ON THE PLANKTON SUCCESSION OFF CHANGI POINT

By

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INTRODUCTION

The study of marine plankton of Singapore waters was pioneered by Tham (1950, 1952, 1953). He studied simultaneously the food and feeding relationships of the fishes, the physical, chemical and biological characteristics of Singapore Straits, and established a tentative plankton calendar. Later, Wickstead (1958) gave an account of Singapore Straits' larger zooplankton.

Recently, the estuarine and marine plankton of Singapore waters have been the subject of some academic exercises, i.e., diploma project reports, theses and dissertations, a few publications. The only academic exercises which were in a series of plankton studies appear to be those of Chua (1967) and Khoo (1967) who, in their dissertations, accounted for the hydro-biological conditions of an estuary (Ponggol River), and the Serangoon Harbor in Johore Straits, respectively. Tham, Khoo and Chua (1970) presented an overall comparison of their studies of the hydro-biological conditions of Singapore estuarine and marine waters, i.e., the effect of Singapore Straits to Johore Straits, in turn, to Ponggol estuary and vice versa. Lately, Tham et al. (1972) discussed the distribution of plankton in the Singapore Straits from April 1968 to March 1969 in comparison with the previous studies.

The present study deals with the sequence of plankton components in relation to hydrological and meteorological events off Changi Point. Since all marine life depends ultimately on the association of phytoplankton, special attention was given to the succession of the species, genera or groups to get a more or less accurate assessment of the coastal fishery environmental conditions in the area.

DESCRIPTION OF THE SURVEY AREA

Figure 1 shows the coastal waters off Changi Point and its vicinities. East Johore Straits is like a big pond with two main gates, one between Changi Point and the southern shore of Pulau Ubin, and the other on the north of Pulau Ubin, known also as Nanas Channel. The former is relatively shallow, having an average depth of 14 m in the middle. Its water current is tidal in nature.

MATERIALS AND METHODS

The systematic collection of data of the present study was limited to important physical-chemical-biological parameters. Innovations were made on the collection method of Tham (1953).

Plankton and water samplings

The water sampling during the 52-week survey was carried out weekly with the use of an ordinary outboard motor boat (9.9 hp). Figure 2 shows the sampling stations off Changi Point during the period from late February 1974 to mid February 1975. Comparison of random distribution of parameters between off Changi Point and the nearest vicinities was made in December 1974 as shown in Figure 2.

Weekly sampling was undertaken in the daytime during high tide. Kitahara type water bottle was used to collect one liter of seawater near the surface of 20 stations 0.57 nautical mile apart. Average water temperature of the stations was calculated. Samples of larger zooplankton were collected from station 1 to 20 by towing a nylon plankton net with a mouth diameter of 45 cm, length of 140 cm and mesh size of 0.263 mm near the surface at a towing speed of about two knots. The net was fitted with a flow-meter at the central part of the mouth. Water straining coefficient of the flow-meter was evaluated monthly.

From the 20-liter compounded water sample, a volume of 200 ml was drawn for salinity and phosphate-phosphorus (PO_4-P) content analysis. The remaining volume was vigorously agitated by an aerator from which were drawn five liters for smaller zooplankton and one liter for phytoplankton samples. Left over was set aside for pre-examination and identification of plankton components in the living state. The idea was to spot components in bloom and facilitate identification of others later in the preserved state. All plankton samples were preserved in 5% neutral formalin. Identification of plankton components followed Lebour (1930), Subrahmanyan (1946), Wood (1954), Davis (1955), Shirota (1966) and Migita (1967).

Samples of phytoplankton and smaller zooplankton were preserved, sedimented and respectively reduced to 5 and 10 ml concentrated samples from which were drawn aliquots for enumeration. Preserved larger zooplankton was subsequently divided by a plankton splitter until a 16th portion was obtained for enumeration. Subsamples of plankton were enumerated into generic or group level though phytoplankton sub-samples were enumerated into species level in times of bloom. Attention was not given to bacteria, the fragile groups of flagellates, and *Chlorella*.

Qualitative and quantitative comparisons of each plankton genus or group between aliquots of the same sample were made occasionally. Although complete duplication of the quantity of each group between aliquots was never attained, it was gratifying to find out that the qualitative orders of abundance among plankton groups were generally similar between aliquots.

Tidal and meteorological aspects of sampling area

The heights of high tide during the sampling days were referred from the Tide Tables for Malaysia and Singapore (1974 & 1975) having East Johore Straits — Sembawang Shipyard (1°28'N; 103°50'E) as the reference station.

Being one mile from Changi Point, monsoon, rainfall and atmospheric temperature data at Changi Airfield were obtained from the Meteorological Service Singapore. The dates on which the monsoons were estimated to begin and end over the South China Sea, south of 5°N latitude Singapore from January 1974 to February 1975 are as follows (NE-northeast, SW-southwest):

NE monsoon ended 5 Apr '74
NE-SW intermonsoon
SW monsoon began 13 May'74
SW monsoon ended 10 Nov '74
SW-NE intermonsoon
NE monsoon began 4 Dec '74
NE monsoon ended 5 Apr '75

From the rainfall and atmospheric temperature data, weekly average and monthly mean values were calculated.

Statistical analysis

The plankton succession off Changi Point was analyzed in relation to hydrological and meteorological fluctuations. Correlation coefficient (r) was used to measure the association of two parameters at a time. The value of r was calculated as described by Campbell (1967). Comparison of random distribution of parameters between off Changi Point and vicinities was accomplished by applying Kendall's rank correlation coefficient whereby association between two ranked parameters was measured at a time.

RESULTS

PHYSICAL-CHEMICAL ENVIRONMENT

Tide

The weekly mean height of high tide during the sampling period was 2.9 m having maximum and minimum values of 3.7 m (January 1975) and 2.4 m (May 1974) respectively. Figure 3 shows the weekly heights of high tide.

In the area having a dominant semi-diurnal type of tide, mean values were calculated as a matter of interest. The mean of weekly means for the sampling period was 2.9 m while the mean of monthly means was 3.0 m. The monthly mean was maximum in December 1974, January 1975 and February 1974/75 (3.1 m) and minimum in May, June and July 1974 (2.8 m). The monthly mean heights are illustrated in Figure 3.

Rainfall

The maximum weekly average rainfall was in February 1975 (23.1 mm) and the minimum were in March and April 1974 and January 1975 (traces of rainfall). The mean of weekly averages for the sampling period was 6.2 mm while the mean of monthly means was 6.5 mm. The monthly mean was heaviest in February 1974/75 (15.2 mm) and lightest in April 1974 (2.7 mm). Weekly and monthly mean variations in rainfall are shown in Figure 3.

Atmospheric temperature

The maximum weekly average atmospheric temperature was in May 1974 (29.0°C) and the minimum were in October and December 1974 and February 1975 (25.7°C). Weekly and monthly means of weekly averages for the sampling period were both 27.2°C. The monthly mean was maximum in May 1974 (28.0°C) and minimum in February 1974/75 (26.2°C). Figure 4 shows variations in atmospheric temperatures.

Water temperature

The maximum weekly water temperature was in May 1974 (31.0°C) and the minimum were in February and March 1974 (27.6°C). The weekly mean for the sampling period was 29.1°C. The monthly mean was maximum in May 1974 (29.9°C) and minimum in February 1974/75 (28.0°C). The mean of monthly means for the period was 29.1°C. Weekly and monthly mean variations in water temperature are illustrated in Figure 4.

Salinity

The weekly mean value of salinity during the sampling period was 29.22°/oo having maximum and minimum values of 32.62°/oo (March 1974) and 25.14°/oo (September 1974) respectively. The mean of monthly means for the period was 29.26°/oo having maximum and minimum values of 31.86°/oo (March 1974) and 27.43°/oo (September 1974) respectively. Figure 5 shows weekly and monthly variations in salinity.

Concentration of PO_4-P

The weekly mean concentration of PO_4P during the sampling period was 0.84 µg-atom/1 having maximum and minimum values of 2.51 µg-atom/1 (November 1974) and 0.20 µg-atom/1 (June 1974) respectively. The mean of monthly mean values was the same as the weekly mean being 0.84 µg-atom/1. The monthly mean was maximum in April 1974 (1.16 µg-atom/1) and minimum in June 1974 (0.42 µg-atom/1). Weekly and monthly mean variations in PO_4P concentration are shown in Figure 5.

Tables 1, 2 and 3 show the values of mean, standard deviation (SD) and coefficient of variation (CV) of the foregoing physical and chemical parameters.

Table 1. Monthly mean values of principal parameters off Changi Point

Time	* Height of high tide (m)	Rainfall (mm)	* Atmospheric temperature (°C)	** Water temperature (°C)	Salinity (°/oo)	** PO_4-P (ug-atom/l)	** Phytoplankton (cell no./m³ x 10⁶)	** Smaller zooplankton (no./m³ x 10³)	** Larger zooplankton (no./m³)
Weekly	2.9	6.2	27.2	29.1	29.22	0.84	548	935	1 478
Monthly	3.0	6.5	27.2	29.1	29.26	0.84	557	936	1 490
Mar 74	3.0	5.2	26.6	28.1	31.86	0.89	66	1 616	533
Apr 74	2.9	2.7	27.7	29.3	31.20	1.16	8	574	467
May 74	2.8	5.4	28.0	29.9	27.97	0.89	225	716	1 875
Jun 74	2.8	4.9	27.8	29.8	28.19	0.42	684	802	2 606
Jul 74	2.8	4.5	27.5	29.6	29.40	0.82	1 248	432	3 360
Aug 74	2.9	3.9	27.5	29.3	28.06	0.65	890	736	1 330
Sep 74	2.9	10.5	27.0	29.0	27.43	0.67	2 075	2 182	1 784
Oct 74	3.0	8.9	27.4	29.4	28.08	0.95	311	975	1 649
Nov 74	3.0	4.2	27.0	29.5	29.46	1.03	732	1 674	2 104
Dec 74	3.1	8.3	26.3	28.9	30.22	0.81	65	733	581
Jan 75	3.1	3.7	26.8	28.4	29.02	0.95	342	228	798
Feb 74/75	3.1	15.2	26.2	28.0	30.26	0.88	34	564	793
NE monsoon	3.1	6.9	26.7	28.5	30.55	0.89	128	838	622
NE-SW intermonsoon	3.0	4.3	26.7	29.5	29.38	1.12	598	1 481	2 524
SW monsoon	2.9	6.4	27.5	29.4	28.22	0.76	931	1 047	2 001
SW-NE intermonsoon	2.8	2.8	28.1	30.1	29.29	1.02	28	265	1 375

* Based on weekly mean values
** Based on weekly values

Table 2. Values of SD of principal parameters off Changi Point

Time	* Height of high tide (m)	* Rainfall (mm)	* Atmospheric temperature (°C)	** Water temperature (°C)	** Salinity (°/oo)	** PO_4-P (ug-atom/1)	** Phytoplankton (cell no/m^3 x 10^6)	** Smaller zooplankton (no./m^3 x 10^3)	** Larger zooplankton (no./m^3)
Weekly	0.3	5.2	0.8	0.7	1.70	0.41	1 206	959	1 204
Monthly	0.1	3.6	0.6	0.6	1.40	0.84	619	583	1 490
Mar 74	0.4	3.9	0.5	0.3	0.40	0.38	66	1 616	533
Apr 74	0.3	2.9	0.3	0.3	0.87	0.45	8	574	467
May 74	0.3	4.9	0.7	0.7	1.01	0.38	225	716	1 875
Jun 74	0.2	3.4	1.0	0.6	1.61	0.22	684	802	2 606
Jul 74	0.3	1.9	0.7	0.3	1.83	0.14	1 248	432	3 360
Aug 74	0.3	3.1	1.4	0.3	1.13	0.24	890	736	1 330
Sep 74	0.3	6.4	0.6	0.3	1.17	0.17	2 075	2 182	1 784
Oct 74	0.3	4.4	1.3	0.4	1.35	0.52	311	975	1 649
Nov 74	0.3	1.1	0.7	0.5	0.79	1.00	732	1 674	2 104
Dec 74	0.2	1.7	0.5	0.4	0.59	0.10	65	733	581
Jan 75	0.3	4.3	0.3	0.0	0.61	0.28	342	228	798
Feb 74/75	0.3	12.3	0.5	0.3	1.22	0.37	34	564	793
NE monsoon	0.3	6.5	0.6	0.6	1.42	0.28	317	1 033	447
NE-SW inter-monsoon	0.4	1.5	0.6	0.8	1.41	1.21	834	1 076	2 092
SW monsoon	0.3	4.6	1.0	0.5	1.30	0.34	1 584	940	1 170
SW-NE inter-monsoon	0.3	3.0	0.6	0.7	1.21	0.64	34	214	1 016

* Based on weekly mean values
** Based on weekly values

Table 3. Values of CV of principal parameters off Changi Points*

Time	Height of high tide	Rainfall	Atmospheric temperature	Water temperature	Salinity	PO_4-P	Phytoplankton	Smaller zooplankton	Larger zooplankton
Weekly	0.08	0.84	0.04	0.03	0.06	0.50	2.20	1.03	0.81
Monthly	0.04	0.56	0.02	0.02	0.05	0.23	1.11	0.62	0.61
Mar 74	0.06	0.75	0.02	0.01	0.02	1.45	1.50	1.10	0.40
Apr 74	0.09	1.11	0.02	0.01	0.04	0.40	0.74	1.25	0.59
May 74	0.07	0.92	0.03	0.02	0.01	0.44	1.69	1.08	0.33
Jun 74	0.05	0.69	0.04	0.02	0.03	0.53	1.92	0.94	0.60
Jul 74	0.06	0.44	0.03	0.01	0.03	0.19	1.23	0.38	0.44
Aug 74	0.10	0.81	0.05	0.01	0.06	0.41	1.83	0.73	0.50
Sep 74	0.12	0.61	0.03	0.01	0.07	0.27	1.51	0.71	0.69
Oct 74	0.08	0.50	0.05	0.02	0.04	0.56	1.49	0.48	0.27
Nov 74	0.04	0.29	0.03	0.02	0.04	0.97	1.00	0.57	0.90
Dec 74	0.05	0.21	0.02	0.02	0.04	0.14	0.91	0.51	0.34
Jan 75	0.09	1.17	0.01	0.01	0.03	0.30	1.75	0.65	0.82
Feb 74/75	0.05	0.81	0.02	0.01	0.34	0.43	0.97	0.43	0.87
NE monsoon	0.06	0.94	0.02	0.02	0.05	0.32	2.49	1.23	0.72
NE-SW inter-monsoon	0.09	1.09	0.02	0.02	0.04	0.62	1.20	0.81	0.74
SW monsoon	0.08	0.71	0.04	0.02	0.05	0.45	1.70	0.90	0.58
SW-NE inter-monsoon	0.05	0.35	0.02	0.03	0.05	1.08	1.40	0.73	0.83

* Based on Tables 1 and 2

PHYTOPLANKTON

Composition

The most conspicuous principal groups of the phytoplankton consisted of diatoms and dinoflagellates. Less obvious were green algae, silicoflagellates and detritus.

The diatoms were represented by 48 genera: *Melosira, Hyalodiscus, Skeletonema, Stephanopyxis, Dactyliosolen, Leptocylindrus, Guinardia, Corethron, Schroderella, Lauderia, Thalassiosira, Coscinodiscus, Cyclotella, Planktoniella, Actinoptychus, Hemidiscus, Asteromphalus, Rhizosolenia, Bacteriastrum, Chaetoceros, Biddulphia, Triceratium, Cerataulina, Hemialus, Lithodesmium, Ditylum, Eucampia, Climacodium, Streptotheca, Fragilaria, Asterionella, Thalassionema, Thalassiothrix, Striatella, Grammatophora, Rhabdonema, Licmophora, Climacosphenia, Plagiogramma, Cocconeis, Navicula, Diploneis, Mestogloia, Pleurosigma, Nitzschia, Amphora, Surirella* and *Campylodiscus.* In addition, there was a group of unidentified diatoms; it was enumerated as one genus/group.

The dinoflagellates were classified into 13 genera: *Prorocentrum, Dinophysis, Orinthocercus, Amphisolenia, Noctiluca, Gymnodinium, Pyrophacus, Gonyaulax, Goniodoma, Peridinium, Ceratium, Oxytoxum* and *Triposolenia.*

The three groups, green algae, silicoflagellates and detritus were not identified into generic level. Thus, they were enumerated in their group levels. Nevertheless, the obvious elements of the silicoflagellates were two genera: *Dictyocha* and *Distephanus.*

Abundance and occurrence

The most numerous groups of phytoplankton were diatoms and dinoflagellates and the less abundant were green algae, silicoflagellates and detritus.

Based on the 52 weekly samples, general occurrence of plankton was classified intc two classes: common (when certain genus or

group occurred in the samples from 50 to 52 weeks) and occasionally common (from 40 to 49 weeks).

The common diatoms were *Coscinodiscus, Nitzschia* and *Chaetoceros.* It was found that *Coscinodiscus* occurred in all weekly samples.

Occasionally common representatives were *Thalassionema, Rhizosolenia, Thalassiosira, Leptocylindrus, Navicula, Pleurosigma, Skeletonema* and *Ditylum.* The rest were rather occasional or rare.

Among the dinoflagellates, the common representative was *Peridinium;* while occasionally common ones were *Ceratium* and *Dinophysis.* Others were rather occasional or rare.

Maximum weekly and monthly abundance (cell no./m^3) of each genus/group including percentage (%) in total phytoplankton was noted as follows:

Plankton	No./m^3 x 10^3 (%)	Weekly date	No./m^3 x 10^3 (%)	Month
In order of magnitude:				
Phytoplankton	6 642 095	12 Sep 74	2 075 567	Sep
Diatoms	6 640 775 (99.98)	12 Sep 74	2 073 882 (99.92)	Sep
Dinoflagellates	864 805 (55.63)	22 Nov 74	218 414 (29.82)	Nov
Green algae	31 200 (49.38)	13 Jun 74	9 819 (1.43)	Jun
Detritus (piece no./m^3)	17 325 (1.53)	24 Oct 74	3 750 (1.21)	Oct
Silicoflagellates	75 (.06)	16 Jan 75	26 (.01)	Jan
In order of day, week and month (NS — not significant):				
Biddulphia	213 (1.99)	2 Jan 75	Not maximum	
Bacteriastrum	12 500 (.89)	10 Jan 75	2 998 (.87)	
Streptotheca	3 750 (.27)	10 Jan 75	753 (.22)	
Diploneis	1 250 (.90)	10 Jan 75	275 (.08)	
Coscinodiscus	15 838 (11.88)	16 Jan 75	5 343 (1.56)	
Melosira	963 (1.60)	30 Jan 75	323 (.09)	Jan
Schroderella	200 (.33)	30 Jan 75	40 (.01)	
Pleurosigma	1 238 (2.06)	30 Jan 75	375 (.11)	
Lauderia	Not maximum		798 (.23)	
Navicula	Not maximum		4 355 (1.27)	—
Cerataulina	375 (.53)	21 Feb 74	125 (.37)	
Prorocentrum	150 (.21)	21 Feb 74	Not maximum	
Dinophysis	Not maximum		212 (.62)	Feb
Noctiluca	Not maximum		66 (.19)	
Triposolenia	Not maximum		17 (.05)	—
Fragilaria	3 075 (13.79)	1 Mar 74	765 (1.15)	
Thalassiothrix	475 (2.13)	1 Mar 74	248 (.37)	
Plagiogramma	825 (3.70)	1 Mar 74	165 (.25)	
Actinoptychus	75 (1.01)	7 Mar 74	15 (.02)	
Stephanopyxis	10 838 (51.27)	14 Mar 74	2 168 (3.27)	

Asterionella	788 (3.73)	14 Mar 74	263 (.40)	Mar
Triposolenia	75 (.35)	14 Mar 74	Not maximum	
Leptocylindrus	197 100 (81.07)	22 Mar 74	39 495 (59.57)	
Rhabdonema	17 525 (46.76)	29 Mar 74	3 775 (5.69)	
Orinthocercus	500 (1.33)	29 Mar 74	100 (.15)	
Triceratium	Not maximum		33 (.05)	
Striatella	838 (1.08)	3 May 74	208 (.09)	
Hemialus	725 (3.91)	9 May 74	260 (.12)	
Campylodiscus	25 (.03)	17 May 74	Not maximum	May
Gymnodinium	30 750 (32.04)	17 May 74	7 325 (3.26)	
Dinophysis	355 (.56)	13 Jun 74	Not maximum	
Pyrophacus	55 (.09)	13 Jun 74	16 (NS)	
Campylodiscus	25 (.20)	20 Jun 74	10 (NS)	Jun
Oxytoxum	25 (.20)	20 Jun 74	6 (NS)	
Cocconeis	75 (NS)	28 Jun 74	Not maximum	
Amphora	200 (.01)	28 Jun 74	66 (.01)	
Amphisolenia	50 (.35)	4 Jul 74	13 (NS)	
Cyclotella	975 (.03)	11 Jul 74	253 (.02)	
Chaetoceros	3 142 500 (98.71)	11 Jul 74	1 222 975 (97.83)	Jul
Cocconeis	75 (NS)	11 Jul 74	31 (NS)	
Mestogloia	150 (NS)	11 Jul 74	38 (NS)	
Navicula	17 313 (82.98)	1 Aug 74	Not maximum	Aug
Cocconeis	75 (.05)	22 Aug 74	Not maximum	
Planktoniella	38 (.70)	5 Sep 74	13 (NS)	
Skeletonema	3 646 250 (54.90)	12 Sep 74	1 288 438 (62.08)	
Noctiluca	220 (NS)	12 Sep 74	Not maximum	Sep
Prorocentrum	150 (1.03)	19 Sep 74	60 (NS)	
Thalassiosira	325 800 (19.86)	26 Sep 74	137 782 (6.64)	
Dactyliosolen	2 250 (1.07)	3 Oct 74	545 (.18)	
Corethron	213 (.10)	3 Oct 74	50 (.02)	
Lauderia	3 000 (1.43)	3 Oct 74	Not maximum	
Climacosphenia	150 (.07)	3 Oct 74	30 (.01)	
Eucampia	350 (3.02)	16 Oct 74	98 (.03)	
Rhizosolenia	91 800 (8.13)	24 Oct 74	21 010 (6.75)	
Triceratium	150 (.01)	24 Oct 74	33 (.01)	Oct
Nitzschia	315 675 (27.94)	24 Oct 74	70 605 (22.69)	
Goniodoma	60 (.01)	24 Oct 74	Not maximum	
Peridinium	3 848 (.34)	24 Oct 74	1 074 (.35)	
Licmophora	75 (.15)	31 Oct 74	15 (NS)	
Surirella	75 (.15)	31 Oct 74	18 (.01)	
Gonyaulax	125 (.01)	7 Nov 74	56 (.01)	
Guinardia	50 (.22)	14 Nov 74	31 (NS)	
Hemidiscus	213 (.95)	14 Nov 74	72 (.01)	
Ceratium	864 000 (55.58)	22 Nov 74	217 326 (29.67)	Nov
Biddulphia	213 (.10)	28 Nov 74	Not maximum	
Climacodium	75 (.03)	28 Nov 74	19 (NS)	
Goniodoma	Not maximum		14 (NS)	
Grammatophora	525 (1.80)	5 Dec 74	153 (.24)	
Asteromphalus	125 (.25)	12 Dec 74	41 (.06)	
Thalassionema	31 288 (62.27)	12 Dec 74	12 822 (19.71)	
Hyalodiscus	25 (.09)	19 Dec 74	10 (.01)	Dec
Lithodesmium	475 (.31)	27 Dec 74	119 (.18)	
Ditylum	57 588 (37.72)	27 Dec 74	14 482 (22.26)	
Biddulphia	Not maximum		116 (.18)	

Weekly and monthly variations and blooms

The maximum number of weekly total phytoplankton was in September 1974 (6 642 x 10^6 cells/m^3) and the minimum was in April 1974 (2 x 10^6 cells/m^3). The weekly mean for the sampling period was 548 x 10^6 cells/m^3. The monthly mean was maximum in September 1974 (2 075 x 10^6 cells/m^3) and minimum in April 1974 (8 x 10^6 cells/m^3). The mean of monthly means for the period was 557 x 10^6 cells/m^3. The values of mean, SD and CV of phytoplankton fluctuation are shown in Tables 1, 2 and 3.

The maximum weekly diatom number was in September 1974 (6 641 x 10^6 cells/m^3) and the minimum was in April 1974 (1 x 10^6 cells/m^3). The weekly mean for the sampling period was 526 x 10^6 cells/m^3. The monthly mean was maximum in September 1974 (2 073 x 10^6 cells/m^3) and minimum in April 1974 (5 x 10^6 cells/m^3). The mean of monthly means for the period was 533 x 10^6 cells/m^3.

The weekly dinoflagellate number was maximum in November 1974 (865 x 10^6 cells/m^3) but nothing in the first week of May 1974. The weekly mean for the sampling period was 1 932 x 10^3 cells/m^3. The monthly mean was maximum in November 1974 (2 184 x 10^3 cells/m^3) and minimum in April 1974 (18 x 10^3 cells/m^3). The mean of monthly means for the period was 441 x 10^3 cells/m^3.

Weekly and monthly means of green algae, silicoflagellates and detritus were found to occur on and off. Nevertheless, green algae followed by detritus was found to occur more frequently than silicoflagellates.

Table 4 shows the values of mean, SD and CV of the foregoing groups of phytoplankton. Figure 6 shows striking variations in phytoplankton number. Weekly variations in total phytoplankton were found to depend on the changes in abundance of its principal groups.

Out of 52 weekly samples, correlation coefficients (r) were calculated as follows (where r = 0.2732 at 5% significance level):

	Diatoms	Dinoflagellates	Green algae	Detritus	Silicoflagellates
Phyplankton	0.9764	0.1354	−0.2116	−0.2518	−0.1698

Generally, total phytoplankton was found to depend on total diatoms.

Table 4. Values and mean, SD and CV of the main groups of phytoplankton off Changi Point.

Time	Diatoms (cell no./m³ x 10⁶) mean	SD	CV	Dinoflagellates (cell no./m³ x 10⁴) mean	SD	CV	Green algae (cell no./m³ x 10⁴) mean	SD	CV	Detritus (piece no./m³ x 10³) mean	SD	CV	Silicoflagellates (cell no./m³ x 10³) mean	SD	CV
Weekly	526	1200	2.28	1932	1197	6.20	294	491	1.67	484	242	5.01	NS	NS	NS
Monthly	533	618	1.16	441	641	1.45	290	260	0.89	497	1055	2.42	NS	NS	NS
Mar 74	61	98	1.59	105	91	0.86	312	425	1.36	613	1370	2.24	—	—	—
Apr 74	5	6	1.14	18	9	0.51	247	198	1.60	113	142	1.26	—	—	—
May 74	214	385	1.80	755	1323	1.75	338	384	1.14	48	56	1.18	—	—	—
Jun 74	667	1327	1.99	960	1347	1.40	980	144	1.47	3	6	2.00	NS	NS	NS
Jul 74	1247	1534	1.23	19	9	0.48	137	97	0.70	62	75	1.20	NS	NS	NS
Aug 74	889	1634	1.84	60	37	0.62	56	114	2.04	15	34	2.24	—	—	—
Sep 74	2073	3140	1.51	93	81	0.87	70	60	0.86	66	89	1.35	—	—	—
Oct 74	300	457	1.52	333	370	1.11	332	341	1.03	3740	7596	2.03	NS	NS	NS
Nov 74	510	498	0.98	2184	4309	1.97	425	390	0.92	31	31	1.01	NS	NS	NS
Dec 74	57	65	1.13	678	671	0.99	72	100	1.38	63	64	1.01	NS	NS	NS
Jan 75	338	598	1.77	322	23	0.71	436	242	0.55	135	84	0.62	NS	NS	NS
Feb 74/75	32	34	1.06	57	11	0.20	72	62	0.87	354	344	0.97	—	—	—
NE monsoon	123	316	2.58	190	381	2.00	276	311	1.13	285	695	2.44	8	17	2.08
NE-SW inter-monsoon	304	344	1.18	28910	49857	1.03	487	452	1.70	17	14	0.79	13	22	—
SW monsoon	923	1587	1.72	386	807	2.09	301	621	2.06	776	3386	4.36	1	—	2.94
SW-NE inter-monsoon	26	31	1.13	17	17	1.72	200	340	0.93	59	47	0.85	—	—	1.68

NS: Not significant Dash: Nil or none present

In the linear regression analysis of each group, significant correlation between total diatom and every representative was found dominantly among the following genera:

Chaetoceros	0.7722	*Lauderia*	0.3243
Leptocylindrus	0.4229	*Striatella*	0.3221
Nitzschia	0.3626	*Rhizosolenia*	0.3019
Thalassiosira	0.3621	*Corethron*	0.2759
Skeletonema	0.3511	*Hemialus*	-0.2749

Significant correlation between total dinoflagellate and every representative was found dominantly among the following genera:

Peridinium	0.8389	*Prorocentrum*	0.3776
Ceratium	0.7667	*Gonyaulax*	0.3631
Dinophysis	0.5578	*Goniodoma*	0.3457
Gymnodinium	0.3978		

However, significant correlation between total phytoplankton and every representative of diatoms and dinoflagellates was found dominantly among the following genera:

Chaetoceros	0.7129	*Striatella*	0.2881
Leptocylindrus	0.4278	*Lauderia*	0.2872
Thalassiosira	0.3802	*Gonyaulax*	0.2797
Skeletonema	0.3282	*Goniodoma*	0.2744
Nitzschia	0.3170	*Hemialus*	-0.3075
Prorocentrum	0.3068		

Weekly changes in the abundance of phytoplankton groups were found to cause changes in the dominance between them in succession. Figure 7 shows the patterns of the foregoing succession.

Striking peaks of the abundance of diatoms and dinoflagellates were blooms of rather small number of species and/or one form. Blooms were noted as follows:

May 1974	-*Gymnodinium* bloom
	Chaetoceros bloom
June 1974	-*Skeletonema* bloom
July 1974	-*Chaetoceros* major bloom
August 1974	-*Skeletonema*-cum-*Nitzschia* bloom
September 1974	-*Skeletonema*-cum-*Chaetoceros* bloom
	Chaetoceros-cum-*Skeletonema* bloom

October 1974 -*Chaetoceros*-cum-*Nitzschia* bloom
November 1974 -*Chaetoceros*-cum-*Nitzschia* major bloom
Ceratium bloom
January 1975 -*Chaetoceros*-cum-*Nitzschia* minor bloom

Composition of conspicuous species during the blooms was as follows:

May 1974

Gymnodinium bloom (weekly sampling no. 13); *Chaetoceros* spp. — 37.91% most of *C.* sp. and least of *C. laciniosus* Schutt and *C. decipiens* Cleve; *Gymnodinium* sp. — 32.04%; *Skeletonema costatum* (Greville) Cleve — 19.24%; *Leptocylindrus danicus* Cleve — 5.70%; *Nitzschia* spp. — 1.35% most of *N. longissima* (Brebisson) Ralfs and *N. seriata* Cleve; *Stephanopyxis palmeriana* (Greville) Grunow — 1.06%; others — 2.70%.

Chaetoceros bloom (weekly sampling no. 15); *Chaetoceros* spp. — 95.75% most of *C.* sp. and least of *C. decipiens* and *C. laciniosus; Nitzschia* spp. — 3.76% most of *N. longissima* and least of *N. seriata; Gymnodinium* sp. — 0.38%; others — 0.11%.

June 1974

Skeletonema bloom (weekly sampling no. 19); *Skeletonema costatum* — 99.27%; *Chaetoceros* spp. — 0.17% consisted of *C.* sp., *C. decipiens* and *C. didymus* Ehrenberg; *Thalassiosira decipiens* (Grunow) Jorgensen — 0.15%; *Nitzchia* spp. — 0.14% most of *N. seriata* and *N. delicatissima* Cleve; *Thalassionema nitzschioides* Grunow — 0.13%; others — 0.14%.

July 1974

Chaetoceros major bloom

Weekly sampling no. 21: *Chaetoceros* spp. — 98.71% most of *C.* sp. and least of *C. didymus* Ehrenberg var *anglica* (Grunow) Gran, *C. affinis* Lauder var. *Willei* (Gran) Hustedt *C. lauderi* Ralfs; *Skeletonema costatum* — 0.99%; *Rhizosolenia setigera* Brightwell — 0.07%; *Nitzschia longsissima* — 0.04%; others — 0.19%. Weekly sampling no. 22; *Chaetoceros* spp. 98.28% most of *C.* sp. and least of *C. didymus; C. affinis* and *C. lauderi; Rhizosolenia setigera* — 0.73%; *Leptocylindrus danicus* 0.48%; *Nitzschia longissima* — 0.26%; *Skeletonema costatum* — 0.21%; others — 0.04%.

August 1974

Skeletonema-cum-*Nitzschia* bloom (weekly sampling no. 28); *Skeletonema costatum* — 87.21%; *Nitzschia* spp. — 5.96% most of *N. seriata* and least of *N. longissima; Chaetoceros* spp. — 4.85% most of *C.* sp. and least of *C. affinis, C. lauderi* and *C. lorenzianus* Grunow; *Thalassiosira decipiens* — 1.76%; *Leptocylindrus danicus* — 0.10% *Bacteriastrum hyalinum* Lauder — 0.04%; *Rhizosolenia* spp. — 0.02% consisted of *R. setigera* and *R. stolterfothii* H. Peragallo; *Thalassionema nitzschioides* — 0.02%; *Ditylum sol* Grunow — 0.01%; others — 0.03%.

September 1974

Skeletonema-cum-*Chaetoceros* bloom (weekly sampling no. 31); *Skeletonema costatum* — 69.95%; *Chaetoceros* spp. — 25.24% most of *C.* sp. and *C. affinis* and least of *C. didymus, C. lorenzianus* and *C. diversus* Cleve; *Thalassiosira decipiens* — 3.39%; *Nitzschia seriata* — 1.35%; others — 0.07%.

Chaetoceros-cum-*Skeletonema* bloom (weekly sampling no. 32): *Chaetoceros* spp. — 47.56%; most of *C.* sp., few of *C. didymus* and least of *C. affinis* and *C. lorenzianus; Skeletonema costatum* — 30.87%; *Thalassiosira decipiens* — 19.86%; *Nitzschia seriata* — 0.95%; *Rhizosolenia* spp. — 0.45% consisted of *R. stolterfothii* and *R. hebetata* forma *semispina* (Hensen) Gran; *Rhabdonema arcuatum* Kutzing — 0.10%; others — 0.21%.

October 1974

Chaetoceros-cum-*Nitzschia* bloom (weekly sampling no. 36); *Chaetoceros* spp. — 53.76% most of *C.* sp., few of *C. lorenzianus* and least of *C. decipiens, C. affinis* and *C. didymus; Nitzschia seriata* — 27.94%; *Rhizosolenia hebetata* — 8.13%; *Leptocylindrus danicus* — 4.34%; *Skeletonema costatum* — 3.21%; *Ceratium furca* (Ehrenberg) Dujardin — 0.35%; *Peridinium* spp. — 0.34%; *Thalassiosira decipiens* — 0.23%; others — 1.70%.

November 1974

Chaetoceros-cum-*Nitzschia* major bloom (weekly sampling no. 38): *Chaetoceros* spp. — 91.01% most of *C.* sp., few of *C.*

lorenzianus and *C. didymus* and least of *C. decipiens* and *C. affinis; Nitzschia seriata* — 5.50%; *Skeletonema costatum* — 2.11%; *Ceratium furca* — 0.29%; *Leptocylindrus danicus* — 0.21%; *Thalassiosira decipiens* — 0.18%; *Peridinium* spp. — 0.13%; *Gymnodinium* sp. — 0.11%; *Thalassionema nitzschioides* — 0.10%; others — 0.36%.

Ceratium bloom (weekly sampling no. 40): *Ceratium furca* — 55.58%; *Chaetoceros* spp. — 17.37%; most of *C.* sp. and *C. lorenzianus* and least of *C. decipiens, C. affinis* and *C. didymus; Thalassiosira decipiens* — 14.56%; *Skeletonema costatum* — 6.75%; *Leptocylindrus danicus* — 4.74%; *Coscinodiscus* spp. — 0.32%; most of *C. excentricus* Ehrenberg and rare of *C. radiatus* Ehrenberg; *Navicula membranacea* Cleve — 0.24%; *Rhizosolenia hebetata* — 0.16%; others — 0.28%.

January 1975

Chaetoceros-cum-*Nitzschia* minor bloom (weekly sampling no. 47); *Chaetoceros* spp. — 91.54% most of *C.* sp., *C. lorenzianus* and *C. didymus* and least of *C. affinis* and *C. decipiens; Nitzschia seriata* — 2.83%; *Thalassiosira decipiens* — 0.91%; *Leptocylindrus danicus* — 0.89%; *Bacteriastrum hyalinum* — 0.89%; *Navicula membranacea* — 0.68%; *Coscinodiscus* spp. — 0.59% most of *C. excentricus* and rare of *C. radiatus; Thalassionema nitzchioides* — 0.36%; *Streptotcheca thamensis* Schrubsole — 0.27%; *Skeletonema costatum* — 0.25%; *Diploneis splendica* (Greg.) Cleve — 0.09%; others — 0.70%.

SMALLER ZOOPLANKTON

Composition

The principal groups of smaller zooplankton consisted of Radiolaria, Ciliata, Calcarea and Rotifera (Rotatoria). All in all, smaller zooplankton were represented by 26 genera, and a group of unidentified ciliates was enumerated as a genus.

Radiolaria were classified into six genera: *Aulosphaera, Dictyophimus Dictyocephalus, Gazelleta* and *Collozoum.*

Ciliata were represented by Peritricha and Holotricha (Tintinnoinea). The former consisted of *Sticholanche* and *Zoothanium* and the latter consisted of *Codonella, Tintinnopsis, Codonellopsis, Stenosemella, Cyttarocylis, Dictyocysta, Favella, Metacylis, Rhabdonella, Amphorella, Amphorellopsis, Dadayiella, Eutintinnus, Tintinnus, Undella* and unidentified ciliates.

The only representative of Calcarea (Homocoela) was *Leucosolenia* and Rotifera was represented by *Keratella, Notholca* and *Trichocerca.*

Abundance and occurrence

The common representative of smaller zooplankton was *Tintinopsis* and occasionally common one was *Codonellopsis.*

Maximum weekly and monthly abundance (no./m^3) of the foregoing genera was noted as follows:

Plankton	No./m^3 x 10^3	Weekly date	No./m^3 x 10^3	Month
In order of day, week and month:				
Tintinnus	30	10 Jan 75	8	Jan
Rhabdonella	188	21 Feb 74	63	Feb
Dictyocephalus	18	1 Mar 74	4	
Stenosemella	1 600	1 Mar 74	328	
Cyttarocylis	68	1 Mar 74	14	
Aulosphaera	50	29 Mar 74	10	Mar
Codonella	250	29 Mar 74	70	
Codonellopsis	1 850	29 Mar 74	375	———
Favella	Not maximum		31	Apr
Amphorellopsis	150	17 May 74	Not maximum	
Eutintinnus	225	17 May 74	45	May
Sticholanche	5	6 & 13 Jun 74	3	
Amphorella	30	13 Jun 74	8	Jun
Dictyocysta	5	20 Jun 74	1	———
Gazelleta	5	4 Jul 74	1	Jul
Dictyophimus	50	8 Aug 74	19	
Zoothanium	400	8 Aug 74	193	
Leucosolenia	5	22 Aug 74	1	Aug
Notholca	5	22 Aug 74	1	
Keratella	53	12 Sep 74	13	
Favella	110	26 Sep 74	Not maximum	Sep
Metacylis	615	26 Sep 74	154	———
Leucosolenia	5	16 Oct 74	1	Oct
Tintinnopsis	1 800	7 Nov 74	894	
Undella	20	7 Nov 74	5	
Dadayiella	50	22 Nov 74	13	Nov
Collozoum	1 750	28 Nov 74	438	———
Amphorellopsis	150	27 Dec 74	58	
Tricbocerca	225	27 Dec 74	56	Dec

Weekly and monthly variations

In view of weekly variation, the maximum number of smaller zooplankton was in September 1974 (4 298 x $10^3/m^3$) and the minimum was in April 1974 (60 x $10^3/m^3$). The weekly mean for the sampling period was 935 x $10^3/m^3$. The monthly mean was maximum in September 1974 (2 182 x $10^3/m^3$) and minimum in January 1975 (228 x $10^3/m^3$). The mean of the monthly means for the period was 936 x $10^3/m^3$. The values of mean SD and CV of smaller zooplankton fluctuation are shown in Tables 1, 2 and 3.

Weekly variations of smaller zooplankton seemed to depend on the changes in the abundance of its representatives. Out of 52 weekly samples, the significant correlation (r = 0.2732 at 5% significance level)' between total smaller zooplankton and every representative was found among the following genera:

Tintinnopsis	0.7567	*Amphorellopsis*	0.3205
Codonellopsis	0.5207	*Eutintinnus*	0.3289
Favella	0.3701		

Weekly and monthly variations in smaller zooplankton are shown in Figure 7.

LARGER ZOOPLANKTON

Composition

The general representatives of larger zooplankton were 10 phyla viz: Coelenterata, Annelida, Arthropoda, Mollusca, Ectoprocta, Brachiopoda, Chaetognatha, Phoronidea, Echinodermata and Chordata.

Specifically, they were classified into 44 genera/groups: Hydrida, Siphonophora, polychaete larvae, *Evadne, Penilia, Podon, Asterope, Conchoecia, Cypridina,* calanoid, cyclopoid, harpaticoid, *Balanus,* stoma-topod larvae, *Mysis, Hyperia,* decapod eggs, penaeid larvae, *Acetes* adult, *Lucifer* larvae, *Lucifer* adult, caridean larvae, caridean adult, anomuran larvae, brachyuran larvae, gastropod larvae, lamellibranch larvae, cyphonautes larva (*Bugula*), Lingula larvae, *Sagitta* Actino-trocha larva (*Phoronis*), Bipinnaria larva (*Asterina*), ophiopluteus larva, echinopluteus larvae, Auricularia larva (*Holothuria*), *Oiko-pleura, Fritillaria, Ciona, Pyrosoma, Salpa, Thalia,* fish eggs and fish larvae.

Abundance and occurrence

The common representatives of larger zooplankton were calanoid, caridean larvae, brachyuran larvae, *Sagitta,* cyclopoid, *Balanus, Acetes* larvae, *Lucifer* larvae, fish eggs and fish larvae, while the occasionally common ones were Hydrida, gastropod larvae, Siphonophora, *Oiko-pleura* and cyphonautes larva.

Maximum weekly and monthly abundance (no./m^3) of each genus/group occurred maximum as follows:

Plankton	No./m^3	Weekly date	No./m^3	Month
In order of day, week and month:				
Siphonophora	94.1	25 Jan 75	25.7	Jan
Caridean adult	34.7	1 Mar 74	7.2	
Brachyuran larvae	238.3	1 Mar 74	160.5	Mar
Fish eggs	368.0	14 Mar 74	100.4	
Bipinnaria larvae	0.6	29 Mar 74	Not maximum	——
Ciona	4.2	4 Apr 74	1.2	
Polychaete larvae	23.3	18 Apr 74	Not maximum	Apr
Bipinnaria larva	Not maximum		0.2	——
Oikopleura	2 187.0	3 May 74	473.5	
Fritillaria	1.9	3 May 74	0.6	
Balanus	547.8	9 May 74	Not maximum	May
Asterope	0.4	24 May 74	0.1	
Acetes larvae	299.6	31 May 74	75.9	——
Evadne	22.1	6 Jun 74	7.5	
Lucifer adult	38.0	6 Jun 74	9.5	Jun
Caridean larvae	194.0	6 Jun 74	Not maximum	
Ophiopluteus larva	6.3	13 Jun 74	1.6	——
Calanoid	4 419.3	19 Jul 74	2 787.4	
Hydrida	Not maximum		30.8	Jul
Caridean larvae	Not maximum		88.4	——
Echinopluteus larva	183.9	8 Aug 74	43.4	Aug
Hydrida	67.7	22 Aug 74	Not maximum	——
Cyclopoid	99.2	5 Sep 74	31.1	
Sagitta	195.8	5 Sep 74	129.7	Sep
Decapod eggs	29.1	12 Sep 74	7.3	
Salpa	0.8	19 Sep 74	0.2	——
Anomuran larvae	50.1	9 Oct 74	13.0	
Cyphonautes larva	56.7	9 Oct 74	18.6	
Lingula larvae	9.6	9 Oct 74	3.3	
Penilia	70.4	16 Oct 74	16.7	
Conchoecia	67.3	16 Oct 74	15.5	
Cypridina	1.0	16 Oct 74	0.2	
Harpaticoid	28.5	16 Oct 74	16.4	

Hyperia	9.8	16 Oct 74	2.6	Oct
Gastropod larvae	109.8	16 Oct 74	48.5	
Stomatopod larvae	5.2	24 Oct 74	2.7	
Acetes adult	4.7	24 Oct 74	1.4	
Lamellibranch larvae	43.0	24 Oct 74	19.2	
Auricularia larva	4.7	24 Oct 74	1.8	
Fish larvae	12.7	24 Oct 74	6.8	
Actinotrocha larva	2.3	31 Oct 74	0.6	
Polychaete larvae	Not maximum		7.4	
Podon	78.3	7 Nov 74	35.0	
Penaeid larvae	3.9	14 Nov 74	1.2	
Thalia	1.0	14 Nov 74	0.2	
Lucifer larvae	214.1	14 Nov 74	75.9	Nov
Mysis	0.8	28 Nov 74	0.2	
Balanus	Not maximum		216.3	
Pyrosoma	0.6	27 Dec 74	0.2	Dec

Weekly and monthly variations

The maximum number of larger zooplankton based on weekly variation was in July 1974 (5 159/m³) and the minimum was in January 1974 (111/m³). The weekly mean for the sampling period was 1 478/m³). The monthly mean was maximum in July 1974 (3 360/m³) and minimum in April 1974 (467/m³). The mean of monthly means for the period was 1 490/m³. The values of mean SD and CV of larger zooplankton fluctuation are shown in Tables 1, 2 and 3.

Weekly variation of larger zooplankton was found to depend on the changes in the abundance of its representatives. Out of 52 weekly samples, significant correlation between total larger zooplankton and every representative was found dominantly among the following genera/groups ($r = 0.2732$ at 5% significance level):

Calanoid	0.8678	*Evadne*	0.4219
Lucifer larvae	0.6705	Gastropod larvae	0.4140
Sagitta	0.6686	Cyphonautes larva	0.3087
Hydrida	0.5729	*Acetes* larvae	0.3828
Cyclopoid	0.5166	*Balanus*	0.3454
Fish larvae	0.5058	*Hyperia*	0.3168
Caridean larvae	0.4997	Harpaticoid	0.3146
Anomuran larvae	0.4927	Penaeid larvae	0.3007
Lucifer adult	0.4910	Fish eggs	-0.2922
Polychaete larvae	0.4642		

Weekly and monthly variations in larger zooplankton are shown in Figure 7.

Addendum copepod nauplii

Although its number was not included in the larger zooplankton, the group of copepod nauplii was treated as an added representative. Weekly abundance was independently enumerated from samples of smaller zooplankton.

Maximum and minimum weekly numbers both occurred in March 1974 having 1 625 x 10³/m³ and 32 x 10³/m³ respectively. The weekly mean for the sampling period was 381 x 10³/m³ (327 x 10³ SD, 0.86 CV). The monthly mean was maximum in March 1974 (905 x 10³/m³) and minimum in January 1975 (191 x 10³/m³). The mean of monthly means for the period was 371 x 10³/m³ (194 x 10³ SD, 0.52 CV). The monthly SD was maximum in March 1974 (675 x 10³) and minimum in May 1974 (69 x 10³). The monthly CV was maximum in October 1974 (0.83) and minimum in May 1974 (0.25). The weekly mean by season was maximum during NE monsoon having 427 x 10³/m³ (446 x 10⁶ SD, 1.04 CV) followed by SW-NE intermonsoon and SW monsoon having 424 x 10³/m³ (382 x 10³ SD, 0.90 CV) and 363 x 10³/m³ (237 x 10³ SD, 0.65 CV) respectively and minimum during NE-SW intermonsoon having 241 x 10³/m³ (130 x 10³ SD, 0.54 CV). Table 5 shows the weekly and monthly relative abundance and occurrence of copepod nauplii.

PHYSICAL-CHEMICAL-BIOLOGICAL RELATIONSHIPS

Out of 52 weekly samples, a correlation coefficient was used to measure the relationship between two parameters at a time. Table 6 summarizes the parameters having significant coefficients.

Being evident from Table 6, higher weekly height of high tide was directly related to the higher value of salinity and the abundance of *Melosira, Corethron, Lauderia, Bacteriastrum, Biddulphia, Hemialus, Asterionella, Thalassionema, Pleurosigma,* silicoflagellates, Siphonophora and brachyuran larvae. On the other hand, the inverse relationship was found in the following parameters: PO_4-P concentration, total phytoplankton, total diatom, *Chaetoceros, Tintinnopsis, Codonellopsis, Acetes* larvae, echinopluteus larvae, *Oikopleura* and copepod nauplii.

Weekly mean rainfall was directly related to total smaller zooplankton, *Prorocentrum, Stenosemella* and fish eggs and inversely related to mean atmospheric temperature and penaeid larvae.

Table 5. Weekly and monthly relative abundance and occurrence of copepod nauplii off Changi Point

Weekly sampling no.	Date	Weekly (no./m^3 x 10^3)	Mean monthly (no./m^3 x 10^3)
1	21 Feb 74	130	
2	1 Mar	1 368	
3	7	32	
4	14	1 125	Mar 74 905
5	22	375	
6	29	1 625	
7	4 Apr	300	
8	11	275	Apr 74 272
9	18	415	
10	25	100	
11	3 May	225	
12	9	225	May 74 269
13	17	210	
14	24	325	
15	31	360	
16	6 Jun	160	
17	13	425	Jun 74 231
18	20	53	
19	28	288	
20	4 Jul	143	
21	11	175	Jul 24 233
22	19	240	
23	25	375	
24	1 Aug	378	
25	8	498	Aug 74 434
26	15	338	
27	22	155	
28	29	800	
29	5 Sep	288	
30	12	555	Sep 74 389
31	19	338	
32	26	375	
33	3 Oct	270	
34	9	1 140	Oct 74 510
35	16	160	
36	24	758	
37	31	220	
38	7 Nov	420	
39	14	188	Nov 74 423
40	22	865	
41	28	220	
42	5 Dec	190	
43	12	128	Dec 74 262
44	19	410	
45	27	320	
46	2 Jan 75	95	
47	10	140	Jan 75 191
48	16	258	
49	25	330	
50	30	130	
51	8 Feb	385	Feb 74/75 338
52	14	500	

Table 6. Summary of parameters having significant coefficients (r = 0.2732 at 5% significance level of 52 weekly samples).

Parameter	Height of high tide	Rainfall	Atmospheric temperature	Water temperature	Salinity	PO_4-P
Height of high tide	*	...	...	...	0.4287	-0.3246
Rainfall	...	*	-0.3852	...	...	...
Atmospheric temperature	...	-0.3852	*	0.5617	...	...
Water temperature	...	...	0.5617	*	-0.2764	...
Salinity	0.4287	...	...	-0.2764	*	...
PO_4-P	-0.3246	...	...	...	...	*
Phytoplankton (Total)	-0.4271	...	...	...	-0.5007	...
Diatoms (Total)	-0.3641	...	...	...	-0.4717	...
Melosira	0.3358	...	...	...	...	...
Skeletonema	...	...	...	...	-0.4224	...
Leptocylindrus	...	...	...	...	-0.3450	...
Corethron	0.2767	...	...	...	...	-0.3119
Lauderia	0.3156	...	...	...	-0.2854	...
Thalassiosira	...	...	-0.2749	-0.4197	...	...
Coscinodiscus	...	...	-0.4697	-0.4067	...	...
Bacteriastrum	0.4277	...	...	...	...	...
Chaetoceros	-0.3032	...	...	...	-0.3518	...
Biddulphia	0.4591	...	-0.2884	-0.4752	0.4370	...
Hemialus	0.2786	...	...	...	0.4311	...
Lithodesmium	...	...	...	-0.3844	...	...
Ditylum	...	...	...	...	...	-0.3458
Streptotheca	...	...	...	-0.3173	...	...
Fragilaria	...	...	...	...	0.4688	...
Asterionella	0.3388	...	...	...	0.3713	...
Thalassionema	0.4010	...	-0.2854	...	0.3456	...
Striatella	...	...	...	...	-0.2975	...
Rhabdonema	...	...	...	...	...	-0.4044
Diploneis	...	...	...	-0.2908	...	...

Table 6 — continued

Parameter	Height of high tide	Rainfall	Atmospheric temperature	Water temperature	Salinity	PO_4-P
Pleurosigma	0.5324	...	...	...	...	-0.3674
Nitzschia	...	...	...	...	...	-0.4639
Dinoflagellates (Total)	...	...	...	...	...	0.3594
Prorocentrum	...	0.3969	...	...	...	...
Gymnodinium	...	...	...	0.3861	-0.3790	...
Pyrophacus	...	...	...	...	...	-0.2958
Gonyaulax	...	...	...	...	...	0.3747
Goniodoma	...	...	...	...	...	0.4260
Silicoflagellates (Total)	0.4355	...	...	...	...	...
Smaller zooplankton (Total)	...	0.3528	...	...	...	...
Codonella	...	...	...	...	0.3572	...
Tintinnopsis	-0.3437	...	...	...	...	...
Codonellopsis	-0.3752	...	...	0.4966	...	...
Stenosemella	...	0.2894	-0.2824	...	...	...
Eutintinnus	...	...	...	...	-0.4362	...
Larger zooplankton (Total)	...	...	...	0.5136	-0.4848	...
Hydrida	...	...	...	0.3790	...	...
Siphonophora	0.4053	...	...	-0.5352	0.2994	...
Polychaete larvae	...	...	...	0.3835	-0.4637	...
Evadne	...	...	0.2907	0.2968	...	...
Calanoid	...	...	...	0.3817	-0.5161	...
Cyclopoid	...	...	0.3414	0.5055	...	-0.2864
Balanus	...	...	...	0.4637	-0.3569	...
Penaeid larvae	...	-0.3777	...	...	...	...
Acetes larvae	-0.5324	...	...	...	-0.4797	...
Lucifer larvae	...	...	...	0.2932	-0.4784	...
Lucifer adult	...	...	...	0.3539	...	...
Caridean larvae	...	...	...	0.4354	...	...
Anomuran larvae	...	...	...	0.3397	...	...
Brachyuran larvae	0.3214	...	...	...	...	...

Table 6 — continued

Parameter	Height of high tide	Rainfall	Atmospheric temperature	Water temperature	Salinity	PO_4-P
Gastropod larvae	...	...	0.2848	0.5105	...	...
Cyphonautes larva	...	...	...	0.4787	...	...
Sagitta	...	...	...	0.3802	-0.2812	...
Echinopluteus larva	-0.5532	...	...	...	-0.4423	...
Oikopleura	-0.5235	...	...	...	-0.3339	...
Fish eggs	...	0.2759	...	...	...	...
Copepod nauplii (Addendum)	-0.4921	...	...	...	...	0.2921

*: no meaning ...: insignificant coefficient at 5% significance level

Direct relationship was found between weekly mean atmospheric temperature and the following parameters: water temperature, *Evadne*, cyclopoid and gastropod larvae. However, inverse relationship was found between mean rainfall and the following: *Thalassiosira, Coscinodiscus, Biddulphia, Thalassionema* and *Stenosemella*.

Higher weekly water temperature was directly related to higher mean atmospheric temperature, abundance of *Gymnodinium, Codonellopsis*, total larger zooplankton, Hydrida, polychaete larvae, *Evadne*, calanoid, cyclopoid, *Balanus, Lucifer* larvae and adult, caridean larvae, anomuran larvae, gastropod larvae, cyphonautes larva and *Sagitta*. On the contrary, an inverse relationship was found in salinity, *Thalassiosira, Coscinodiscus, Biddulphia, Lithodesmium, Streptotheca, Diploneis* and *Siphonophora*.

Higher weekly salinity was directly related to higher height of high tide, the abundance of *Biddulphia, Hemialus, Fragilaria, Asterionella, Thalassionema, Codonella* and Siphonophora. The inverse relationship was found in water temperature, total phytoplankton, total diatom, *Skeletonema, Leptocylindrus, Lauderia, Chaetoceros, Striatella, Prorocentrum, Gymnodinium, Eutintinnus*, total larger zooplankton, Hydrida, polychaete larvae, calanoid, *Balanus, Acetes* larvae, *Lucifer* larvae, *Sagitta*, echinopluteus larvae and *Oikopleura*.

The weekly concentration of PO_4-P was inversely related to height of high tide, *Corethron, Ditylum, Rhabdonema, Pleurosigma, Nitzschia, Pyrophacus* and cyclopoid. On the other hand, the direct relationship was found in total dinoflagellate, *Gonyaulax, Goniodoma* and copepod nauplii.

The monthly mean correlation coefficients between the abundance of plankton and each physical-chemical parameter (water temperature, salinity and PO_4-P concentration) were recognized as to be significant ($r = 0.5529$ at 5% significance level):

	Phytoplankton	Larger zooplankton
Water temperature	0.4165	0.6938
Salinity	-0.7682	-0.7172
PO_4-P concentration	-0.5668	-0.4631

As shown above, direct correlation exists between water temperature and total larger zooplankton. The inverse relationship was found between salinity and total phytoplankton as well as larger zooplankton. The fluctuation of total phytoplankton was also inversely related to PO_4-P concentration.

PHYTOPLANKTON-ZOOPLANKTON INTERRELATIONSHIPS

Weekly variations of the major plankton groups are shown in Figure 7. The correlation coefficients between the weekly variations of phytoplankton, smaller zooplankton and larger zooplankton were found insignificantly to be positive as follows ($r = 0.2732$ at 5% significance level of 52 weekly samples):

	Smaller zooplankton	Larger zooplankton
Phytoplankton	0.1710	0.1431
Smaller zooplankton		0.1445

Likewise, coefficients between most dominant representatives of the foregoing groups were also found insignificantly to be positive as follows:

	Tintinnopsis	Calanoid
Chaetoceros	0.0027	0.0843
Tintinnopsis		0.0033

Significant instances of correlation were noted between phytoplankton and larger zooplankton as well as between *Chaetoceros* and calanoid (Figures 8 and 9 respectively). In Figure 8, it seems reasonable to consider that peaks of larger zooplankton were noted to lag behind peaks of phytoplankton intermittently, i.e., every three, four, five, or more weeks. A similar relationship between calanoid and *Chaetoceros* was also noted.

Monthly mean coefficients between two major plankton groups as well as their most dominant representatives were found as follows ($r = 0.5529$ at 5% significance level):

	Smaller zooplankton	Larger zooplankton
Phytoplankton	0.2176	0.8276
Smaller zooplankton		0.1410

	Tintinnopsis	Calanoid
Chaetoceros	-0.1680	0.6062
Tintinnopsis		0.0135

The abundance of larger zooplankton was directly correlated with the abundance of phytoplankton and calanoid with *Chaetoceros* likewise, and Figure 10 shows patterns of their fluctuations.

HYDRO-BIOLOGICAL OBSERVATIONS IN THREE STATIONS

A stational comparison among three stations, outer vicinity (station A), off Changi Point (station B) and inner vicinity (station C), was undertaken in December 1974 as shown in Figure 2. Table 7 shows details of observations made in these stations.

Variations in water temperature among stations were very little (0.01 CV), station C being slightly warmer, in all tidal conditions. Salinity was found to be in a slightly decreasing trend (0.01 CV) from station A to C in all tidal conditions. Concentrations of PO_4-P were varied as follows: 0.26 and 0.45 CV during high tide, 0.24 and 0.57 during low tide, and 0.43 and 0.27 CV between high and low tide on 12 and 27 December 1974 respectively. Decreasing concentration of PO_4-P from station A to C was also found.

Random distribution of plankton components was measured between stations, i.e., A — B, A — C and B — C, at the same tide level and between two tidal levels at the same station, i.e., A (high tide) — A (low tide) and in a similar manner for B and C.

Phytoplankton and larger zooplankton sampled during the month were selected for comparison of their random distribution. The representatives of phytoplankton were *Skeletonema, Leptocylindrus, Thalassiosira, Coscinodiscus, Rhizosolenia, Chaetoceros, Ditylum, Nitzschia, Peridinium,* and *Ceratium.* The group of larger zooplankton were calanoid, *Balanus, Acetes* larvae, *Lucifer* larvae, caridean larvae, anomuran larvae, brachyuran larvae, *Sagitta,* fish eggs and fish larvae.

Table 8 shows the coefficients of rank correlation between two stations at a time (r = 0.746 at 1% and 0.564 at 5% significance levels).

At high tide on 12 December 1974, the relationship of phytoplankton composition was only significant between B and C at 1% level. However, A and B were significantly related at 5% level.

Table 7. Comparison of hydro-biological observations in stations A (1°23.7'N; 104°0.5'E), B (1°23.9'N; 103°59'E) and C (1°23.4'N; 103°58'E) at East Johore St. and vicinity.

Date	12 December 1974					
Tide & time (hr)	High Tide (0927)			Low Tide (1546)		
Station	A	B	C	A	B	C
Sampling time (hr)	0920	0945	1020	1420	1445	1515
Water temperature (°C)	28.4	28.4	28.6	29.0	29.0	29.2
Salinity (°/oo)	30.12	30.02	29.52	29.62	29.45	28.95
PO_4-P (ug atom/l)	0.64	0.88	1.10	1.20	1.70	1.97
Phytoplankton (cell no./m^3 x 10^3):						
Skeletonema	7 000	2 100	2 950	25 600	70 463	12 400
Leptocylindrus	438	863	1 813	4 775	7 438	4 600
Thalassiosira	2 300	425	938	3 900	9 100	2 000
Coscinodiscus	1 238	775	1 100	1 063	763	1 200
Rhizosolenia	1 125	863	475	600	1 800	338
Chaetoceros	3 700	2 625	2 500	2 300	4 600	2 900
Ditylum	463	150	113	538	75	138
Nitzschia	56,400	5 950	5 075	6 500	1 813	1 000
Peridinium	1 400	198	980	1 920	5 760	6 960
Ceratium	600	2 340	11 700	22 300	161 640	120 810
Larger zooplankton (no./m^3):						
Calanoid	195.776	260.451	269.741	301.096	282.751	609.395
Balanus	36.047	73.395	90.605	94.402	241.516	154.724
Acetes larvae	12.303	5.554	10.049	7.613	5.891	11.536
Lucifer larvae	17.916	17.258	39.241	25.123	217.365	916.806
Caridean larvae	10.577	3.967	5.583	2.284	8.247	9.501
Anomuran larvae	1.943	0.595	1.435	0.761	1.767	13.572
Brachyuran larvae	30.003	18.448	15.792	5.710	32.988	23.751
Sagitta	6.907	6.149	3.988	9.516	8.247	37.324
Fish eggs	5.180	8.133	11.166	2.665	4.713	3.393
Fish larvae	0.216	1.389	0.319	0.381	1.178	0.679

Table 7 — continued

Date	27 December 1974					
Tide & time (hr)	High Tide (0852)			Low Tide (1520)		
Station	A	B	C	A	B	C
Sampling time (hr)	1120	0935	1045	1620	1555	1355
Water temperature (°C)	28.7	28.5	28.7	28.7	29.1	29.2
Salinity (°/oo)	29.21	29.20	29.20	29.12	29.08	29.19
PO_4-P (ug atom/l)	0.59	0.69	1.30	0.45	1.50	1.84
Phytoplankton (cell no./m^3):						
Skeletonema	24 900	900	9 625	94 500	659 400	671 250
Leptocylindrus	84 500	19 413	404 100	164 700	578 175	912 525
Thalassiosira	1 300	1 875	2 750	21 600	23 800	52 500
Coscinodiscus	1 100	1 475	1 125	6 263	23 988	25 288
Rhizosolenia	12 788	24 050	25 275	50 250	94 500	71 700
Chaetoceros	8 700	2 400	2 375	95 850	15 400	16 250
Ditylum	57 625	57 588	68 475	136 725	92 700	30 675
Nitzschia	34 325	36 975	34 388	97 200	579 600	451 275
Peridinium	400	305	2 120	1 320	2 640	3 160
Ceratium	40	198	1 080	600	960	20 360
Larger zooplankton (no./m^3):						
Calanoid	314.940	426.238	397.655	618.999	148.839	605.793
Balanus	60.406	116.135	302.499	468.640	787.114	552.293
Acetes larvae	71.765	89.572	171.282	101.176	81.268	266.680
Lucifer larvae	23.749	51.890	142.735	415.242	369.816	763.825
Caridean larvae	3.098	6.177	1.502	5.621	13.697	12.346
Anomuran larvae	2.065	3.706	11.018	3.513	0.913	21.400
Brachyuran larvae	15.487	14.826	19.031	28.807	27.394	53.501
Sagitta	10.842	8.648	–	39.346	10.958	44.447
Fish eggs	22.201	13.590	63.605	7.729	22.828	42.801
Fish larvae	–	1.853	–	0.703	0.913	4.938

—: none present

Table 8. Coefficients of rank correlation of parameters between stations off Changi Point (B) and vicinities (A and C)*

Tide and plankton	12 Dec 74 Station	12 Dec 74 r**	27 Dec 74 Station	27 Dec 74 r**
High tide (between stations):				
Phytoplankton	A – B	0.648	A – B	0.794
	A – C	0.442	A – C	0.964
	B – C	0.891	B – C	0.818
Larger zooplankton	A – B	0.879	A – B	0.915
	A – C	0.915	A – C	0.952
	B – C	0.939	B – C	0.927
High tide – low tide (same station):				
Phytoplankton	A – A	0.430	A – A	0.963
	B – B	0.103	B – B	0.527
	C – C	0.491	C – C	0.746
Larger zooplankton	A – A	0.854	A – A	0.927
	B – B	0.861	B – B	0.854
	C – C	0.697	C – C	0.879
Low tide (between stations):				
Phytoplankton	A – B	0.715	A – B	0.673
	A – C	0.636	A – C	0.612
	B – C	0.842	B – C	0.891
Larger zooplankton	A – B	0.885	A – B	0.891
	A – C	0.854	A – C	0.915
	B – C	0.836	B – C	0.879

*: Based on Table 7.
**: 0.746 at 1% and 0.564 at 5% significance levels

Relationship of A and C was insignificant at both levels. On 27 December 1974, the relationship of phytoplankton between two stations at a time was all significant at 1% level.

At low tide, phytoplankton composition between B and C was all significantly related at 1% level while A and B as well as A and C were insignificant. At 5% level, however, the relationships were all significant.

The relationships of phytoplankton composition between tidal levels at the same station were significant only at A and C on 27 December 1974 at 1% level. Others were all insignificant.

Zooplankton composition between two stations at a time was closely related at 1% significance level except C (between two tidal levels) on 12 December 1974 which was significant at 5% level.

Irrespective of the significance level, the rank correlation coefficients of plankton components between two stations at a time were all positive.

DISCUSSION AND CONCLUSIONS

As mentioned in the materials and methods, innovations were made in the collection method of Tham (1953) which was followed by Khoo (1967) and Chua (1967). Though comparative observations are useful when data are collected in the same area and season, methodical innovations were made in the present study to improve plankton observations to make interpretation more clear.

The particular collection method used in the present study permitted the sampling of plankton components nearer to their possible peaks of abundance and occurrence which is in line with the quick rotation of plankton generations in the tropics and sub-tropics as pointed out by Riley (1941). It is also useful for the selection of samples at random taking into consideration the patchy distribution of plankton. Furthermore, though axiomatic, it is available to make the phytoplankton sample more fully representative of the population, especially very small diatoms (length and/or diameter of less than 50 μ) which can readily spare collection by filter net having mesh opening of 50 μ or more. The mesh selectivity of the net for the above-mentioned diatoms is remarkably important. It is related to the biological phenomenon of quick rotation of plankton generations.

This phenomenon, coupled with the asexual reproduction of diatom by cell division results in a decrease in the average cell size of the population. Although the above -mentioned reproductive process cannot continue indefinitely because the original cell size is commonly restored by the formation of so-called auxospores, it is a precaution against distortion of representative sample of the phytoplankton population through filtration.

In the present work, it was suggested that the influence of tides adversely affected the hydro-biological parameters responsible for the growth of plankton population in the area. Tidal movements bring out changes in salinity, PO_4-P concentration and the density of plankton population.

As the area is not far from the Johore River of Malaysia, the water condition is generally oligohaline seawater (17-30°/oo) which is apparently maintained by the weaker inflow of the river and the stronger incoming water from the open sea. However, the area tends to be mesohaline seawater (30-34°/oo) during the NE monsoon as the incoming of water from the open sea is accentuated by the monsoon wind.

The area is subject to rapid changes in PO_4-P concentration. The incoming tides bring in lower concentration seawater from the open sea and the outgoing tides bring out higher concentration from the inner portion of the straits, derived from inland tributaries.

The direct relationship between higher heights of high tide and the abundance of some plankton groups suggests that incoming tides bring such groups to the area. The inverse relationship of total phytoplankton and other specific groups of plankton shows that incoming tides bring in lesser density of plankton population.

In sharp contrast, based on the stational comparison of three stations in December 1974, the quantity of the same quality of plankton, especially phytoplankton, at low tides is more or less double their former quantity at high tide. This suggests that local conditions somewhere inside the straits are favorable for phytoplankton growth. Higher quantity of plankton is then carried down to the area during low tide.

The presence of benthic organisms such as some genera of harpaticoid in the surface suggests tidal turbulence in the area.

The inverse relationship between weekly salinity and total phytoplankton, together with larger zooplankton, shows that salinity is the most important limiting factor off Changi Point. It suggests then that prevailing lower salinity is generally conducive to rapid plankton growth, resulting in the bloom of some species.

RED TIDE ORGANISM

Gymnodinium sp. is a red tide organism whose bloom in May 1974 is due to the prevailing conditions which are favorable for its rapid growth. As mentioned in the results, each species is inversely related to salinity and directly related to water temperature. Tracing the local conditions during the red tide bloom show that the values or monthly SD (0.40) and CV (0.01) of salinity fluctuation in May are the lowest for the period. In addition, record shows that the monthly mean of salinity (27.97°/oo) in May is second to the lowest (27.43°/oo) for the period. On the other hand, monthly mean water temperature of 29.9°C is the warmest temperature for the period. The month of May is also characterized with sufficient concentration of PO_4-P, having 0.89 µg-atom/1 which is above the mean of monthly means (0.84 µg-atom/1) for the period. The foregoing conditions coupled with considerably low monthly CV (0.07) in the heights of high tide, maximum and minimum monthly CV for the period being 0.12 and 0.04 respectively, favored the *Gymnodinium* bloom in that particular month.

It is worthwhile mentioning here that the enumeration of this species was troublesome because of its fragility. Finding a special method of preserving this fragile organism will contribute to its future comprehensive study.

In addition to the combined effect of the above mentioned parameters, the numerical standing among the genera or groups of phytoplankton plays an important role in the hierarchy of succession. As shown in the results, the blooms are dominated by a small number of species and/or one form. Generally, it is either *Chaetoceros* or *Skeletonema*. The main reason is that they happen to have a head start numerically over the others. Thus, when local conditions become favorable for rapid growth they can easily forge ahead, resulting in a bloom. Moreover, it appears that *Chaetoceros* and *Skeletonema* are most favored by local conditions.

The genus of *Chaetoceros* is composed of different species but mostly dominated by *Chaetoceros* sp. This species resembles *Chaetoceros debilis* Cleve. However, it may not be identified specifically because it is only known in the temperate regions. A detailed study, therefore, on this particular species is of special interest.

The bloom of *Ceratium furca* in November 1974 is also interesting because it has no significant correlation with important physical and chemical parameters.

Diverging into the meroplankton, it is interesting to know that the weekly mean rainfall is directly related to fish eggs but inversely related to penaeid larvae. The direct relationship of fish eggs seems to suggest similarity to the spawning behavior of some inland fishes like common carp, catfish (*Clarias*), etc. The spawning periods of these fishes commonly coincide with the rainy season. On the other hand, the inverse relationship between rainfall and penaeid larvae is similar to the observations of Poernomo (1968) and Prawirodihardjo (1975). According to them, the two peaks of abundance in the occurrence of shrimp fry at Jakarta Bay coincide with the beginning and the end of the rainy season. These observations apparently suggest the spawning periods of penaeids in the region.

In view of plankton association, the remarkable morphological and ecological differences among the components necessitate further analysis. It is, however, a complex subject that needs to be studied in depth. Somehow, the major groups, together with their respective dominant representatives, could be analyzed. The correlation coefficients based on weekly fluctuation in abundance show that phytoplankton-larger zooplankton and *Chaetoceros*-calanoid interrelationships are apparently insignificant, however, monthly interrelationships are significant.

Narrowing down the morphological and ecological differences, particular interest is given to the interrelationships of *Chaetoceros* and calanoid. The insignificant coefficient based on their weekly abundance is hardly surprising. It apparently suggests that the interaction between the two is in progress whereby no form of relationship can be measured. However, it was noted that there were instances where striking abundance of calanoid intermittently lagged behind peaks of *Chaetoceros* as shown in Figure 9. Such intermittent relationship seems to indicate that calanoid is dependent upon its association with

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Chaetoceros. Undoubtedly, the correlation coefficient based on monthly means shows that calanoid is directly related to *Chaetoceros* which is clearly seen in Figure 10. The strikingly unique abundance of calanoid in June 1974 is apparently sustained by the *Skeletonema* bloom which occurred in the same month.

The intermittent relationship also apparently indicates that the grazing effect of calanoid in the rapidly growing *Chaetoceros* is rather slow, hence it requires a considerable lapse of time before a clear collapse of *Chaetoceros* becomes evident.

The intermittent collapse of *Chaetoceros* may not be attributed entirely to the grazing of calanoid. The concentration of PO_4-P seems to play an important role as indicated by the insignificant relationship of its weekly concentration and the inverse relationship of its monthly concentration with the abundance of *Chaetoceros*. The former apparently indicates that the supply of PO_4-P is abundant sustaining the continuous growth of *Chaetoceros* for quite some time. And the latter apparently indicates the impoverishment of PO_4-P supply causing the collapse of *Chaetoceros*. In short, it appears that the intermittent collapse of *Chaetoceros* is caused by the impoverishment of PO_4-P concentration coupled with the increased grazing of calanoid, irrespective of the effect of salinity.

Since calanoid is the most dominant group of larger zooplankton, it is interesting to compare the present study with other studies made in nearby vicinities. Tham (1953) reported three peaks of copepod adults in Singapore Straits; July, October and April of 1948 and 1949. Khoo (1966) reported four peaks in East Johore Straits; July and October of 1965 as well as February and April of 1966. Chua (1969) reported four peaks in Ponggol estuary; October and November of 1965, and February and April of 1966.

Matching the above-mentioned, the calanoid, cyclopoid and harpaticoid data of the present work were combined forming a group of copepod adults. The combination shows four peaks; June, July, October and November of 1974. These peaks can fit in with their results except June. It is noted that the number per cubic meter of copepod adults in their results is much higher than the present work. The remarkable difference between their results and the present work may be attributed largely to the difference in the methods of collection. Accepting the phenomena of vertical migration of zooplankton, their

collection of copepods by pumping water samples at nighttime at different depths surely gave much more quantity of copepods than the present study where samples were obtained by surface towing a plankton net in the daytime during high tide. There is no need to argue at length that copepods comprise the bulk of zooplankton. The remarkable bulk in both numbers of individuals and species is also a point which can be readily accepted. To reach worthwhile qualitative and quantitative conclusions in their presence, the samples obtained by plankton net are good enough because representative samples of three major groups: calanoid, cyclopoid and harpaticoid can be collected by the plankton net as well as the pump sampler. At this juncture, it is necessary to emphasize that the abundance in the occurrence of plankton components in the present study is presented not in absolute values but relative numbers of each type of plankton.

Throughout the period of water sampling, the blooms of phytoplankton generally collapsed in less than a week. This apparently indicates that local conditions are not alarming yet giving stable opportunity for ecological succession to set in. However, the sporadic blooms are perhaps early signs of excessive eutrophication which may throw the present steady state of ecological succession off beam sooner or later. Thus, a more comprehensive study should be undertaken in the area and its vicinities. In the final analysis, it seems to be quite reasonable to consider that the necessary frequency of future water sampling is every three days during high and low tides, hence representative sample of the population is obtained nearest to any possible peak or change in its abundance and occurrence.

SUMMARY

1. Records of water temperature, salinity, PO_4-P concentration, and plankton abundance and composition were based on weekly sampling in the daytime during high tide near the surface of 20 stations off Changi Point. Sequence of plankton components was correlated to hydrological and meteorological factors. Interrelationships between major groups of plankton, together with their respective dominant representatives, were measured. Stational comparisons of random distribution of parameters between off Changi Point and nearest vicinities were carried out in the daytime during high and low tides.

2. Dominant genera of diatoms were *Chaetoceros, Leptocylindrus, Nitzschia, Thalassiosira, Skeletonema, Lauderia, Striatella, Rhizosolenia, Corethron* and *Hemialus*. Dominant genera of dinoflagellates were *Peridinium, Ceratium, Dinophysis, Gymnodinium, Prorocentrum, Gonyaulax* and *Goniodoma*. Overall, dominant genera of phytoplankton were *Chaetoceros, Leptocylindrus, Thalassiosira, Skeletonema, Nitzschia, Prorocentrum, Striatella, Lauderia, Gonyaulax, Goniodoma* and *Hemialus*. Blooms were dominated by *Chaetoceros* sp., *Skeletonema costatum* (Greville) Cleve, *Gymnodinium* sp. and *Ceratium furca* (Ehrenberg) Dujardin.

3. Dominant groups of smaller zooplankton were *Tintinnopsis, Codonellopsis, Favella, Amphorellopsis,* and *Eutintinnus*.

4. Dominant groups of larger zooplankton were calanoid, *Lucifer* larvae, *Sagitta*, Hydrida, cyclopoid, fish larvae, caridean larvae, anomuran larvae, *Lucifer* adult, polychaete larvae, *Evadne*, gastropod larvae, cyphonautes larva, *Acetes* larvae, *Balanus, Hyperia*, harpaticoid, penaeid larvae and fish eggs.

5. Weekly height of high tide was directly related to salinity, *Melosira, Corethron, Lauderia, Bacteriastrum, Biddulphia, Hemialus, Asterionella, Thalassionema, Pleurosigma*, silicoflagellates, Siphonophora and brachyuran larvae, but inversely related to PO_4-P concentration, total phytoplankton, total diatom, *Chaetoceros, Tintinnopsis, Codonellopsis, Acetes* larvae, echinopluteus larva, *Oikopleura* and copepod nauplii. The former suggests that incoming tides bring such groups to the area and the latter means that incoming tides bring in lesser density of plankton population.

6. Weekly mean rainfall was directly related to total smaller zooplankton, *Prorocentrum, Stenosemella* and fish eggs, but inversely related to mean atmospheric temperature and penaeid larvae. The direct relationship of fish eggs seems to suggest similarity to the spawning behavior of some inland fishes like common carp, catfish, etc., since the spawning periods of these fishes commonly coincide with the rainy season.

7. Weekly mean atmospheric temperature was directly related to water temperature, *Evadne*, cyclopoid and gastropod larvae, but inversely related to mean rainfall, *Thalassiosira, Coscinodiscus, Biddulphia, Thalassionema,* and *Stenosemella*.

8. Weekly water temperature was directly related to mean atmospheric temperature, *Gymnodinium, Codonellopsis*, total larger zooplankton, Hydrida, polychaete larvae, *Evadne*, calanoid, cyclopoid, *Balanus, Lucifer* larvae and adult, caridean larvae, anomuran larvae, gastropod larvae, cyphonautes larva and *Sagitta* but inversely related to salinity, *Thalassiosira, Coscinodiscus, Biddulphia, Lithodesmium, Streptotheca, Diploneis* and Siphonophora.

9. Weekly salinity was directly related to height of high tide, *Biddulphia, Hemialus, Fragilaria, Asterionella, Thalassionema, Codonella* and *Siphonophora*, but inversely related to water temperature, total phytoplankton, total diatom, *Skeletonema, Leptocylindrus, Lauderia, Chaetoceros, Striatella, Prorocentrum, Gymnodinium, Eutintinnus*, total larger zooplankton, Hydrida, polychaete larvae, calanoid, *Balanus, Acetes* larvae, *Lucifer* larvae, *Sagitta*, echinopluteus larvae and *Oikopleura*.

10. Weekly concentration of PO_4-P was directly related to total dinoflagellate, *Gonyaulax, Goniodoma* and copepod nauplii, but inversely related to height of high tide, *Corethron, Ditylum, Rhabdonema, Pleurosigma, Nitzschia, Pyrophacus* and cyclopoid.

11. Maximum monthly mean water temperature, low values of monthly mean, SD and CV of salinity fluctuation, and sufficient monthly mean concentration of PO_4-P, coupled with considerably low monthly CV in the heights of high tide, favored the Gymnodinium bloom in May 1974.

12. Based on monthly mean values, water temperature was directly related to larger zooplankton. Salinity was inversely related to phytoplankton and larger zooplankton. Concentration of PO_4-P was inversely related to phytoplankton. Larger zooplankton was directly related to phytoplankton and calanoid to *Chaetoceros* likewise. It was noted that there were instances where striking abundance of calanoid intermittently lagged behind peaks of *Chaetoceros*. Such intermittent relationship seems to indicate that calanoid is dependent upon its association with *Chaetoceros*.

13. Zooplankton components of the area were closely related to its nearby vicinities but phytoplankton components were patchy.

14. The sporadic blooms are perhaps early signs of excessive eutrophication which may throw the present steady state of ecological succession off beam sooner or later. Thus, a more comprehensive

study should be undertaken in the area and its vicinities. It seems to be quite reasonable to consider that the necessary frequency of future water sampling is every three days during high and low tides, hence representative sample of the population is obtained nearest to any possible peak or change in its abundance and occurrence.

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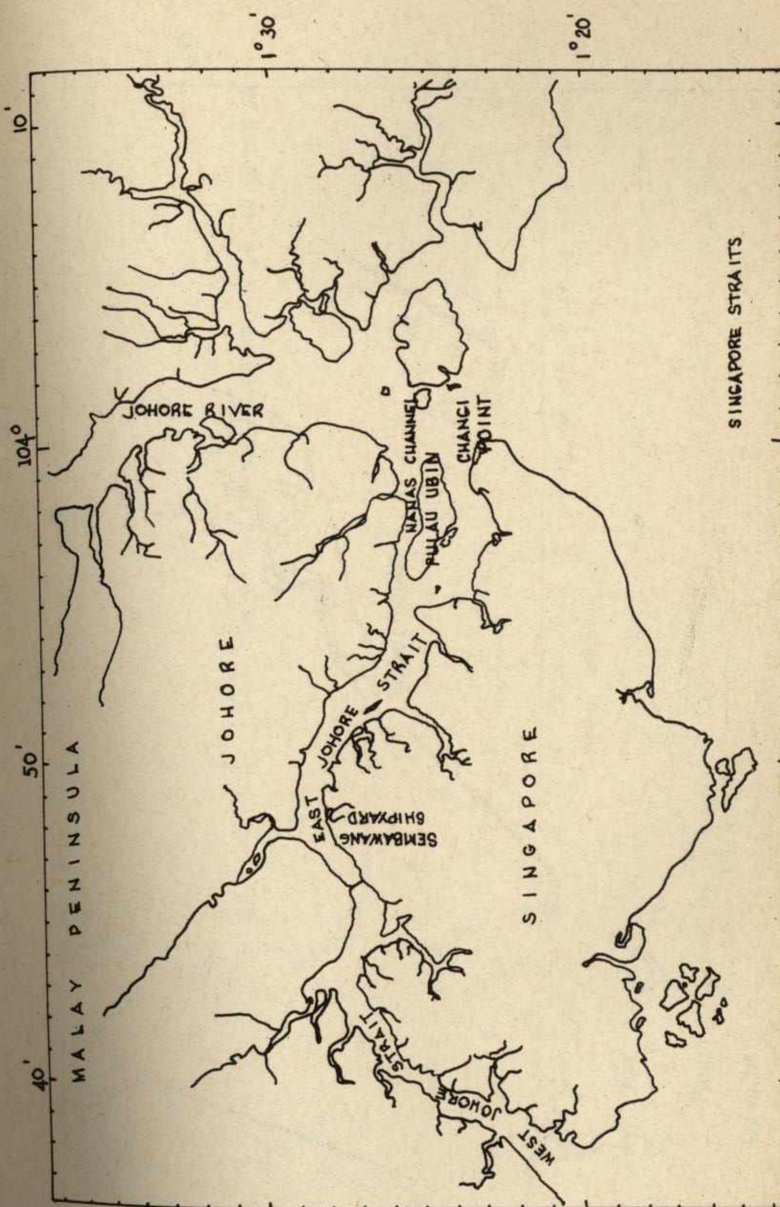

Figure 1. Coastal waters off Changi Point and its vicinities.

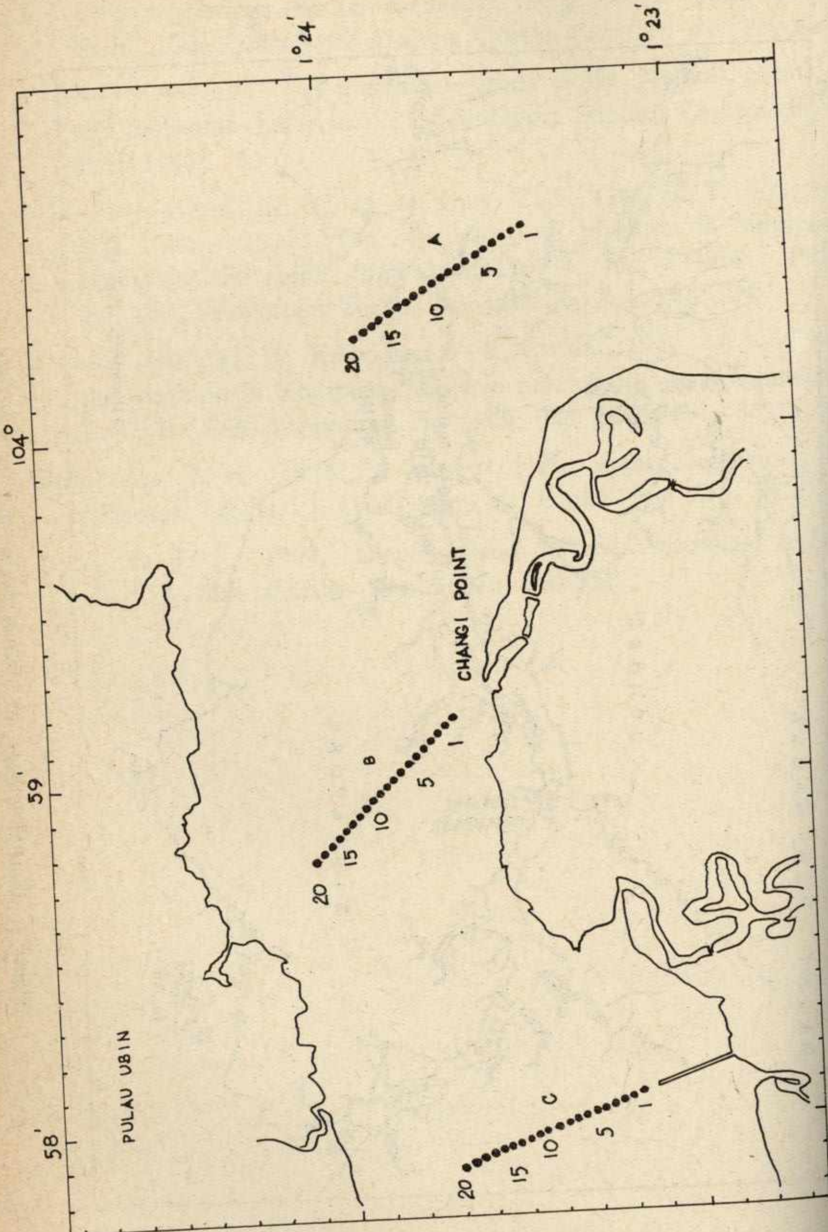

Figure 2. Layout of sampling stations off Changi Point (B) and nearby vicinities (A

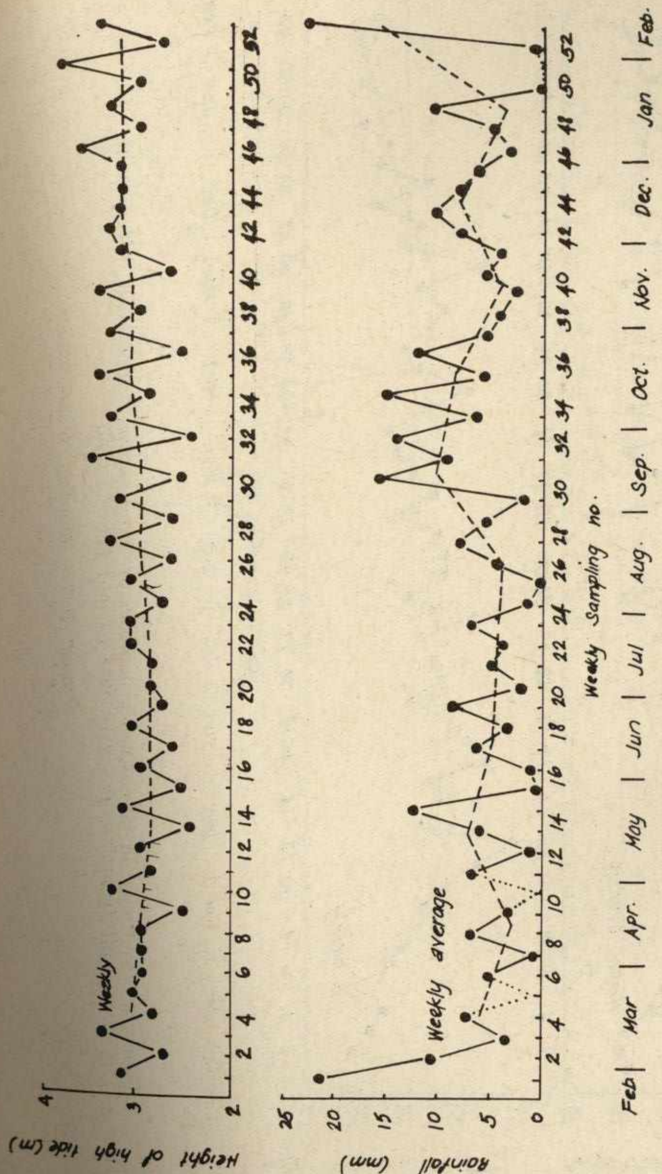

Figure 3. Variations in height of high tide and rainfall off Changi Point from late February 1974 to mid February 1975.

Broken lines: Monthly mean values
Dotted lines: Traces of rainfall

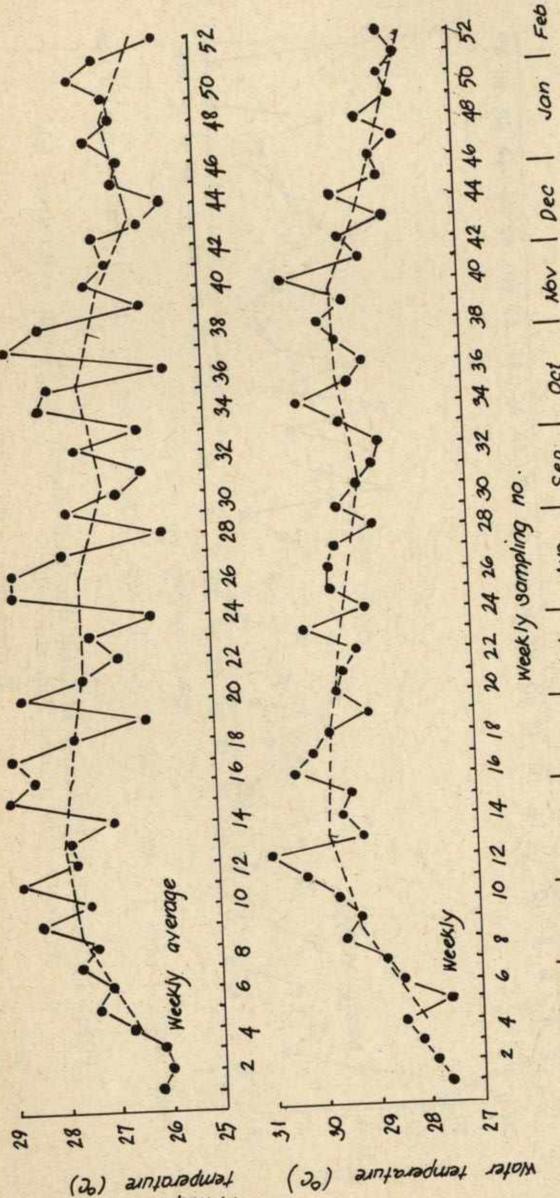

Figure 4. Variations in atmospheric temperature and water temperature off Changi Point from late February 1974 to mid February 1975.

Broken lines: Monthly mean values

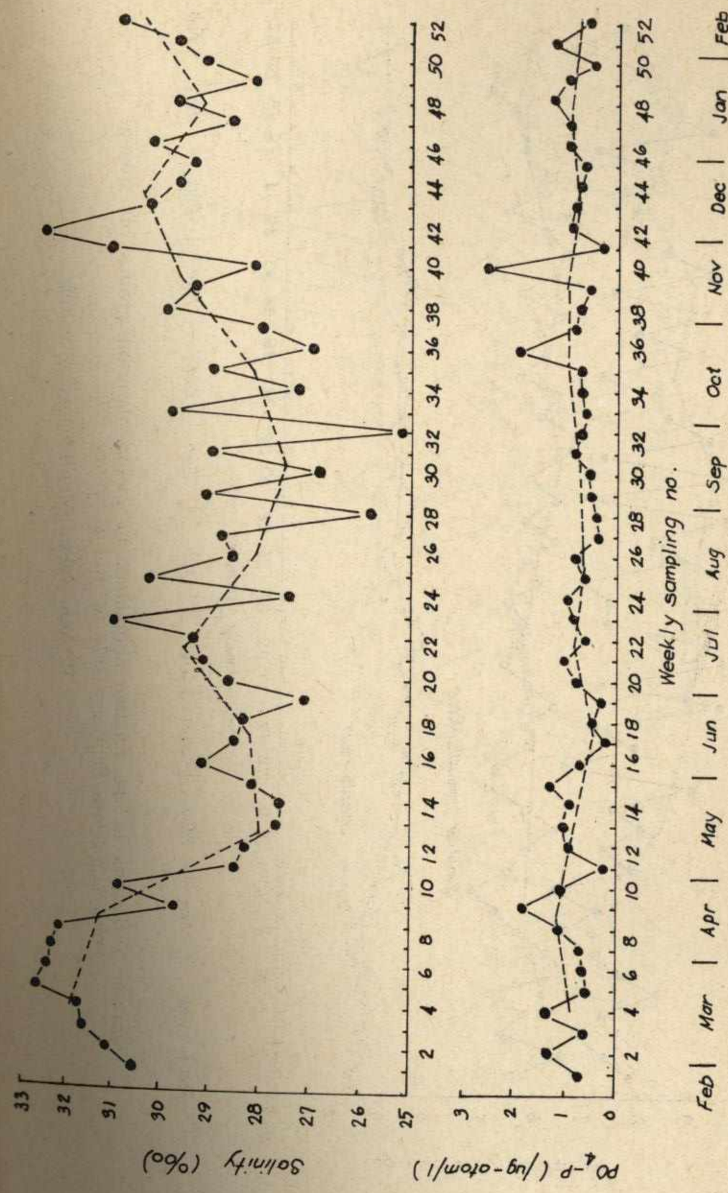

Figure 5. Variations in salinity and PO_4-P off Changi Point from late February 1974 to mid February 1975.

Broken lines: Monthly mean values.

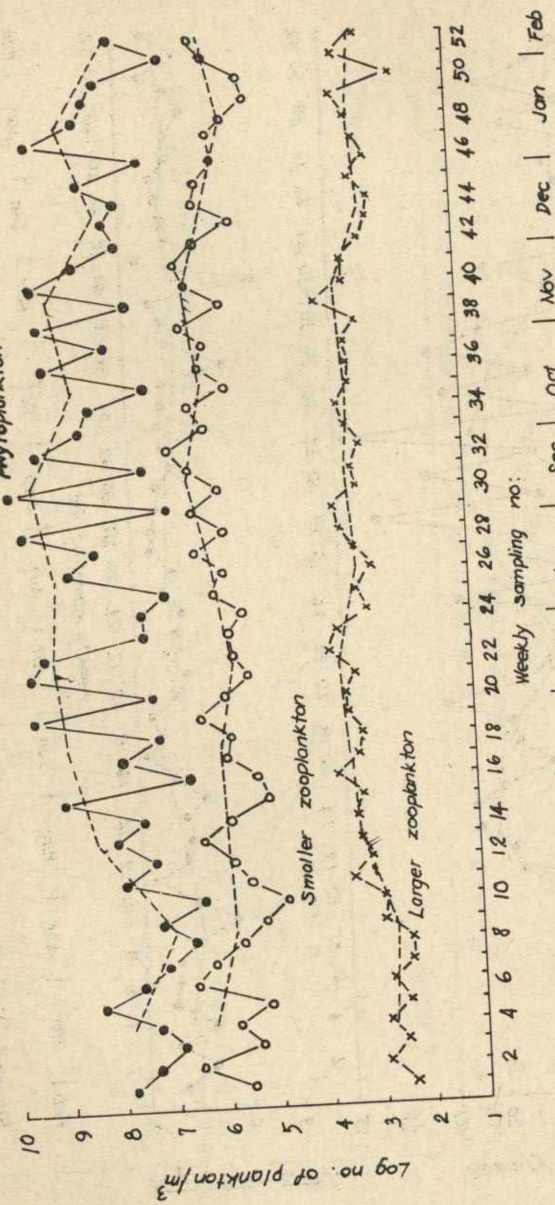

Figure 6. Variations in the relative abundance of major plankton groups off Changi Point from late February 1974 to mid February 1975.

Broken lines: Monthly mean values.

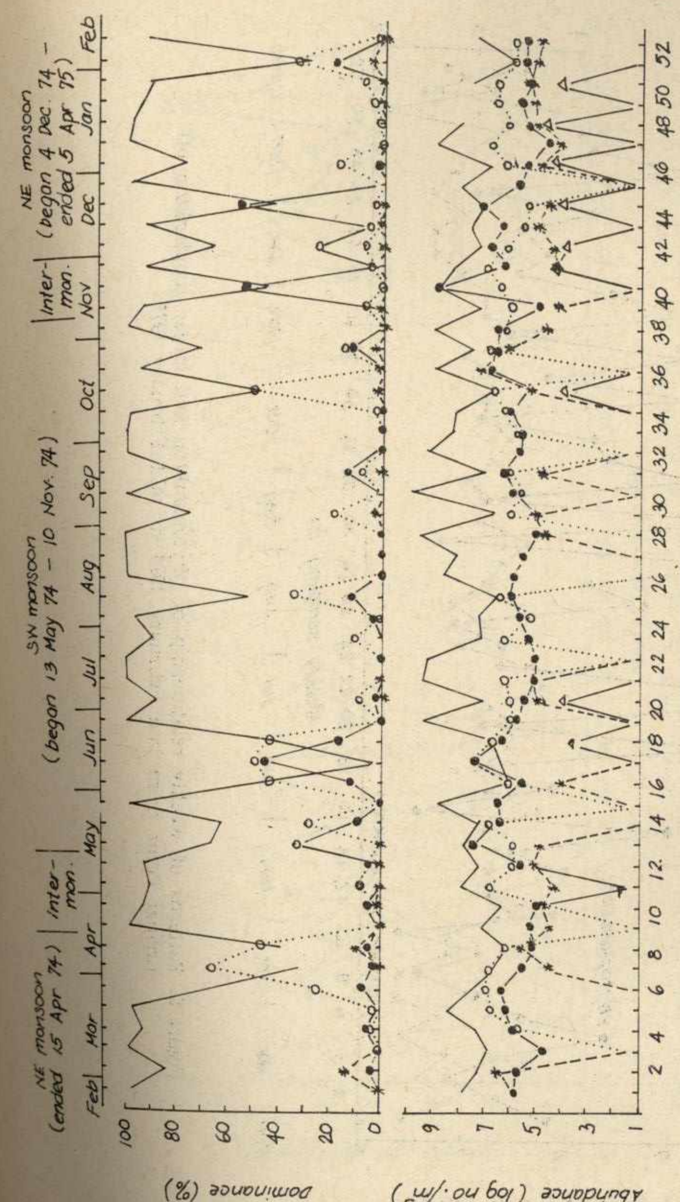

Figure 7. Phytoplankton succession off Changi Point from late February 1974 to mid February 1975.

— Diatoms o . . . Green algae ✻ - - Detritus
● - Dinoflagellates Δ — silicoflagellates

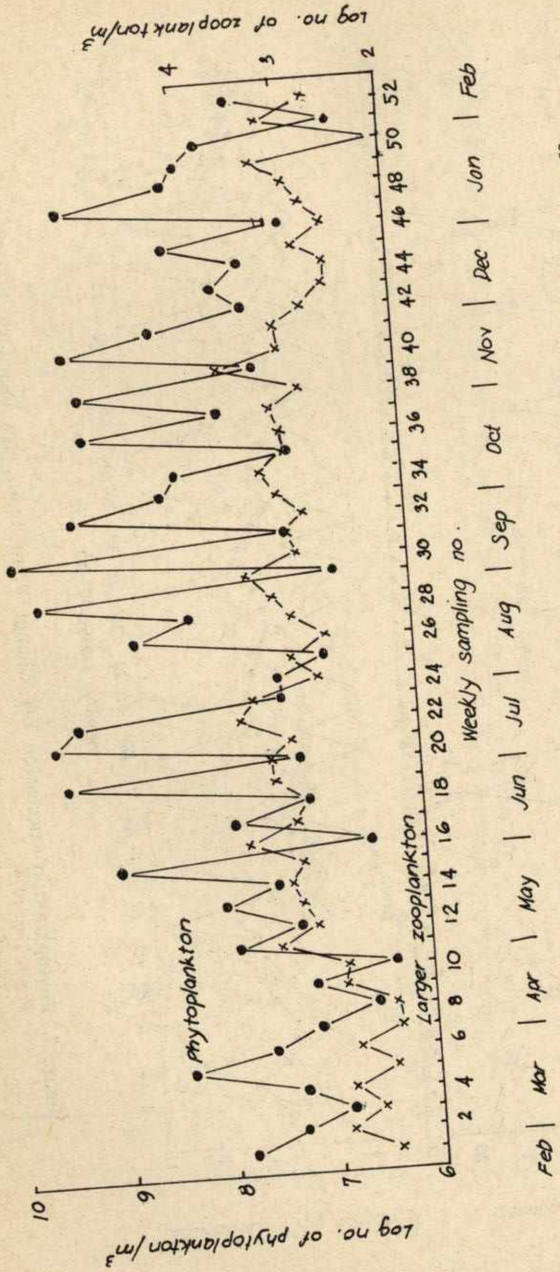

Figure 8. Patterns of weekly relationship of phytoplankton and larger zooplankton off Changi Point from late February 1974 to mid February 1975.

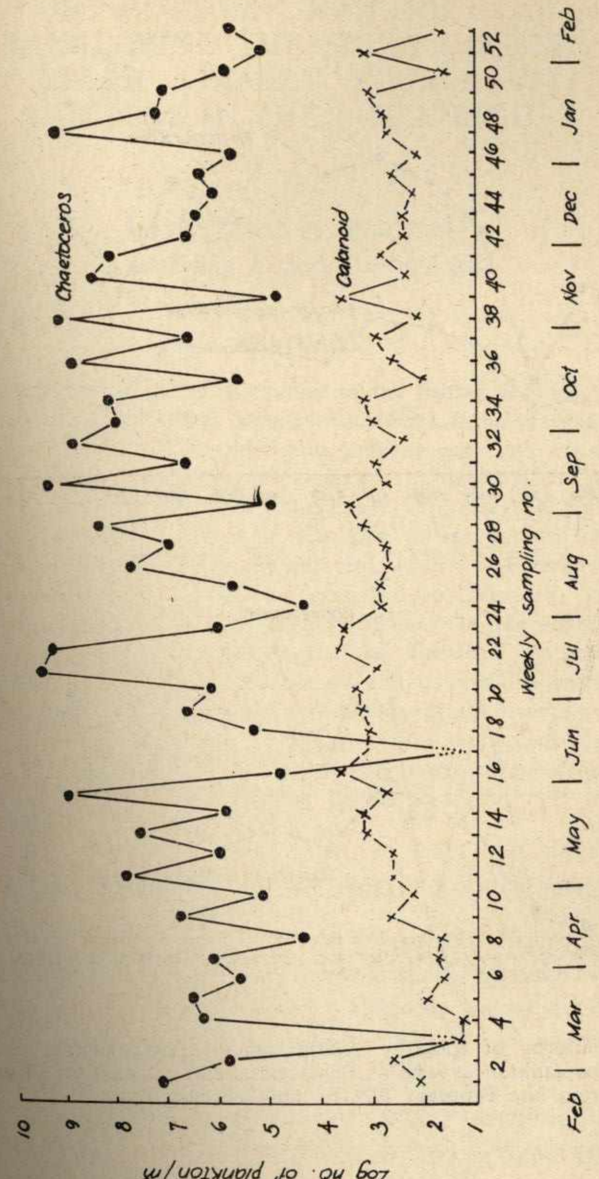

Figure 9. Patterns of weekly relationship of *Chaetoceros* and calanoid off Changi Point from late February 1974 to mid February 1975.

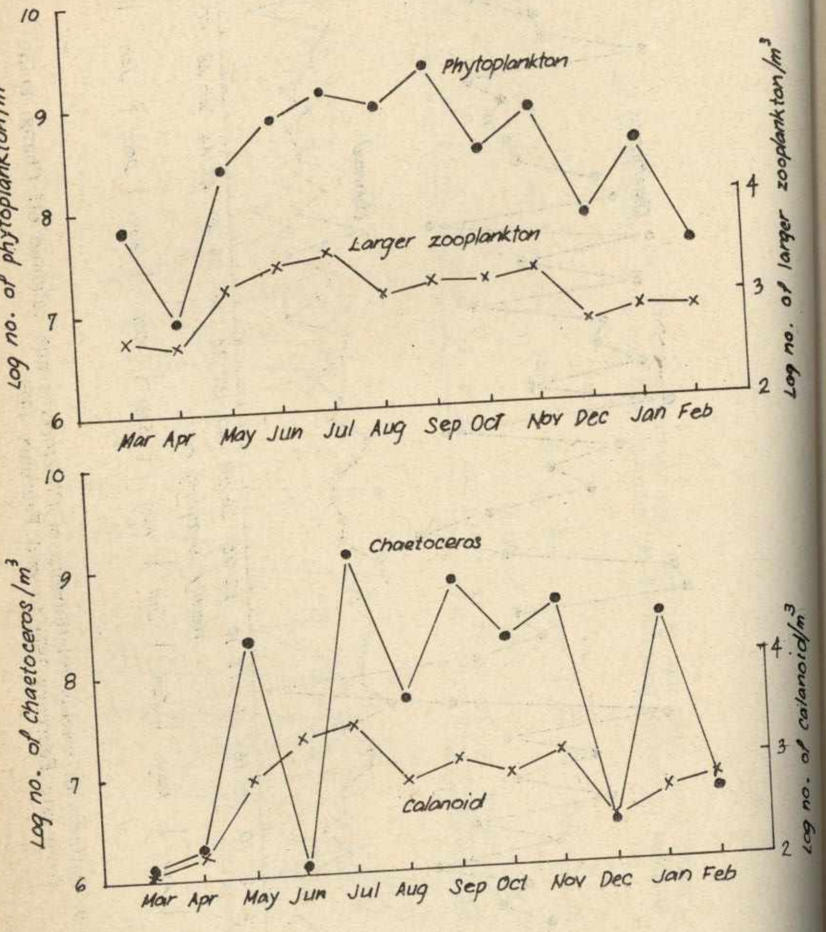

Figure 10. Patterns of monthly relationship of phytoplankton and larger zooplankton as well as Chaetoceros and calanoid off Changi Point from late February 1974 to mid February 1975.