ANALYSIS ON THE RELATIONSHIP BETWEEN THE SCATTERING LAYER AND SOME OCEANOGRAPHIC FACTORS IN THE SOUTH CHINA SEA

By

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INTRODUCTION

Scattering layer as recorded on an echo sounder paper is caused by the difference between the water mass and the presence of zooplankton.

In this paper, the relationship between the scattering layer and some hydro-biological factors in the South China Sea is discussed based on the records obtained during the survey cruises of RV CHANGI in April, June, and September, 1972. The diurnal vertical movement of scattering layer and the composition and biomass of zooplankton are also discussed.

MATERIALS AND METHODS

Oceanographic observations were carried out by the 390-ton research vessel, CHANGI, of the Marine Fisheries Research Department, Southeast Asian Fisheries Development Center (SEAFDEC), during the months of April, June, and September, 1972. The locations of the sampling stations are shown in Fig. 1.

TRACINGS OF FISH ECHO SOUNDER

Tracing records of scattering layer, fish schools, and depth of the sea were obtained by a fish echo sounder. These tracings were compared with the depths of thermocline and halocline, and plankton biomass. The echo sounder used was the SR-II type of high frequency (200 kc) made by Kaijo Electric Co. Ltd., Japan.

WATER TEMPERATURE

Continuous graphical records of water temperature in the sea were obtained by Bathythermograph (BT). The depths of the thermocline were read from BT records. Water samples for the determination of salinity were collected by Nansen reversing bottles at depths of 0m, 10m, 20m, 30m, 50m, 75m, 100m, and 150m. However water samples near the bottom were collected at 3m above the sea floor. The temperature of each depth was measured by a pair of reversing thermometers attached to the Nansen bottles and the results were compared with those recorded by the BT.

SALINITY

Salinity (°/oo) was computed from the specific gravity of the sample measured by the Akanuma type hydrometer. The results obtained were standardized with Standard Sea Water (P55 prepared in Denmark). Depth of halocline was estimated from interpolation of values of salinity in each depth at each station.

PLANKTON

Plankton samples were collected by vertical hauling from 5m above the sea floor, or from a maximum depth of 150m from the surface. The zooplankton net used was the North Pacific standard (Norpac) net with a mouth diameter of 45 cm. To analyze the relationship between plankton biomass in each depth stratum and scattering layer at the desired station (04°50'N, 104°00E), the samples were collected from three layers (0-20m, 20-40m and 40-60m) by a type of closing net with 25 cm diameter and 24 meshes per cm. Each net was fitted with a flowmeter at the center of its mouth to measure the total volume of water filtered through the net. The collected samples were preserved in 5% neutral formalin. The plankton biomass (mg/m^3) was determined by wet weight method, and the samples were sorted into some main groups, and the individual number of each group was counted.

RESULTS

Scattering layer

1. Types of scattering layer

From the analysis of all samples, the patterns of the scattering layer were classified into four main types (Fig. 2) described as follows:

Type A: When the scattering layer occurred at the upper stratum of the thermocline (Fig. 2-A).

Type B: When the scattering layer occurred in the mid-stratum of the thermocline (Fig. 2-B).

Type C: When the scattering layer occurred at the lower stratum of the thermocline (Fig. 2-C).

Type D: When there are two or more scattering layers that coincided with respective numbers and/or strata of thermocline which may occur with a combination of the foregoing types (Fig. 2-D).

2. Thermocline and scattering layer

The depths of the thermocline (y) and scattering layer (x) obtained from different stations were compared and shown in Table 1 and Fig. 3. Linear curves (y = x) were obtained in all types. Thus, the depth strata of the thermocline exactly coincided with the depths of the different types of scattering layers.

The depths of thermocline and scattering layers were observed to change within a short interval. This phenomenon may be due to the movement of the internal wave. Fig. 4 shows the obvious shifting of the depths of thermocline and scattering layer within a lapse of only 12 minutes (01:13 hr to 01:25 hr). At 01:13 hr, the depths of thermocline were recorded at between 38-49.5m and 49.5-52m while the depths of scattering layer were recorded at 38-39 m (Type A) and 49.5-52 m (Type A). At 01:25 hr, the depths of thermocline shifted and occurred in between 20-29 m, 29-35m, and 35-44 m, while the depths of scattering layer respectively followed at 20-22 m (Type A), 27-29 m (Type A) and 33-35 m (Type C)

3. Halocline and scattering layer

The problem on why the scattering layer at times occurs either at the upper, middle, or lower depth stratum of the thermocline was encountered. The phenomenon may not only be attributed to the temperature, but may also be related to the halocline (discontinuity layer of salinity).

To confirm which one has a greater influence on the scattering layer, thermocline and halocline were therefore analyzed. The results are shown in Table 2.

TABLE 1. Comparison of the depths of thermocline and scattering layer

Stn. No.	Date	Time (hr)	Depth of thermocline by B T (m)	Depth of scattering layer by echogram (m)	Type
4A	22.4.72	13:00	20 -26.5	20	A
22	2.5.72	08:00	32.7 -50.5	32.7	A
10	18.6.72	17:12	14 -15	14	A
14	19.6.72	07:51	12 -14	12	A
16	25.9.72	04:55	29.5 -34.5	29.5	A
7	25.4.72	23:55	9.7 -13.7	11.7	B
29	10.5.72	12:53	20 -24	22	B
3	17.6.72	16:05	34 -40	37	B
11	18.6.72	23:14	7 -13	10	B
26	25.6.72	14:45	24.2 -35	29.6	B
28	27.9.72	14:54	37 -43.5	40.2	B
3	21.4.72	20:12	20 -25	25	C
11	26.4.72	04:00	10 -18	18	C
4	17.6.72	20:45	34.5 -40	40	C
6	18.6.72	03:15	21 -30	30	C
8	18.6.72	10:03	10 -13	13	C
11	24.9.72	18:08	36 -44	44	C
2	17.6.72	05:30	20 -24	22	D
			28 -36.7	36.7	
7	18.6.72	07:36	9.5 -11	11	D
			20 -24.2	24.2	
14A	19.6.72	18:39	7 - 9.7	9.7	D
			9.7 -19	14	
16	21.6.72	17:20	11 -14	11	D
			15.2 -18	15.2	
17	21.6.72	19:24	9.7-12.7	9.7	

TABLE 1. Comparison of the depths of thermocline and scattering layer (Continuation)

Stn. No.	Date	Time (hr)	Depth of thermocline by B T (m)	Depth of scattering layer by echogram(m)	Type
17	21.6.72	19:24	12.7 -18	12.7	
			18 -19.7	19.7	D
			36 -38	36	
18	21.6.72	22:43	15.7 -18.3	17	
			24 -29	29	D
			29 -31	31	
19	22.6.72	18:37	28 -29	28	D
			28 -29	29	
20	22.6.72	20:52	18 -24	22	D
			37 -39	37	
21	23.6.72	16:49	11 -15.5	15.5	
			33.5 -35.5	35.5	D
			34 -36.5	36.5	
22	23.6.72	18:48	10 -13.5	10	
			13 -16	13	
			13 -16	16	D
			21.7 -25.2	21.7	
			21.7 -25.2	25.2	
4	21.9.72	16:04	44 -55	44	
			55 -61	55	D
			55 -61	61	
5	21.9.72	18:09	50 -59.5	50	
			50 -59.5	59.5	D
			59.5 -65	65	
6	21.9.72	19:49	29 -33.5	33.5	
			46 -50	46	D
			55.5 -58.5	58.5	

TABLE 1. Comparison of the depths of thermocline and scattering layer (Continuation)

Stn. No.	Date	Time (hr)	Depth of thermocline by B T (m)	Depth of scattering layer by echogram (m)	Type
6A	21.9.72	21:20	22 -26	22	
			22 -26	26	
			39 -40	39	
			49.5 -52	49.5	
			49.5 -52	52	D
			54 -58	54	
			54 -58	58	
			62 -66	62	
			62 -66	66	
7	22.9.72	07:50	47.5 -52	47.5	
			47.5 -52	52	D
			54 -58	58	
7A	22.9.72	15:00	46 -50	50	
			56 -61.5	56	D
			56 -61.5	61.5	
			65 -68	68	
7B	22.9.72	15:51	41 -44.5	41	
			50 -56.2	50	D
			50 -56.2	56.2	
8A	23.9.72	19:38	41 -45	45	
			45 -50	50	D
			55.8 -56	55.8	
			56 -59.8	59.8	
9	23.9.72	18:34	45.5 -46.5	46.5	D
			50 -55	55	
10	23.9.72	20:19	30 -34	32	
			45 -44.5	44.5	D
			51 -55.2	51	
			51 -55.2	55.2	

TABLE 2. Comparison of the depths of halocline, thermocline and scattering layer at Station 4 off the Malay Peninsula on 22 April 1972.

Stn. No.	Date	Time (hr)	Depth of halocline (m)	Depth of Stratum of thermocline same as scattering layer (m)	Depth of scattering layer (m)	Type
4A	22.4.72	13:00	20	20 (upper)	20	A
22	2.5.72	08:30	none present	32.7 (upper)	32.7	A
10	18.6.72	17:12	14	14 (upper)	14	A
14	19.6.72	07:51	12	12 (upper)	12	A
16	25.9.72	04:55	29.5	29.5 (upper)	29.5	A
7	25.4.72	23:55	11.7	11.7 (mid)	11.7	B
29	10.5.72	12:53	22	22 (mid)	22	B
3	17.6.72	16:05	37	37 (mid)	37	B
11	18.6.72	23:14	10	10 (mid)	10	B
26	25.6.72	14:45	29.6	29.6 (mid)	29.6	B
28	27.9.72	14:54	none record	40.2 (mid)	40.2	B
3	21.4.72	20:12	25	25 (lower)	25	C
11	26.4.72	04:00	18	18 (lower)	18	C
4	17.6.72	20:45	40	40 (lower)	40	C
6	18.6.72	03:15	30	30 (lower)	30	C
8	18.6.72	10:03	13	13 (lower)	13	C
11	24.9.72	18:08	44	44 (lower)	44	C

When the halocline existed in the thermocline, it was found that depths of the scattering layer and halocline coincided within the upper, middle or lower stratum of the thermocline.

4. Plankton biomass and scattering layer

The relationship between zooplankton biomass and tracing record of scattering layer was compared at six stations in the September survey cruise off Borneo in 1972. The results are shown in Table 3.

An average zooplankton value of 109 mg/m^3 (33%) was obtained in depths, from 40 m to 0 m, without scattering layers. In the same manner, the value of 221 mg/m^3 (67%) was obtained in depths from 5 m near the bottom to 40 m where the scattering layers occurred. The results indicated that depths where the scattering layers occur have higher zooplankton biomass than depths without scattering layers.

Vertical distribution of zooplankton

1. Vertical movements of the scattering layer

The diurnal vertical movements of scattering layer were observed at all the surveyed areas in the South China Sea. The ascending movement of the layer from the deeper water towards the surface was clearly shown on the echogram soon after sunset (18:00 — 19 :30 hr). It was also recorded that the layer slightly scattered or descended from the surface towards the deeper water before sunrise (05:00 — 07:00 hr). Except for the above-mentioned periods, the scattering layer became stable upon reaching the thermocline and halocline at each of the stations.

2. Vertical distribution of total zooplankton biomass

The zooplankton biomass observed during the period of survey at station 4 (04°50'N, 104°00' E) in April, 1972, is shown in Table 4 and Fig. 5. The average total zooplankton biomass collected from 60 m to the surface in the daytime was 253.9 mg/m^3 which was close to that of 261.6 mg/m^3 at nighttime. However, the biomass at the upper 20 m stratum at nighttime (48% of the total) was higher than those of deeper strata (27% at 20-40 m and 25% at 40-60m), whereas the biomass in daytime was more evenly scattered (37% at 0-20 m, 34% at 20-40 m and 29% at 40-60 m).

TABLE 3. Comparison of Plankton biomass and tracings of scattering layers of six stations (off Borneo).

Stn. No.	Date	Time (hr)	Depth without scattering layer			Depth with scattering layer		
			Depth (m)	Plankton (mg/m^3)	Biomass %	Depth (m)	Plankton (mg/m^3)	Biomass %
6A	21.9.72	21:20	0-40	76	38	40-80	124	62
7	22.9.72	07:50	0-40	98	20	40-73	386	80
7A	22.9.72	15:00	0-40	97	24	40-71	314	76
8	23.9.72	09:25	0-40	136	38	40-68	221	62
8A	23.9.72	19:38	0-40	131	47	40-66	146	53
10	23.9.72	20:19	0-40	113	46	40-69	134	54
Average			0-40	109	33	40-71	221	67

TABLE 4. Vertical distribution of zooplankton biomass during the day and nighttime off the east coast of Malay Peninsula (04°50'N, 104°00'E) in April 1972.

Depth stratum (m)	Day		Night	
	mg/m³	%	mg/m³	%
0-20	93.8	36.9	125.3	47.9
20-40	86.7	34.1	71.8	27.4
40-60	73.4	29.0	64.5	24.7
Total	253.9	100	261.6	100

3. Vertical distribution of total zooplankton

Altogether, 11 main groups of zooplankton were found during the period of survey at Station 4. They are Coelenterata, Polychaeta, Ostracoda, Copepoda, Mysidaceae, Amphipoda, Decapoda, Mollusca, Chaetognatha, Echinodermata, and Prochordata (Table 5). The percentage of occurrence of each group during the period is shown in Table 6.

The groups of ostracods, mysids, amphipods, and decapods were found to migrate towards the upper layer during nighttime and disperse to all layers during daytime. On the other hand, prochordates migrated towards the upper layer during daytime and dispersed to all layers during nighttime. No obvious vertical movement was observed in the other groups of zooplankton.

Due to the significant increase of the nauplii of Copepoda in the upper layer, it is interesting to compare the diurnal vertical distribution of nauplius stage with the other stages. The results are shown in Fig. 6 (see also Table 6). Increases of 16%, 9% and 3% of nauplii respectively were obtained at 0-20 m, 20-40 m, and 40-60 m during nighttime, but incerases of 2%, 14%, and 16% of copepodites, respectively, were obtained at 0-20 m, 20-40 m, and 40-60 m during daytime. For adults, an increase of 4% was obtained at 0-20 m during nighttime, but increases of 1% and 3% were obtained at 20-40 m and 40-60 m during daytime. As an overall comparison, 28% increase of nauplii at nighttime, 22% increase of cope-

TABLE 5. Genera of each main group of zooplankton found at Station 4 in April 1972 (04°50'N, 104°00'E).

Main Group	Form/Genus
Coelenterata	_Lensia_, _Zanclea_, _Bougainvillia_, and _Obelia_
Polychaeta	_Pilidium_ and _Lopadorhyncus_
Ostracoda	_Cypridina_, _Conchoecia_, and _Hormiphora_
Copepoda	_Macrosetella_, _Coryceaus_, and _Paracalanus_
Mysidaceae	_Mysis_ and _Eupheusia_
Amphipoda	_Hyperia_
Decapoda	_Lucifer_
Mollusca	Gastropod larvae, bivalve larvae, _Creseis_, and _Cavolinia_
Chaetognatha	_Sagitta_
Echinodermata	_Ophiopluteus_
Prochordata	_Doliolum_, _Salpa_, and _Oikopleura_

TABLE 6. Vertical distribution in average numbers of each main group at three layers over 25-hour period at Station 4 (April survey-cruise off Malay Peninsula).

Main Group of Zooplankton	Nighttime (20:00-06:00 hr) 0-20m no./m³	20-40m no./m³	40-60m no./m³	Sub-Total no./m³	Daytime (08:00-18:00 hr) 0-20m no./m³	20-40m no./m³	40-60m no./m³	Sub-Total no./m³	Total no./m³
Coelenterata	2.8	0.5	4.7	8	2.9	4.1	0.9	7.9	15.9
Polychaeta	2.5	2.8	10.2	15.5	1.7	1.9	6.3	9.9	25.4
Ostracoda	39.8	53.2	54.7	147.7	13.6	34.4	65.7	113.7	261.4
Copepoda									
Nauplius	1011.8	774.2	694.3	2480.3	407	422.3	589.1	1418.4	3898.7
Copepodite	268.2	373.7	481.2	1123.1	311.9	825.9	1036	2173.8	3296.9
Adult	296.8	147.3	211.8	655.9	242.4	158.3	165.4	566.1	1222
Mysidaceae	9.2	7.7	10.5	27.4	3	3.7	4.4	11.1	38.5
Amphipoda	6.8	5.8	0.2	12.8	0	0	2.7	2.7	15.5
Decapoda	6.5	2.2	0.8	9.5	0.7	0.7	0.6	2	11.5
Mollusca	56.8	55.2	54.2	166.2	24.3	57.7	110.7	192.7	358.9
Chaetognatha	44.3	27.5	33.7	105.5	21.4	9.4	13	43.8	149.3
Echinodermata	7	3.7	0.3	11	3.7	4.4	1	9.1	20.1
Prochordata	1	1.5	2.2	4.7	62.3	18.4	8	88.7	93.4

podites in the daytime, and 6% increase of adults at nighttime were obtained accordingly.

The increase of nauplii (16%) and adults of Copepoda (4%) at the upper layer during nighttime may indicate the direct association of upward migration with spawning. And the increase of copepodites during daytime may probably be explained by the fact that there is growth from nauplius to copepodite stage.

DISCUSSION

The scattering layer and halocline are found to coincide either in the upper, middle, or lower stratum of the thermocline. All echo-sounder records showed that the scattering layer occurred within the depth range of the thermocline and halocline. Thus, the occurrence of scattering layer may indicate the depths where the thermocline and halocline occur.

The degree of darkness of the echogram is found to be directly associated with plankton abundance. The darker the color of the echogram the higher is the plankton biomass. However, when comparing the darkness of the echogram of one place with another, the speed of the vessel and the sensitivity of the fish echo sounder should be constant. In addition, the hauling or sampling distances and time should be done at the same layer, and the layers selected for comparison must all be the same. Sampling layer of 20-40 m is most suitable for comparison due to the clearer echogram and stability of water mass.

In the survey cruises, pelagic fish schools were found to occur at or around the vicinity of the scattering layers. This phenomenon may be related to the feeding activities of pelagic fishes at the scattering layers.

The vertical abundance and composition of zooplankton is also related to the scattering layer. Ostracoda, Mysidaceae, Amphipoda, and Decapoda were found to migrate towards the upper water during nighttime; Prochordata were found to migrate towards the upper layer during daytime. The nauplii of Copepoda increased at the upper layer during nighttime. This maybe due to spawning of adults, not to migration. This may be explained by the fact that nauplii are not hardy enough to migrate or to pass from one body of water through a discontinuity layer into another body of water.

Further studies on the foregoing zooplankton would be of interest to find out what particular species of each main group can serve as indicator species of migration.

SUMMARY

The present paper analyzed the relationship between scattering layer and some hydro-biological factors in the South China Sea. The results obtained are summarized below:

1. Patterns of scattering layer are classified into four main types. Scattering layers occurring at the upper, middle, or lower portions of the thermocline are classified as Types A, B or C, respectively, and a combination of the foregoing types is type D.
2. Zooplankton biomass at depth stratum where the scattering layers occurred was higher than depth stratum without scattering layers. Thus recorded scattering layer is probably formed by concentration of zooplankton.
3. All echo sounder records showed that the scattering layer occurred within the depth range of the thermocline. Thus, the occurrence of scattering layer may indicate the depths where the thermocline and halocline occur.
4. The degree of darkness of the echogram is directly associated with plankton abundance in a certain area. Darker colored echogram shows higher plankton biomass.
5. Pelagic fish schools mostly occurred at or around the vicinity of the scattering layer. It appears that the presence of fish schools in the congregation of the zooplankton is probably associated with their feeding habits.
6. The movement of scattering layer, moving from the bottom toward the surface, was recorded soon after sunset and became stable upon reaching the thermocline. This is a good example of vertical movement of zooplankton and their concentration at the thermocline.
7. Altogether, 11 main groups of zooplankton were found in the samples. They were Coelenterata, Polychaeta, Ostracoda,

Copepoda, Mysidaceae, Amphipoda, Decapoda, Mollusca, Chaetognatha, Echinodermata and Prochordata.
8. The groups of Ostracoda, Mysidaceae, Amphipoda and Decapoda migrate towards the upper layer during the night and disperse to all layers during the day. On the other hand, Prochordata migrate towards the upper layer during the day and disperse to all layers during the night. No obvious vertical movement was observed in the other groups of zooplankton.
9. Population of the nauplii and adults of Copepoda increases at the upper layer during nighttime. This phenomenon may be associated with the upward migration and the spawning activity of adult copepods during the night.

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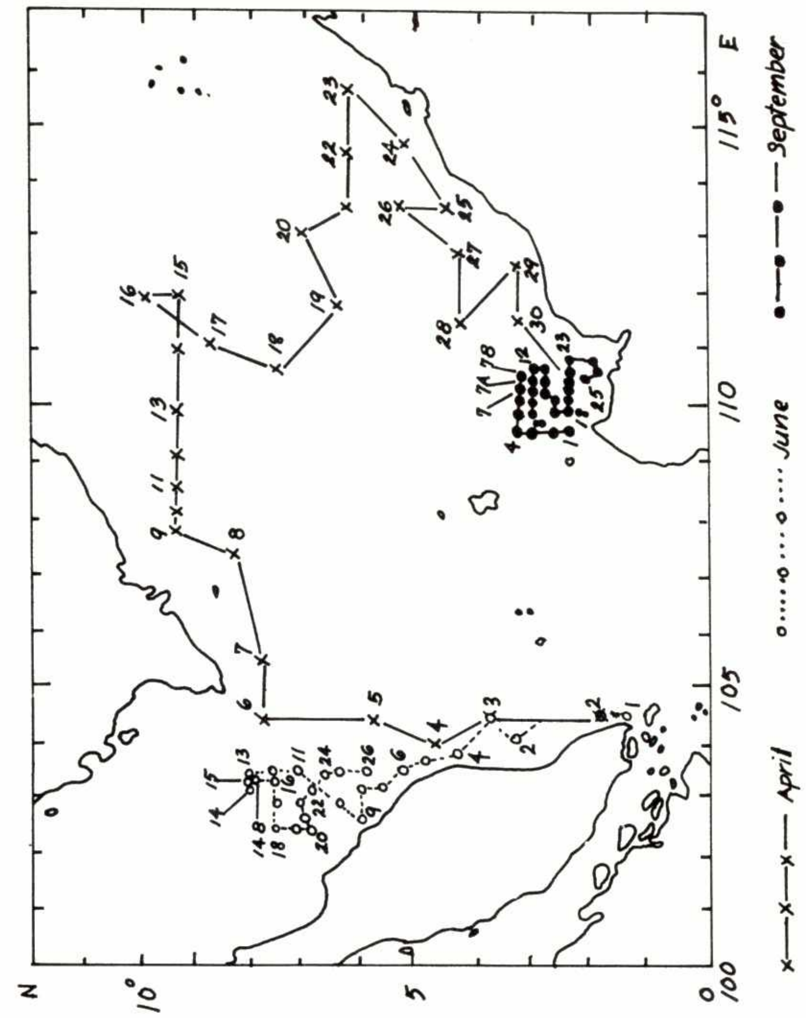

Fig. 1. Lay-out of stations occupied during the cruises of April, June, and September, 1972.

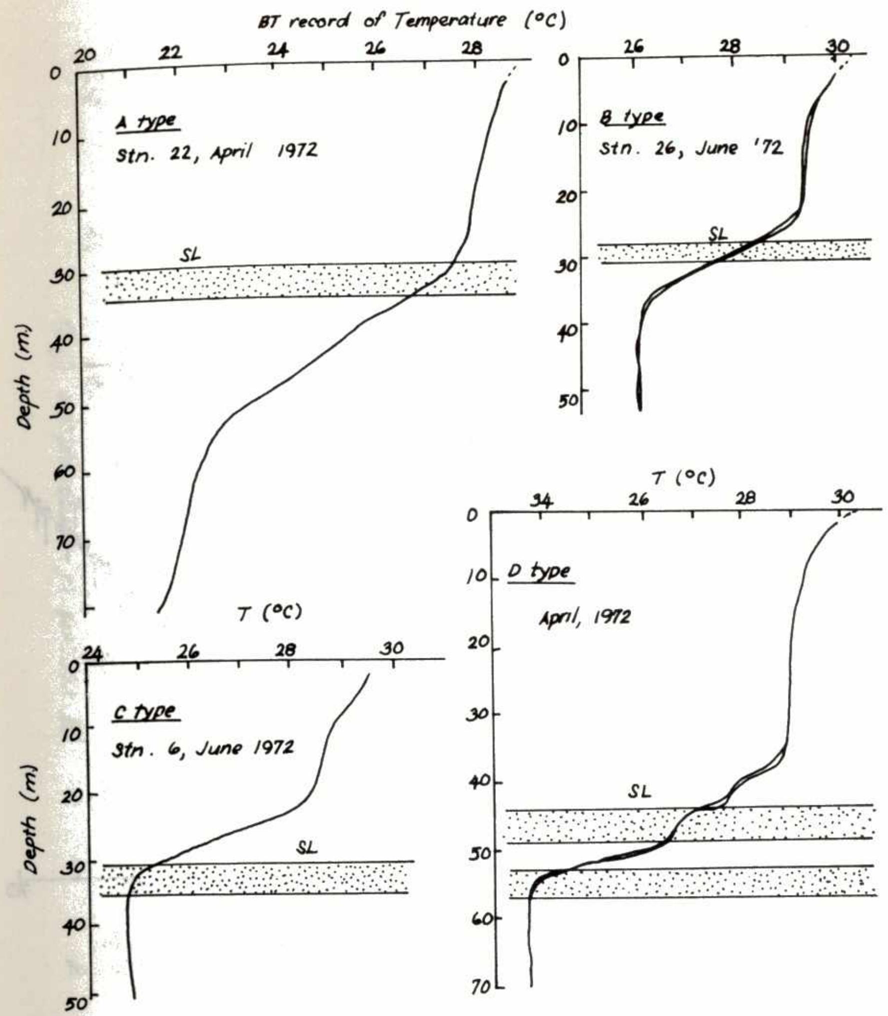

Fig. 2. A diagrammatic representation of thermocline showing typical examples of types A, B, C and D scattering layer.

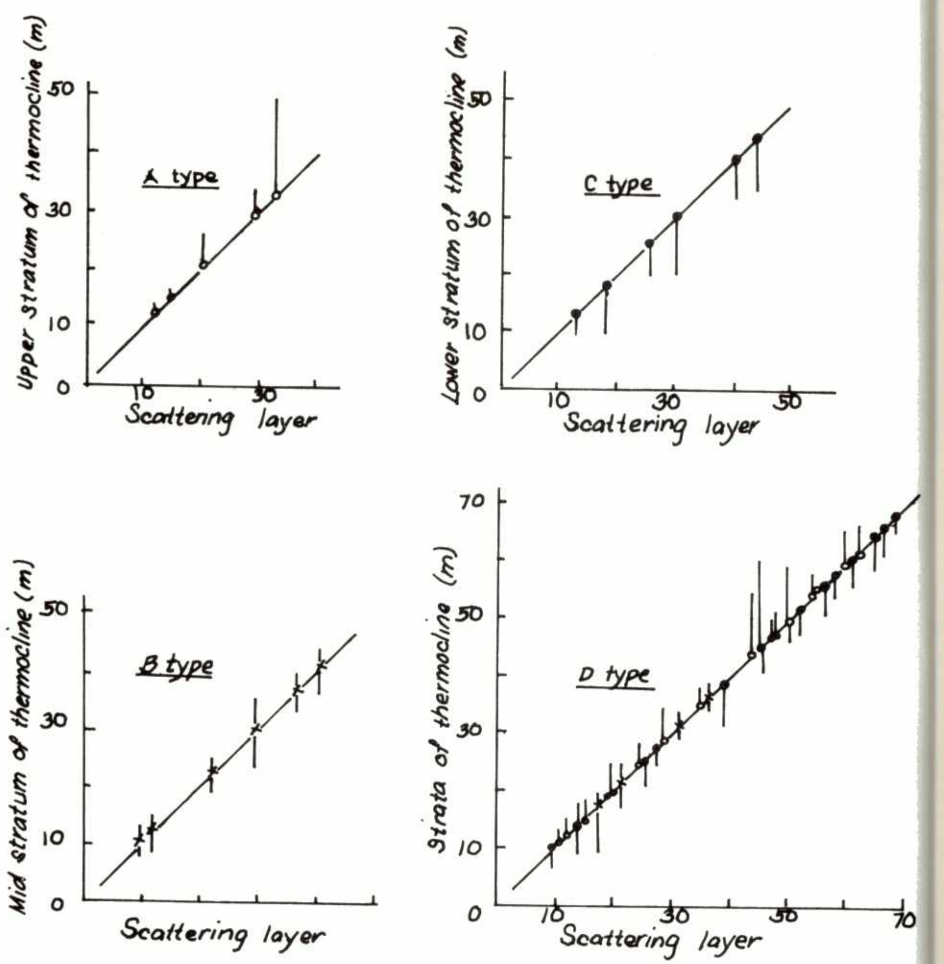

Fig. 3. Comparison of the depth strata of thermocline and depths of scattering layer.

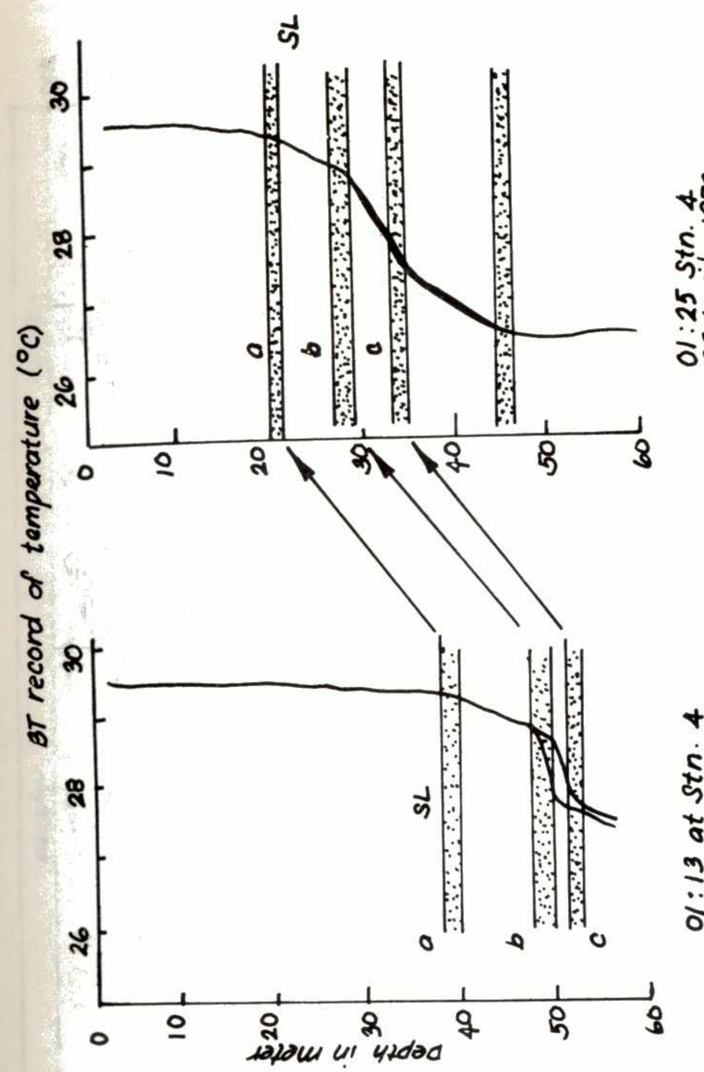

Fig. 4. A diagrammatic representation of thermoclines and tracing layers (SL) showing the shifts in depth after a lapse of 12 minutes at the same station (Stn. 4) 23 April 1972.

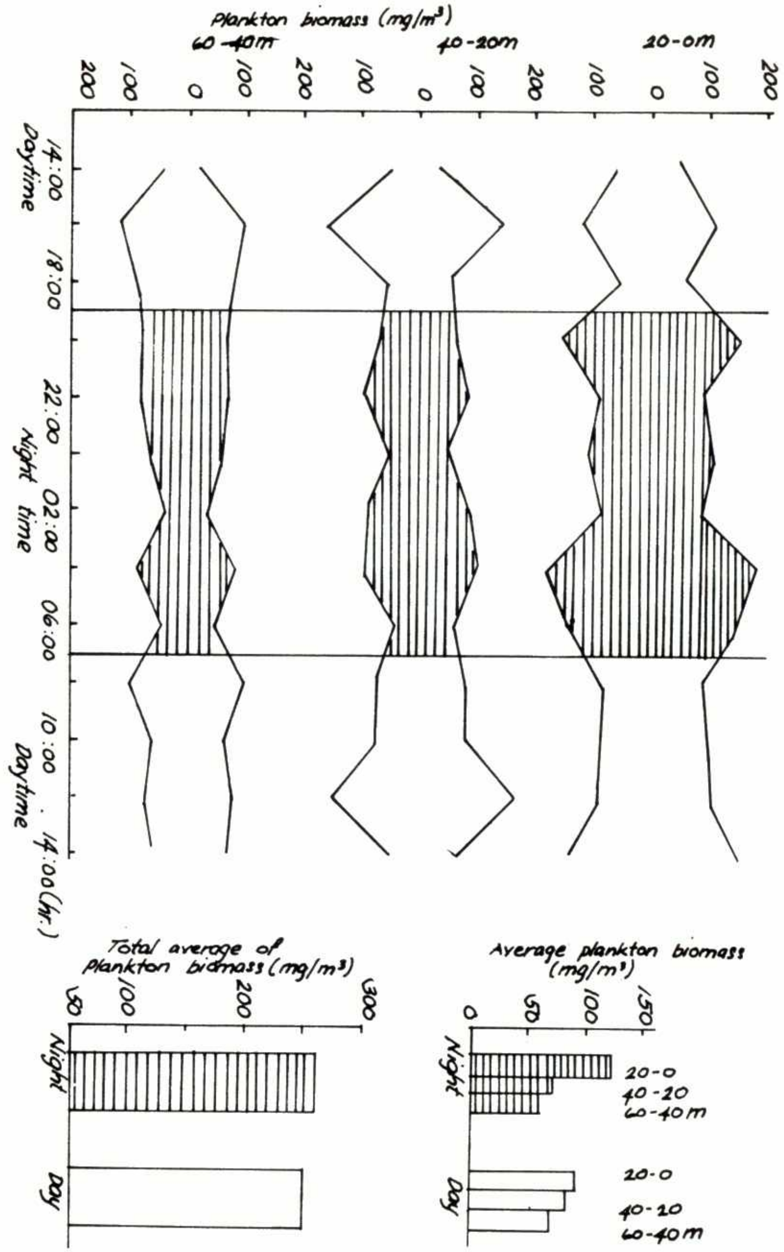

Fig. 5. Comparison of the diurnal vertical variation of plankton biomass within 25 hours (two-hourly intervals) Station 4 in April, 1972.

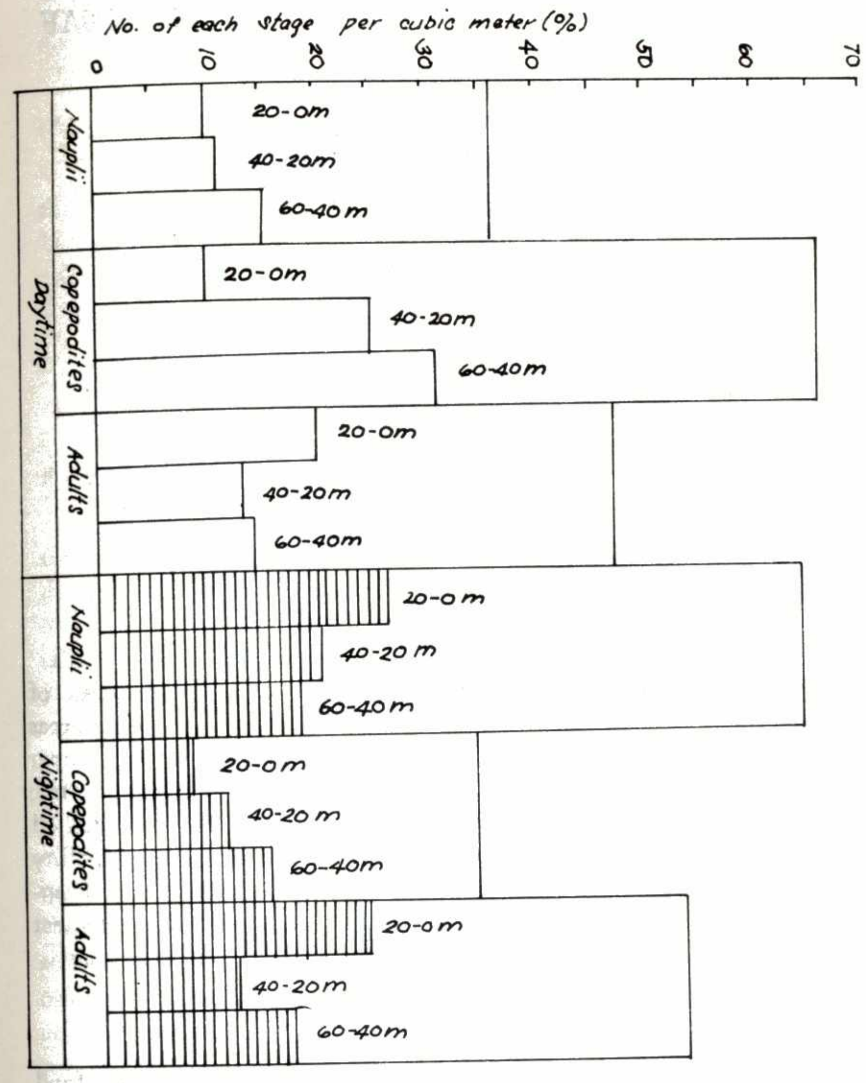

Fig. 6. Comparison of the diurnal vertical distribution of each stage of Copepoda.