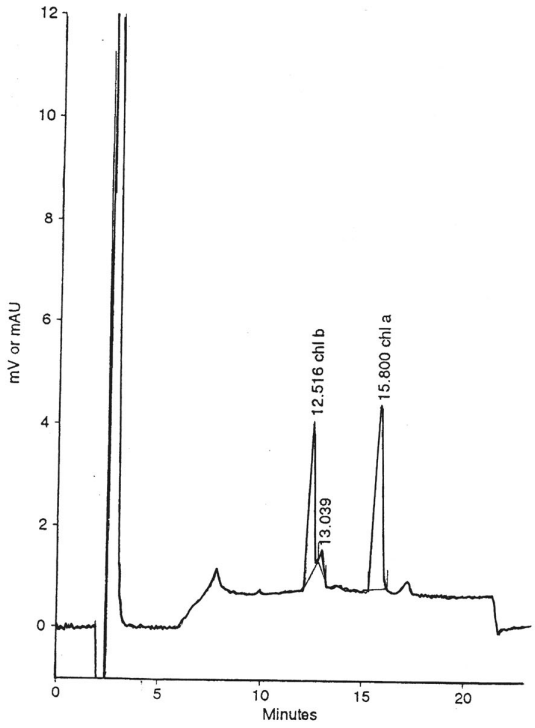


Fig. 4. HPLC chromatogram of reference standard chlorophyll a and b.

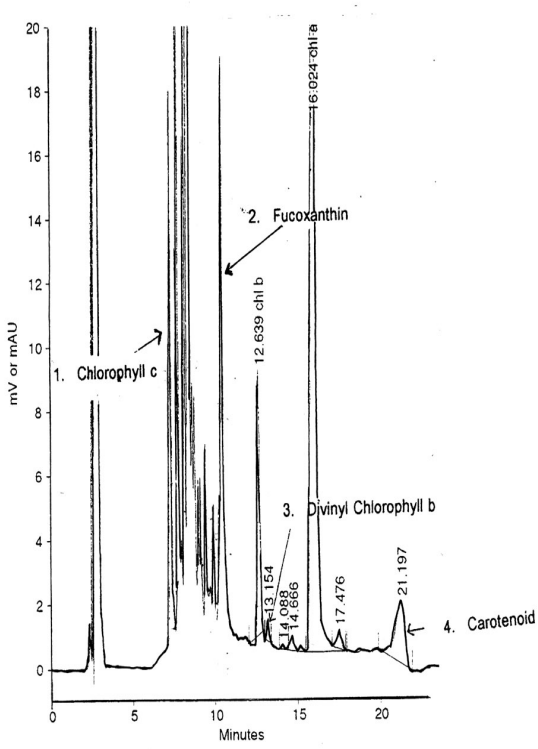


Fig. 5. HPLC chromatogram of extracted pigments.

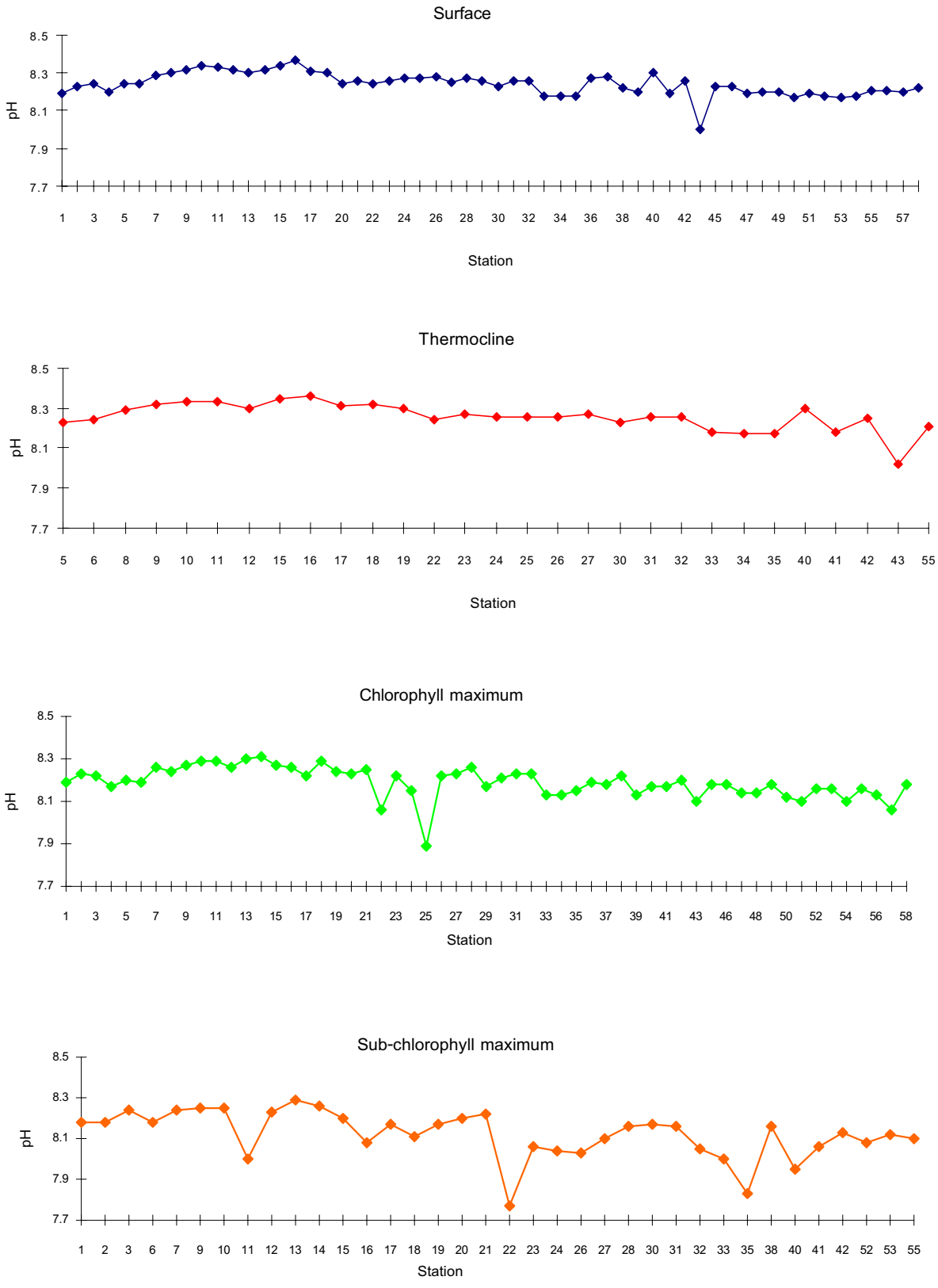


Fig. 6. pH distributions at various sampling depths.

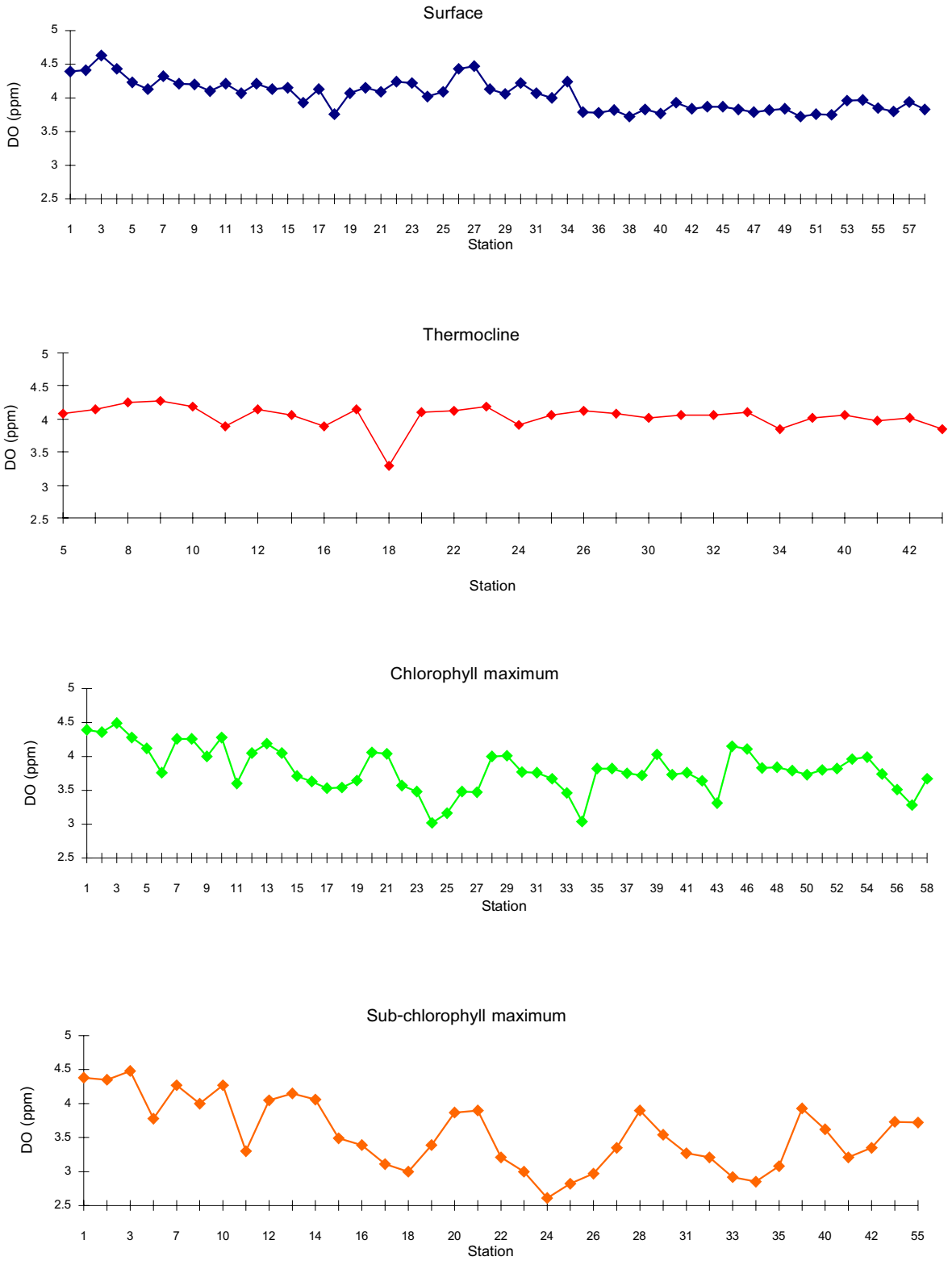


Fig. 7. Dissolved Oxygen (mg/l) distributions at various sampling depths.

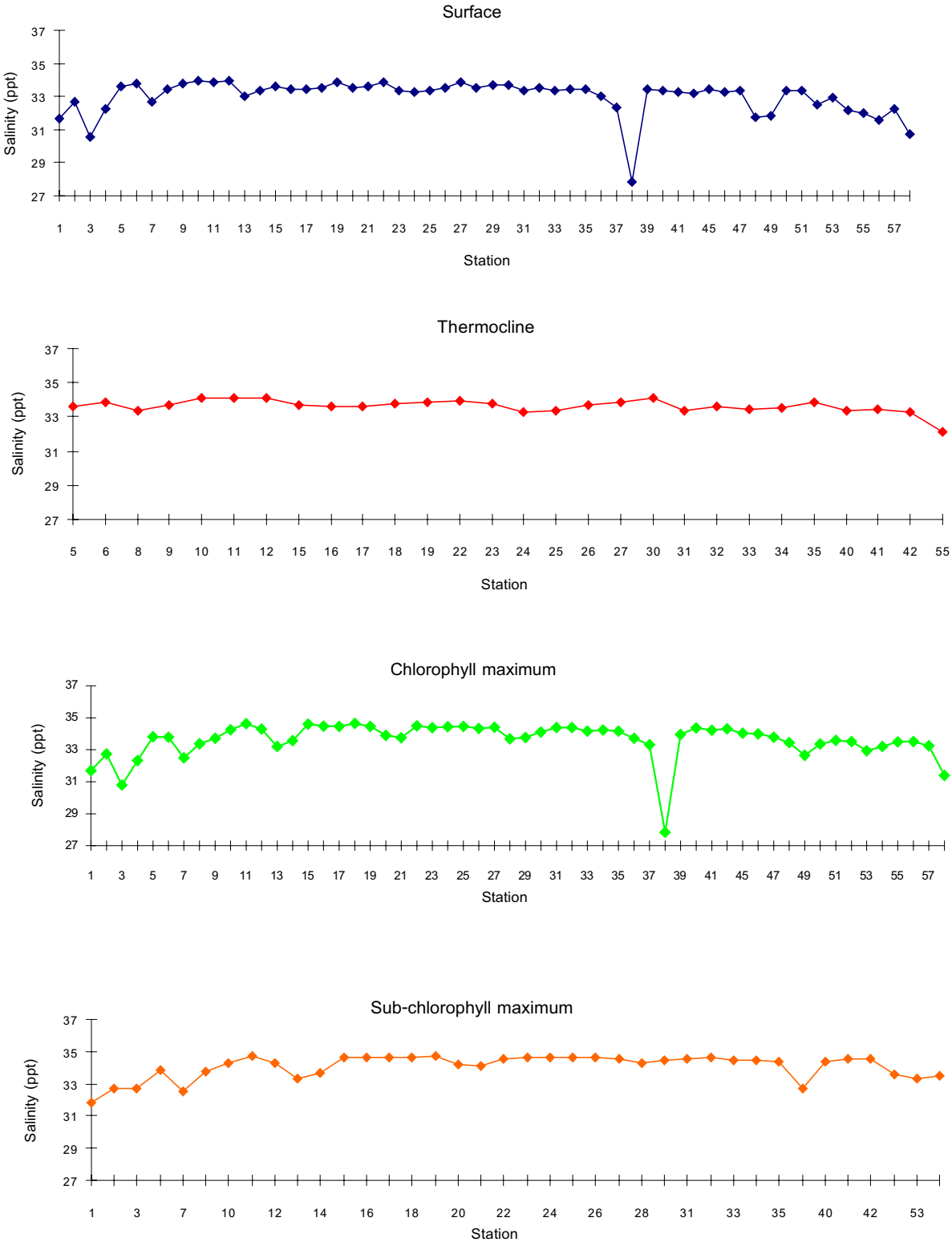


Fig. 8. Salinity (ppt) distributions at various sampling depths.

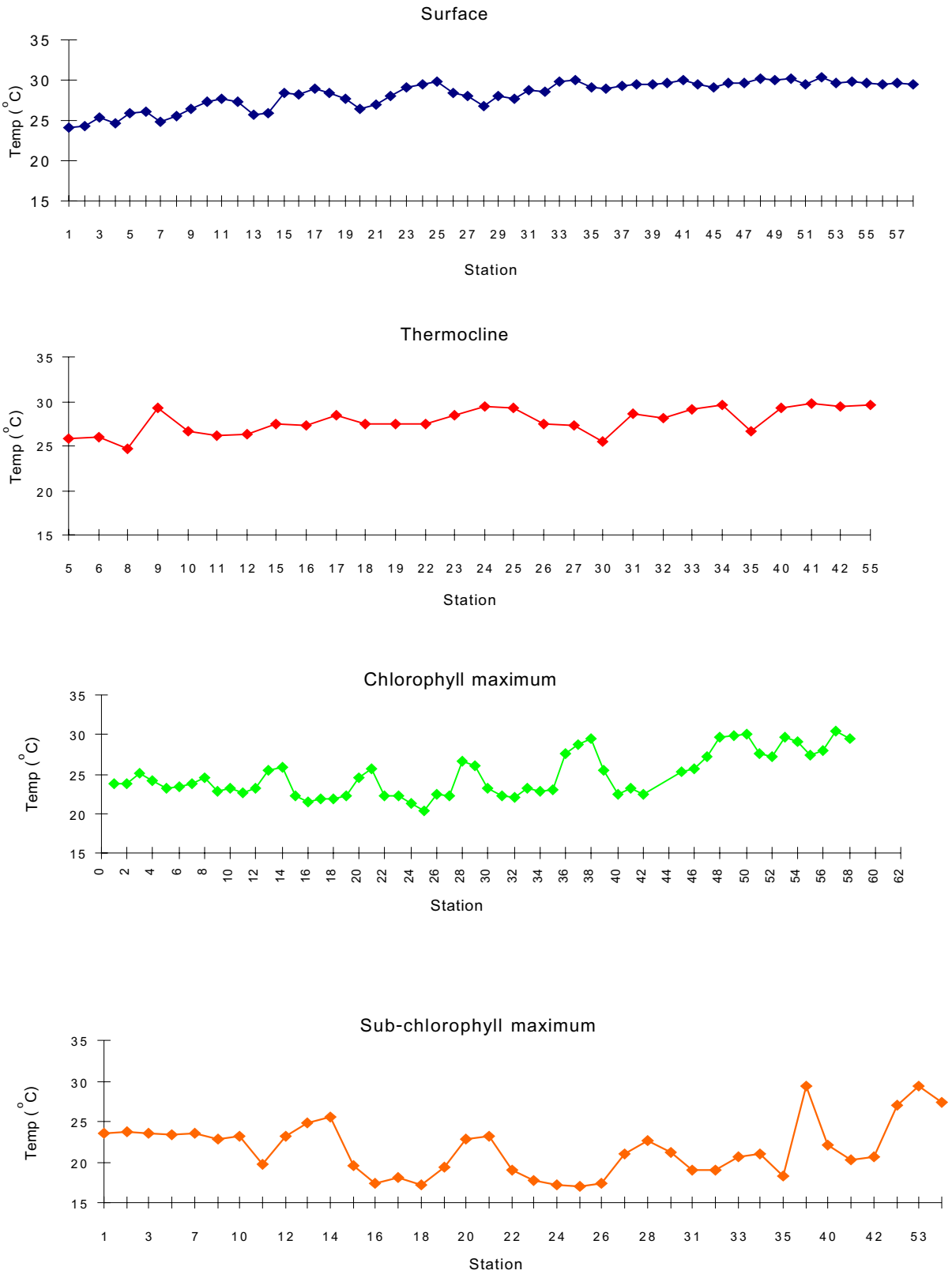


Fig. 9. Water temperature (°C) distributions at various sampling depths.

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References

Anderson G. C. 1969. Subsurface Chlorophyll Maximum in the Northeast Pacific Ocean. *Limnology and Oceanography*, 14, 386-391.

Bajarias F. F. 2000. Phytoplankton in the surface layers of the South China Sea, Area III: Wes- tern Phillipines. in Proceeding of the third technical seminar on marine fishery resources survey in the South China Sea, Area III: Western Phillipines. 220-234.

Djurfeldt L. 1994. The influence of physical factors on a subsurface chlorophyll maximum in an upwelling area. *Estuarine, Coastal and Shelf Science*, 39, 389-400.

Furuya K., .M. Hayashi and Y.Yabushita 1998. HPLC Determination of Phytoplankton Pigments Using N, N-Dimethylformamide. *J.Oceanogr.*, 54, 199-202.

Ichikawa T. 1990. Particulate organic carbon and chlorophyll in the South China Sea off Sabah. *FPSS. UPM. OCC.*, 9, 81-85.

Ilahude A. G. 1987. On the factors affecting the productivity of the Southern Makassar Strait. *Mar. Res. Indonesia*., 21, 87-107.

Jeffrey S. W. and R. F. C. Mantoura 1997. Development of pigment methods for oceanography : SCOR - Supported Working Groups, in "Phytoplankton Pigments in Oceanography" (ed. by S.W. Jeffrey, R.F.C. Mantoura and S.W. Wright), UNESCO, Paris, pp. 19-36.

Keifer D. A. and J. N. Kremer. 1987. Origin of vertical patterns of phytoplankton and nutrients in the temperate open ocean : a stratification hypothesis. *Deep-Sea Research*, 28, 1087-1105.

Lokman B. S., K. B. B. Kaironi and M.N.B. Saadon. 1988. Chlorophyll "a" content off the Sarawak Waters of the South China Sea. *FPSS. U.P.M. OCC.*, 8, 87-90.

Lorenzen C. J. 1981. Chlorophyll b in the eastern North Pacific Ocean. *Deep-Sea Research*, 28, 1049-1056.

Marumo R. 1972. Phytoplankton in the Sea Area of the Southeast Asia. in "Proc. of the Third CSK Symosium" Bangkok, Thailand.

Musikasung W., M.S.B Yosoff and S. B. A. Rasak. 1999. Primary Production Determination in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. in "Proceedings of the first technical seminar on marine fishery resources survey in the South China Sea Area I. Gulf of Thailand and East Coast of Peninsular Malaysia 24-26 November 1997". Bangkok, Thailand, pp. 135-146.

Steele J. H. 1964. A study of production in the Gulf of Mexico. *J. Mar. Res.*, 22, 211-222.

Strass V. H. and J. D. Woods. 1991. New production in the summer revealed by the meridonal slope of the deep chlorophyll maximum. *Deep-Sea Research*, 38, 35-50.

Varela R. A., A. Cruzado, J. Tintore and E. Garcia-Ladona. 1992. Modelling the deep-chlorophyll maximum. A Coupled physical-biological approach. *J. Mar. Res.*, 50, 441-463.

Wauthy B. 1972. Phytoplankton and Circulation North of New guinea in Summer 1971. in "Proc. of the third CSK Symposium, Bangkok, Thailand".