PLANKTON INVESTIGATION IN INLET WATERS ALONG THE COAST OF JAPAN

XX. DIURNAL CHANGE OF PLANKTON ANIMALS AT AN INNERMOST STATION IN WAKAYAMA HARBOR[1]

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With 12 Text-figures and 2 Tables

Many works have already been made on the diurnal migration of plankton animals in fresh- and salt waters (RUSSELL 1925–1934, KIKUCHI 1930, 1939, CLARKE 1933, 1934a & b, JOHNSON 1938, MOTODA 1953, MOTODA and ISIDA 1950, and MOTODA and SATO 1949). In the enclosed sea water, KIKUCHI (1930) found that some copepods, cladocerans, chaetognaths and brachyuran zoea appeared abundantly at the time of sunset or a few hours after, but only *Evadne* sp. was distributed on the surface during daytime and migrated downward to the depth at night. Many workers reported that various plankton animals in sea water are abundantly distributed in the optimum range of light intensity and they change the distribution according to the weather condition as well as to the time in a day. Thus, it has been generally recognized that light intensity is an important factor governing the diurnal movement (RUSSELL 1926, CLARKE 1933, JOHNSON 1938, KIKUCHI 1939 and MOTODA 1953). MARUMO and KAWARADA (1951) and KAWARADA (1952) stated that the quantity of plankton in Sagami Bay fluctuated diurnally in accordance with physical and chemical changes of water—especially water mass movements.

KIKUCHI (1938) learned by the experiment that phototropic sign of crustaceans changes with the intensity of light; some species are positive to weak light but negative to strong light, and others are indifferent to weak light and negative to very strong light. JOHNSON (1938) proved experimentally on the phototropic movement of *Acartia clausi* that the decrease in light intensity forces the plankton animals to migrate upward, and the greater the change of light intensity, the greater the upward movement. And he said that the animals are not seeking an optimum intensity since their distribution becomes uniform when left for some time under the intensity moving first upward.

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The preliminary observations were made to obtain further information on the diurnal migration of plankton animals in relation to environmental conditions in inlet waters. The observation on the diurnal change of plankton abundance on the surface layer was carried out three times at a station in the innermost part of Wakayama Harbor, chosen as representing a typical stagnant environment of inlet water, during the period from March 25, 1947 to April 10, 1947; namely, March 25–26, March 30–April 1 and April 9–10 respectively (Fig. 1).

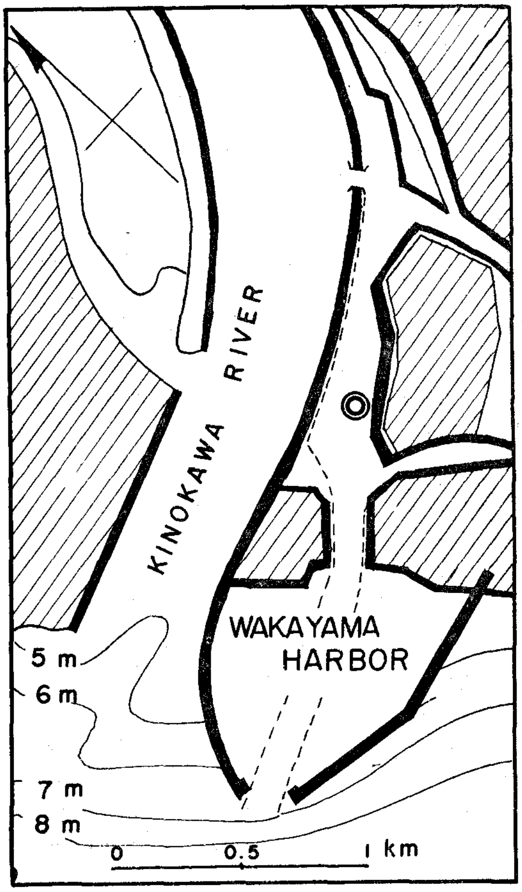

Fig. 1. Station position of investigation in Wakayama Harbor.

To collect plankton in the respective layers from the surface to the 6.5 m depth, or at the surface layer, 15 liters of sea water were pumped up by a bucket at intervals of an hour throughout the day and night, and filtered through a silk net stretching XX 14 gauze. Then, all the plankton animals were counted on the counting slide. The hydrological conditions were also measured at the same time. The results are given in Tables 1 and 2.

Table 1. Vertical distribution of hydrological conditions at an innermost station of Wakayama Harbor.

Date	March				April			March			April			
	26	30	31	"	1	9	10	26	"	"	9	10	"	"
Hour	11:00	13:00	5:00	18:00	6:00	18:00	6:00	11:00	11:00	11:00	18:00	6:00	11:00	15:00
Depth (m) 0	9.9	10.6	9.7	12.5	11.9	14.3	11.6	13.18	8.1	6.85	6.72	6.15	6.26	6.02
1	9.4	10.5	10.1	12.4	12.0	13.7	12.0	13.18	8.2	6.92	6.72	6.41	6.05	6.20
2	9.5	10.4	10.1	12.2	11.2	12.8	11.6	17.75	8.2	6.45	6.58	6.42	6.72	6.60
3	9.6	10.3	10.2	10.9	10.9	12.5	11.6	17.78	8.2	6.36	6.97	6.70	6.74	6.73
4	9.6	10.3	10.3	10.7	10.9	12.0	11.6	18.22	8.2	6.24	7.00	6.77	6.79	6.84
5	9.9	10.3	10.4	10.8	10.8	12.0	11.5	18.25	8.2	6.19	6.93	6.62	6.84	6.89
6.5	10.1	10.4	10.4	10.8	10.8	11.8	11.5	18.25	8.2	6.50	6.68	6.50	6.58	6.61
	Temperature °C							Cl ‰	pH	O_2 (cc/*l*)				

Table 2. Vertical distribution of plankton animals at an innermost station of Wakayama Harbor.
The numbers of plankton denote the individual number per liter.

Date	March 26							March 30						March 31						April 1			April 10		
Hour	11:00–11:10							13:00 –13:07			19:00 –19:07			6:00–6:08				18:00 –18:03		8:00 -8:07			2:00 -2:07		
Depth (m)	0	1	2	3	4	5	6.5	0	3	6.5	0	3	6.5	0	3	5	6.5	0	6.5	0	3	6.5	0	3	6.5
Oithona nana	0	1	1	1	1	3	10	4	2	2	0	3	2	17	3	6	4	3	5	10	6	5	7	4	2
Acartia clausi	3	0	0	0	2	4	1	0	0	1	0	1	0	4	0	1	6	0	2	1	2	2	4	5	2
Microsetella norvegica	0	0	3	1	1	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Copepod nauplii	0	1	5	0	4	6	10	8	7	11	6	9	0	25	8	10	11	2	8	22	5	4	25	7	11
Paracalanus parvus	0	0	2	1	2	4	3	1	1	2	2	2	0	16	0	0	2	0	2	7	0	0	2	3	0
Evadne nordmanni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Oikopleura dioica	1	0	4	0	0	0	1	0	1	1	0	0	0	2	1	0	1	0	1	1	2	0	0	2	0
Sagitta delicata	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	2	0	0	0	0	0	0
Polychaete larvae	0	0	2	0	9	11	19	2	8	10	6	4	1	30	3	4	10	6	7	20	7	14	17	10	6
Tintinnopsis radix	0	2	8	6	4	6	2	1	0	0	1	0	0	8	1	1	0	0	0	2	0	1	0	0	0
Favella taraikaensis	0	0	2	0	1	3	2	1	0	0	1	4	0	2	0	0	0	0	0	2	0	1	0	0	0
Noctiluca scintillans	3	2	0	1	1	1	2	2	6	1	0	8	0	6	7	1	1	6	6	5	2	2	4	3	0

Wakayama Harbor is a recently excavated small harbor in the estuary of Kinokawa River. It is very shallow, being about 8 meters in the deepest. The water is turbid and yellowish, having about 6 m in the maximum transparency. The community of plankton in this area is of the *Acartia—Oithona* type (Yamazi 1956). The quantity of phytoplankton is very small, but the endemic species including the copepods *Oithona nana*, *Acartia clausi*, *Paracalanus parvus* and their nauplii, tunicate *Oikopleura dioica*, chaetognath *Sagitta delicata* and polychaete larvae are abundant. The following species were also observed; *Noctiluca scintillans*, *Tintinnopsis radix*, *Favella taraikaensis*, *Evadne nordmanni*, pelecypod and gastropod veligers, brachyuran zoea, *Microsetella*, *Centropages* and *Oncaea*.

Results of Observations

1. *Observation on March 25–26th, 1947*

(Figs. 2 & 3)

The diurnal changes in the number of individuals of important plankton and the hydrological data are shown in Figs. 2 and 3. Before examining the data it is necessary to show the outlines of the environmental feature, that is, tidal range, illumination, water and air temperature, chlorinity, oxygen contents, etc. Several hours in the afternoon of March 26th, the wind had blown relatively strong (less than 10 meters per second) and atmospheric pressure showed about 755 mm. Hg. However,

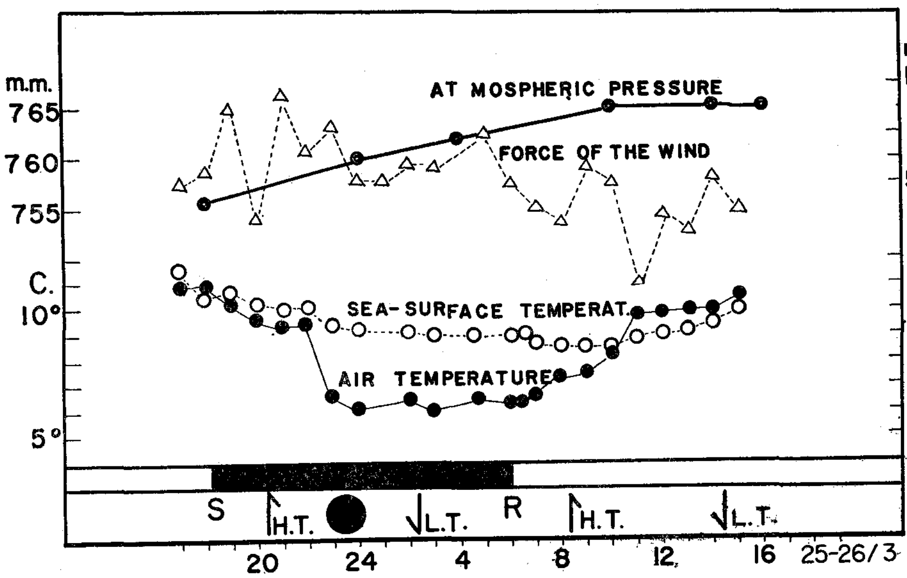

Fig. 2. The environmental conditions during the investigation on March 25–26, 1947.

before sunset the sky was clear away and the sun sank beyond the mountain in the distance at 6 : 10 p.m. After sunset the light intensity decreased suddenly and then darkened. At 9 : 00 p.m. the sky was, however, covered with heavy clouds and began to rain during one hour. At 10 : 00 good weather was restored. The stars shone in the clear sky. There appeared no moon all through the night, though it was new moon. At 6 : 00 a.m. the sun rose and 6 : 30 a.m. the sun beam shone on the surface of the sea.

The water temperature at the surface varied from 8.5°C to 12°C and the maximum value was found in the afternoon, while the minimum was in the early morning. Air temperature was highest (11°C) in the afternoon and lowest (6°C) in the mid-night, and lower temperature less than 7°C was recorded from 11 : 00 p.m. to sunrise.

The thermocline in the under water was not found. The transparency of water was very small at all times, measuring from 3 to 4 meters. The vertical distribution of chlorinity at 11 : 00 a.m. is shown in Table 1. The chlorinity from the surface to the bottom (6.5 meters depth) varied between 13.18‰ to 18.25‰. The lower chlorinity than 14‰ was observed at the surface and one meter layer. At the under water layers the values increased towards the bottom from 17.75‰ to 18.25‰. The dissolved oxygen content was nearly uniform on all layers varying from 6.2cc to 6.9cc per liter and the content was maximum at one meter layer and decreased to the bottom. The value

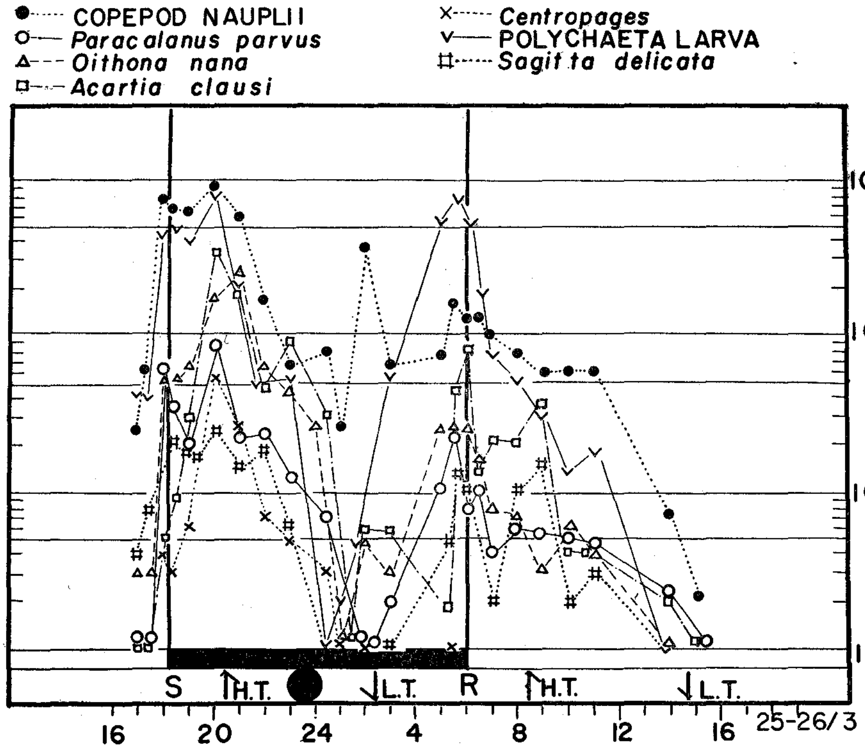

Fig. 3. The diurnal change of the number of plankton animals on the surface layer on March 25-26, 1947.

near the bottom was comparatively higher, between 2 and 5 meter layers. The high tides were 7 : 00 p.m. and 8 : 20 a.m. and low tides were 2 p.m. and 2 : 20 a.m.

From Fig. 3 and these data it may be seen that the maximum abundance of plankton animals took place when illumination changed, that is at dusk and at dawn. The plankton showed a tendency to leave the surface layer during the midday and midnight. The copepod nauplii, polychaete larvae, the adults and copepodids of *Oithona nana*, *Acartia clausi*, *Paracalanus parvus* and *Centropages* sp. showed two times maximal occurrence, one at dusk and the other at dawn. After 8 : 00 p.m. the number of plankton suddenly decreased and from 0 : 00 to 3 : 00 a.m. reached to the minimum. *Noctiluca* and *Oikopleura dioica*, however, did not show any diurnal change in abundance. *Oncaea* was found at midnight. Many *Tintinnopsis radix*, *Favella taraikaensis* occurred abundantly before sunset and after sunrise but were very few all through the night. Pelecypod veligers occurred abundantly in the morning. *Microsetella norvegica* showed one maximal occurrence in the midnight.

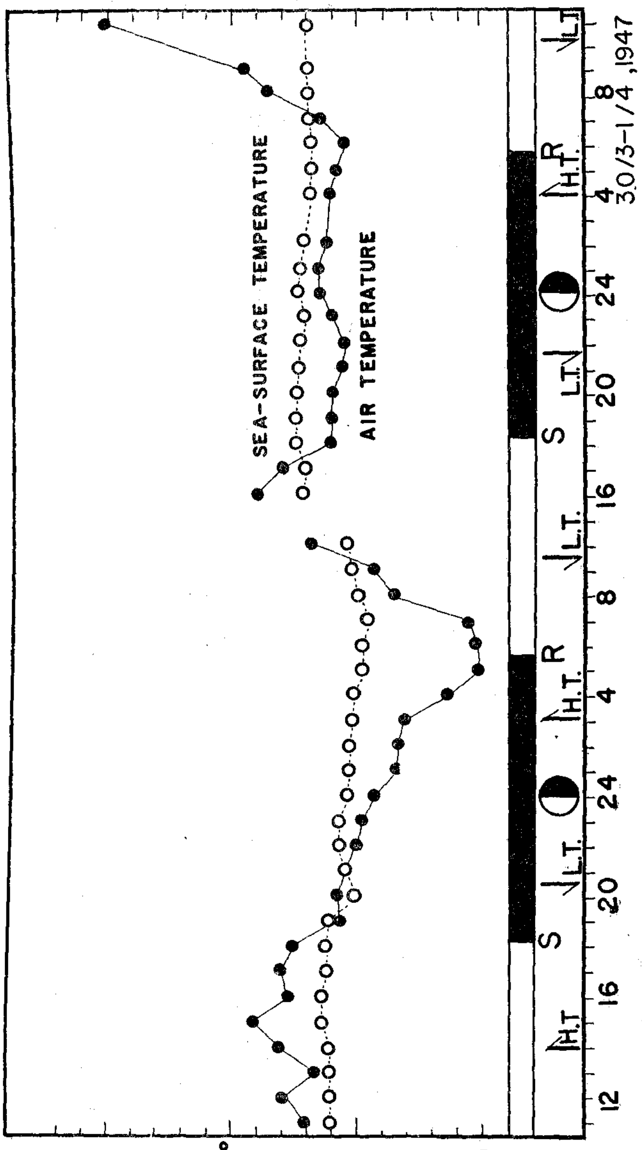

Fig. 4. The environmental conditions during the investigations on March 30-April, 1, 1947.

2. *Observation on March 30th–April 1st, 1947*

(Figs. 4–5)

During the second observation the weather was very fine and calm all day long, except several hours in the evening on March 30th when it was cloudy. The water temperature at the surface changed between 9.7°C and 11.6°C, the maximum value

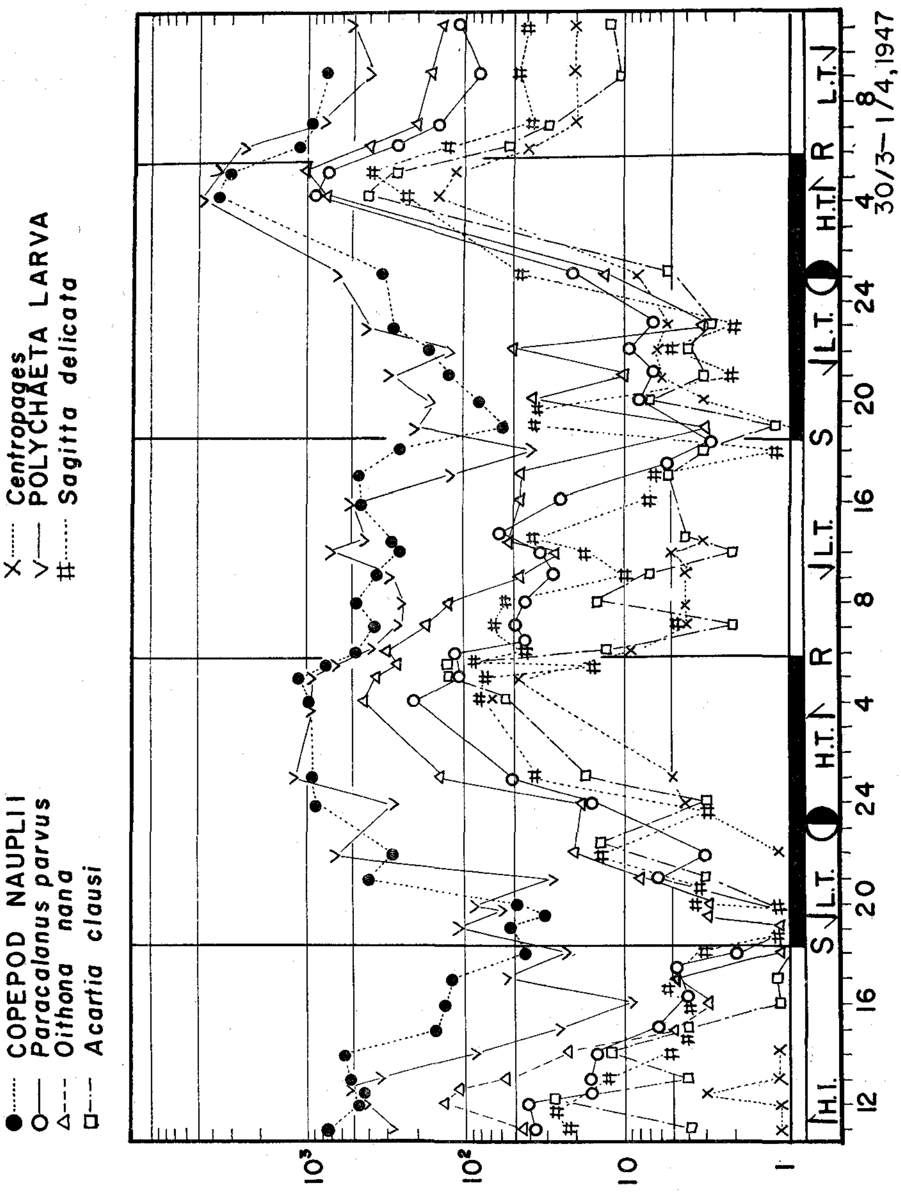

Fig. 5. The diurnal change of the number of plankton animals on the surface layer on March 30–April 1, 1947.

occurred in the afternoon. The air temperature varied largely from 5°C to 20°C and the maximum value was found in the evening. The temperature of March 31st–April 1st was higher than in the 30th–31st. As it was half moon, the tidal range was relatively smaller than that in March 25–26th. The highest tide was found at 2:00 p.m. on the 30th, 3:00 a.m. on the 31st, at 2:40 p.m. on the 31st and at 4:00 a.m. on April 1st. The lowest was at 8:00 p.m. on the 30th, at 9:40 a.m. and 9:50 p.m. on the 31st, and at 10:10 a.m. on April 1st (Fig. 4).

The diurnal changes of the plankton abundance observed in this investigation were not in agreement with the above-mentioned data on March 25–26th. Only one peak was found during the time between midnight and early morning. The minimum abundance of plankton was found during the time from the evening to the dusk, that is the first period of the change in illumination. Copepod nauplii and polychaete larvae were more abundant than the other plankton animals. The maximum abundance was in the midnight and the next was in the daytime. From the afternoon to the dusk there was minimum abundance. The other animals such as *Oithona nana*, *Paracalanus parvus*, *Acartia clausi* and *Centropages* and chaetognath *Sagitta delicata* were found most abundantly at dawn. In the morning they gradually decreased until daytime and reached to the minimum at the sunset. In a few hours after sunset small peaks were found (Fig. 5).

3. *Observation on April 9–10th, 1947*

(Figs. 6–7)

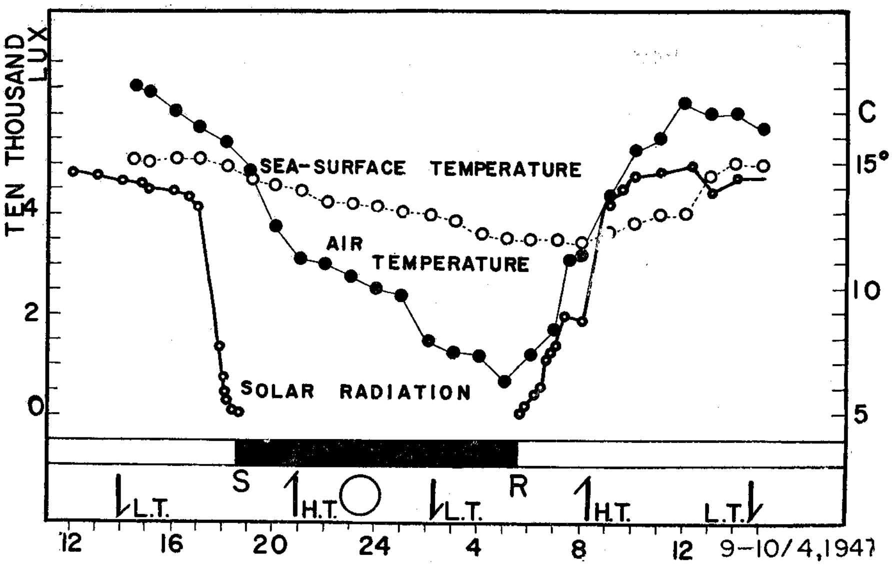

Fig. 6. The enviromental conditions during the investigation on April 9–10, 1947.

The third observation on the diurnal change of plankton animals at the surface was made during the period of full moon in April. Every hourly collection was begun at 3:00 p.m. and stopped at 3:00 p.m. on the next day. The weather was very fine and the surface water was also very calm all day long. The sun was bright in the daytime and the bright full moon shone in the clear sky at night. As shown in Fig. 6 the sun's illumination in the daytime was 40,000–50,000 Lux and at 5:00 p.m.

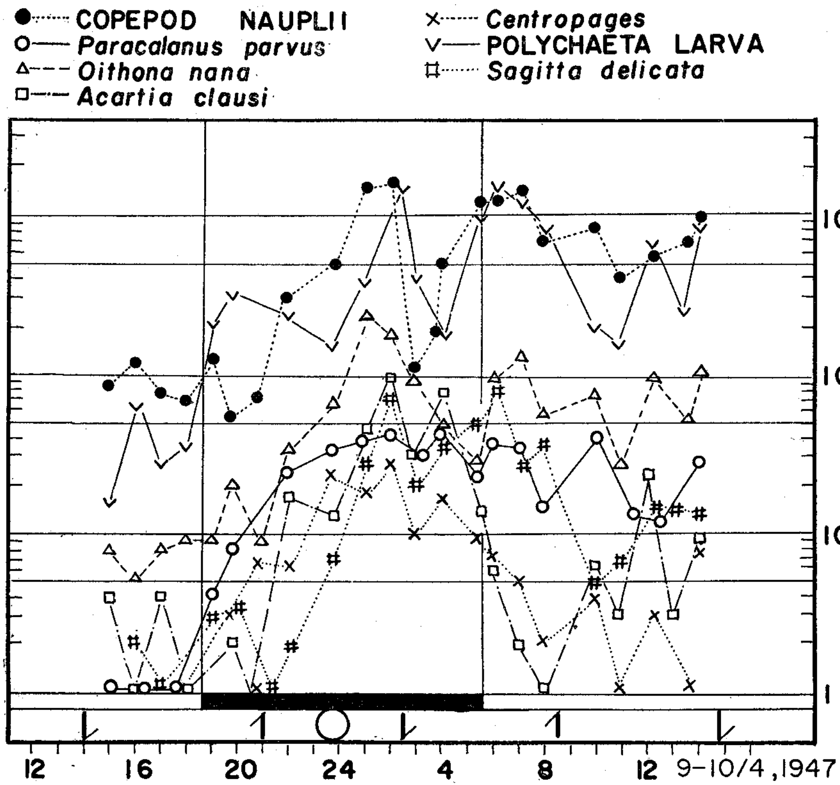

Fig. 7. Diurnal change in the number of plankton animals on the surface layer on April 9–10, 1947.

it decreased and at 6:46 p.m. the twilight faded away. Then the water temperature gradually decreased and attained the minimum at 8:00 a.m. on the next day. The air temperature also decreased and the minimum value 6°C was found at 5:00 a.m. The sky lightened at 5:00. The sun rose at 5:44 a.m. and the illumination increased gradually, while at 8:00 a.m. the sun was covered with light clouds. In the daytime, however, it was quite bright.

Copepod nauplii and polychaete larvae abundantly occurred at 3:00 a.m. and from 6:00 to 8:00 on the 10th, as in the case of the former observation. In the afternoon they were very rare, although they crowded more abundantly than the other animal plankton, such as *Oithona nana*, *Acartia clausi*, *Paracalanus parvus* and *Sagitta delicata*.

The latter four were very few in the evening while after sunset they gradually increased and attained the maximum in the midnight and they remained still rather abundantly at the surface to the next daytime.

4. *Summary of Observations on Diurnal Change*

(Figs. 8–12)

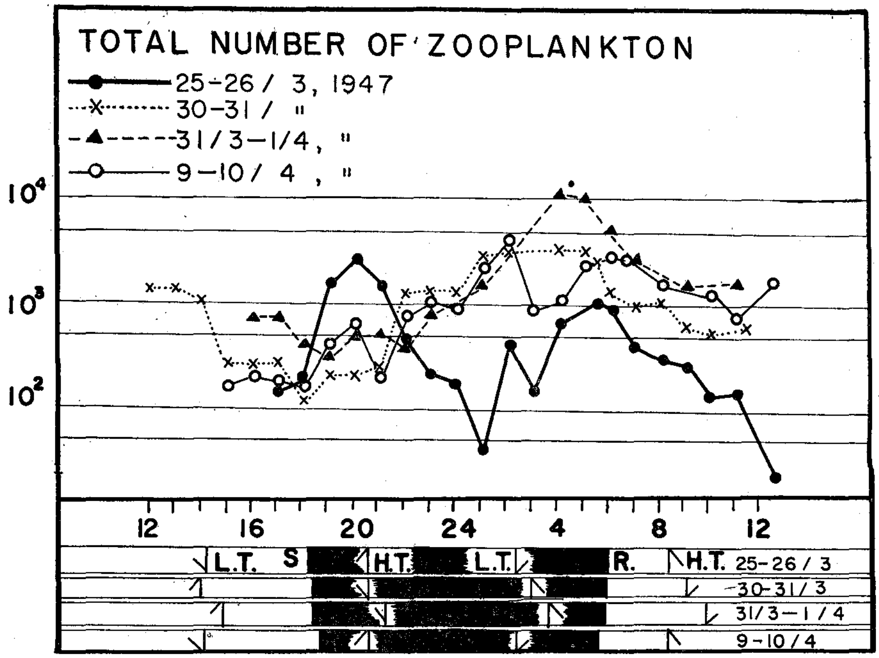

Fig. 8. Total number of zooplankton per 10 liters at the surface layer during the investigations.

The diurnal changes in the abundance of plankton animals at the surface water observed three times at the same station are summarized in the figures. Fig. 8 shows the diurnal change of the abundance of total number of animals. In Figs. 9–12 are given the diurnal changes of individual species of animal plankton.

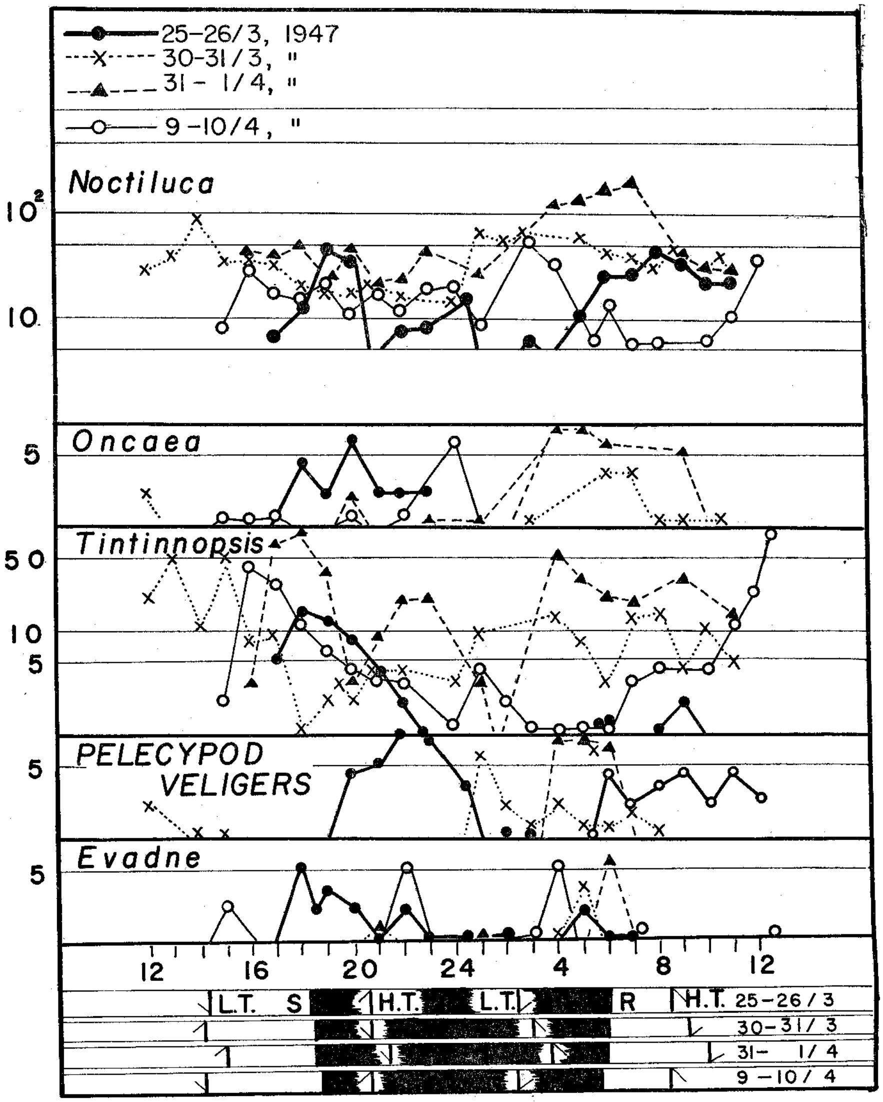

Fig. 9. Diurnal change of number in respective species (1).

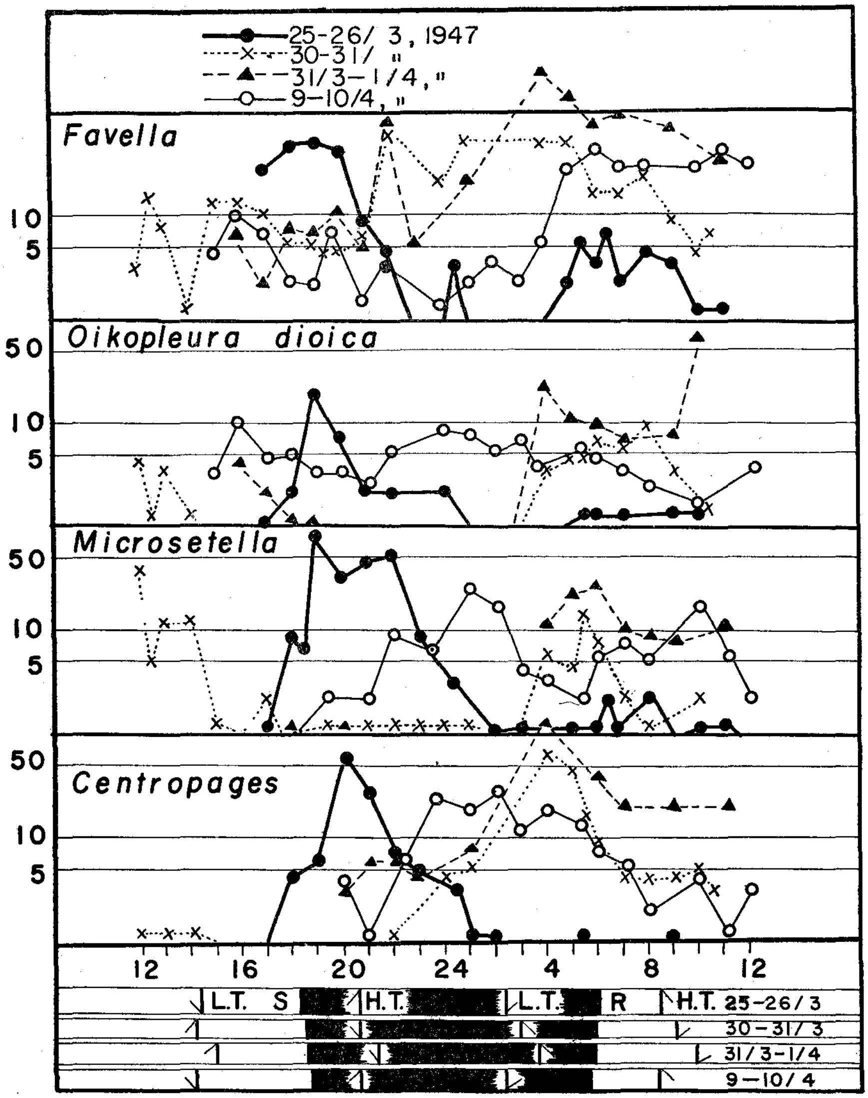

Fig. 10. Diurnal change of number in respective species (2).

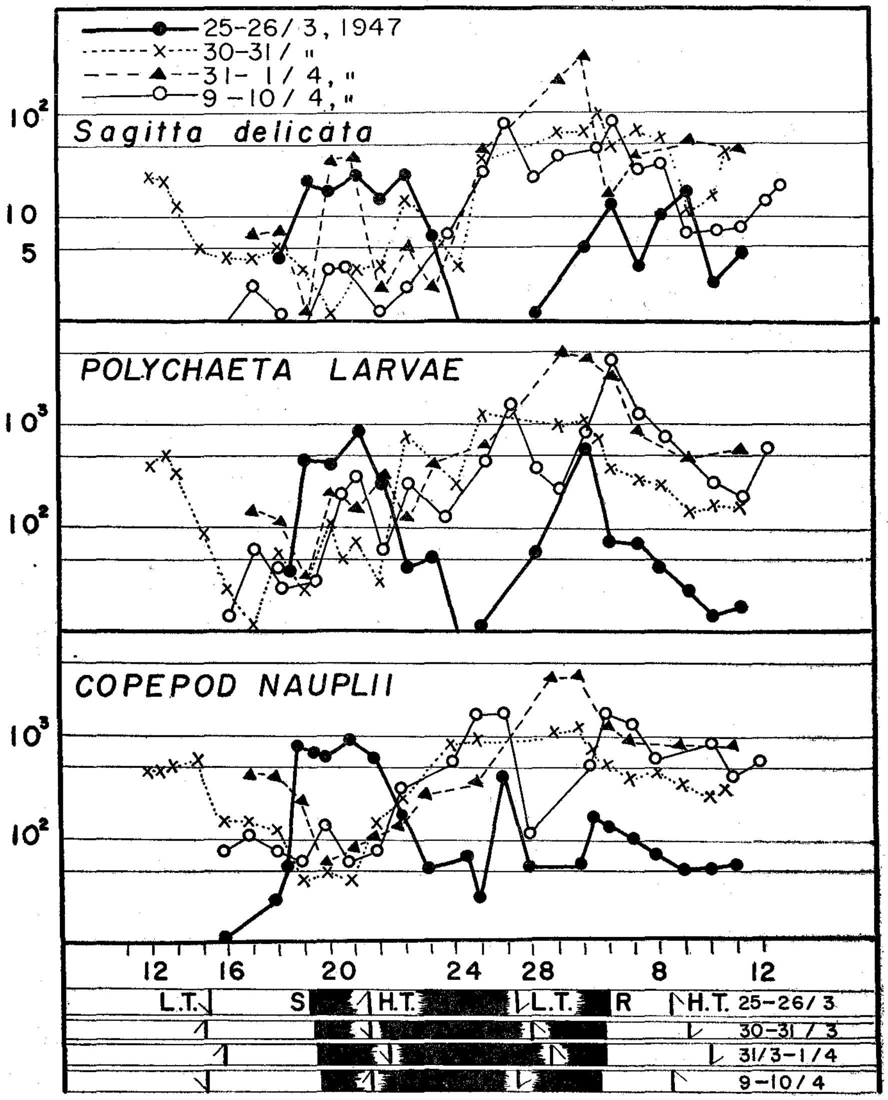

Fig. 11. Diurnal change of number in respective species (3).

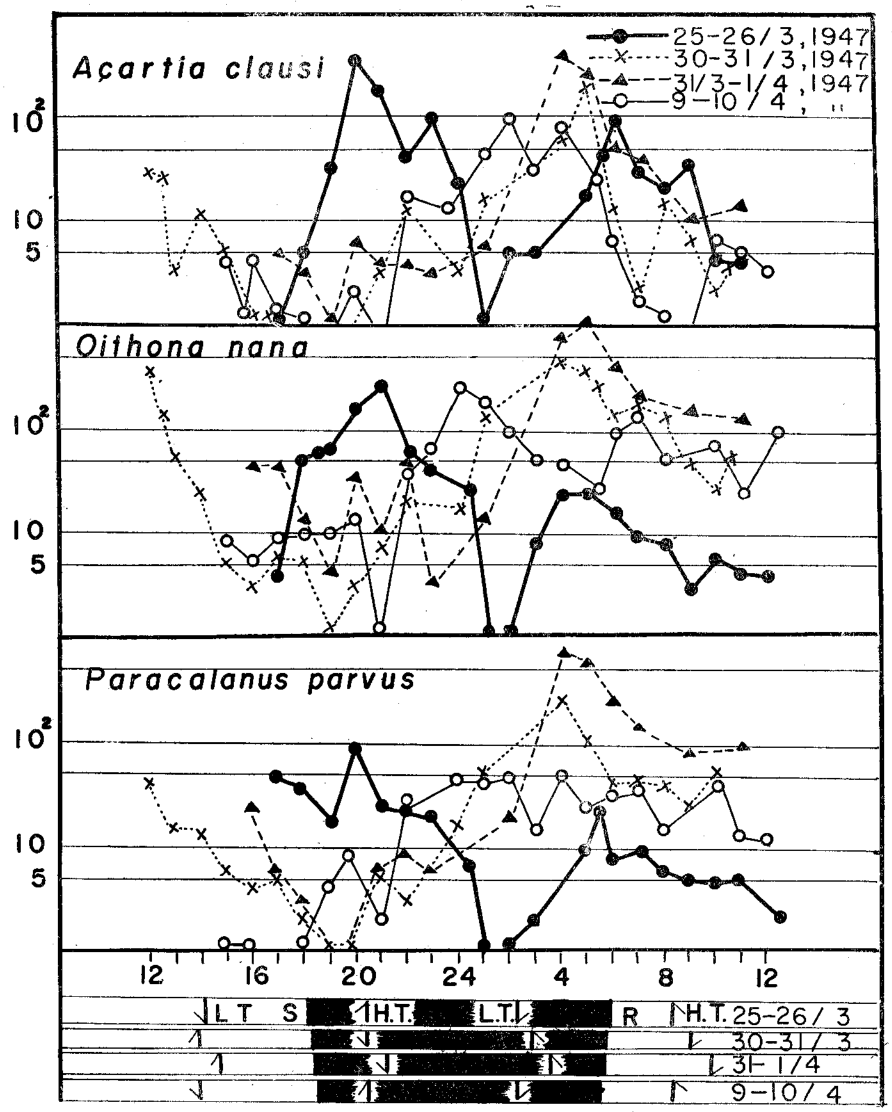

Fig. 12. Diurnal change of number in respective species (4).

Discussion and Conclusion

In these observations it is clear that there are diurnal variations in the abundance of each species of plankton animals in sea water, and it is not only the differences of the type of the diurnal vertical migration of animal themselves by the intensity of light, but also the diurnal differences of the enviromental conditions. The sea water is always moving more or less so that the plankton in it is influenced by water movement. In inlet waters the movement of water masses is forced by mechanical factors such as tidal exchange and wind force and the quantity of plankton containing within them in some particular area is not always constant. In such innermost area of brackish water, the plankton animals of pure saline type are generally sparse (YAMAZI 1956). Therefore, it seems that more saline forms may be transported with the reversible current flows at flood and ebb tides.

However, there are actually various cases in diurnal change.

1. Some species are abundant at the surface during night, while very few during daytime, as in examples of *Oncaea* sp. and *Microsetella.*
2. Some species show a tendency to rise up to the surface at dusk or dawn and to descend down to the depth at noon and night, as in examples of *Paracalanus parvus, Oithona nana, Acartia clausi, Sagitta delicata, Evadne, Centropages* and polychaete larvae.
3. Some species appear abundantly at the surface at dawn and morning, and sink quickly at night, as in examples of *Tintinnopsis radix* and *Favella taraikaensis.*
4. Some species are evenly distributed all day long and show no marked diurnal migration at all, as in examples of *Oikopleura dioica* and *Noctiluca scintillans.*

The "twilight migration" after KIKUCHI (1930), that the plankton animals ascend towards the surface at dawn and evening twilight and descend both in daytime and midnight, was not observed in the present studies as in the results obtained by MOTODA (1953). It is reported that the diurnal movement of plankton animals is one of the most striking characteristics and the source of the effect is the light intensity. In the present studies, generally speaking, the diurnal migration takes place in accordance with the change of light intensities. But it cannot be said that all the factors governing the diurnal change are the light intensities.

The relation between the abundance of plankton at the surface and the intensity of the moon light could not be clarified in the present studies which were performed during the three different lunar ages, new-moon, half-moon and full-moon. And also the difference in the abundance of plankton during daytime in the fine and cloudy weather in daytime is not clear. The marked diurnal change observed on March 25–26th may be due to the mechanical forces caused by strong wind and extreme range of high- or low-tide on a day of new moon.

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