ECOLOGICAL STUDIES ON THE JELLY-FISH, *AURELIA AURITA* (LINNÉ), IN URAZOKO BAY, FUKUI PREFECTURE—VIII. DIEL VERTICAL MIGRATION OF THE MEDUSA IN EARLY FALL, 1969

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With 2 Text-figures

In recent years, accidents caused by flowing of *Aurelia aurita* medusae into the intakes at thermal or atomic power plants and similar large scaled factories have considerably increased along the coasts of Japan (MATSUEDA 1969). For this reason, the biology, especially the abundance and occurring pattern of this medusa has attracted deep interest not only among biologists but also among engineers. However, so far as we know, in spite of the common and world-wide distribution of *Aurelia aurita*, there are very few reports dealing with its biology in natural conditions.

In his previous papers the author has already reported the occurring patterns of the medusa and ephyra, the growth, longevity, breeding season, vertical distribution patterns and their seasonal changes of the medusa in Urazoko Bay on the Japan Sea coast of Middle Honshu (YASUDA 1968, 1969, 1970, 1971). Most recently, he described the vertical migration of the medusae from noon to shortly after the sunset by checking the level of population every or every other hour. The observations were made by means of vertical hauls with a closing plankton-net (51 cm in mouth diameter, 0.33 mm in mesh size) to estimate the quantitative distribution, and also by means of an under-water-television set to see the qualitative distribution (YASUDA 1972). But, the vertical distribution of medusae from midnight to the sunrise was not fully traced at that time.

This paper is prepared to report the results of a more detailed observation on the diel vertical migration of a population of *Aurelia* medusae throughout 24 hours.

Before going further, the author wishes to express his thanks to Professor Emer. T. TAMURA and Professor H. OHMI of the Hokkaido University, Professor T. TOKIOKA and Dr. S. NISHIMURA of the Seto Marine Biological Laboratory, Kyoto University for their criticisms and valuable suggestions for the manuscript. Thanks are also due to Professor Emer. T. UCHIDA of the Hokkaido University, Professor S. MOTODA of the Tokai University, and the captain and crew of the Wakashio-maru of the Fukui Prefectural Fisheries Experimental Station, for their encouragements and kind help during the course of this study.

Material and Methods

In 24-hours from 13:00 on September 9th, 1969 to 12:00 of the next day, *Aurelia aurita* medusae were sampled nearly every other hour after the MOTODA & ANRAKU's method (1951); simultaneous horizontal hauls of three plankton-nets (100 cm in mouth diameter, 220 cm in length, and stretched with gauze of 10 mm meshes) were made at 2.5, 7.5 and 12.5 meters deep by fixing the mouth ring of a net directly to respective wire-ropes with a 30 kg weight at the end (Fig. 1).

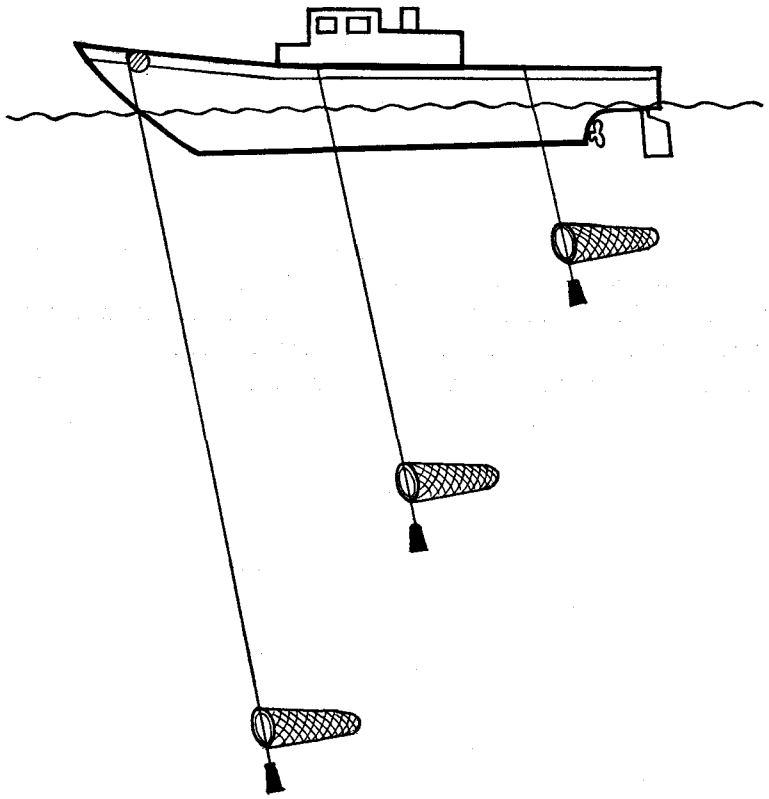

Fig. 1. Diagram showing the simultaneous three hauls.

The nets were hauled for 10 minutes at a speed of 0.5 m/sec. in the outer-western part of Urazoko Bay, a small inlet of Wakasa Bay on the Japan sea coast of Middle Honshu (see YASUDA 1969), which is 14 to 15 meters deep and has been known for the dense distribution of medusae (YASUDA 1969, 1970, 1971). The medusae collected at each depth were separately counted and measured while alive to see a bell-diameter representative of respective groups. The depth of horizontal hauls was estimated by checking the rope length and the angle between the rope and the sea level.

Environmental factors such as air-temperature, surface wind wave, water temperature, chlorinity and underwater illumination were also observed.

Results

Change in Meteorological Condition: It was bright on September 9th, but next morning it drizzled at dawn and then rained from 7:00 to 11:00. As shown in Fig. 2 (above), the air-temperature attained the maximum, 31 °C, at 15:10 on the 9th, and then gradually fell to the minimum, 21 °C, at 11:10 on the 10th as the weather became worse.

Surface wind waves of scale 1 were observed from 13:00 to 19:00, of scale 2 from 21:00 to 7:00 and again of scale 1 from 9:00 to 11:00 in the next morning.

The high tide was seen at 12:20 on the 9th and at 3:30 on the 10th, while the low tide at 20:30 on the 9th and at 8:00 on the 10th.

Change in Hydrographical Condition: Successive changes of vertical distributions of water temperature and chlorinity during the observations are shown in Fig. 2 (middle).

The water temperature was generally nearly homogeneous from the surface to the bottom layer throughout this investigation, though a slightly higher temperature than 27 °C was retained in the upper 6 meter layer from 13:00 to 21:00 and isolatedly in the middle layer (7 to 15 meters) from 19:00 to 21:00 on the 9th. The temperature dropped a little to 26.5 °C in both the surface and the bottom layer around midnight and further to 26 to 25 °C from 7:00 to 11:00 in the next morning as the weather grew worse. There was almost no vertical change in chlorinity as seen in figure, but a slightly lower chlorinity, 17.7‰ was observed in the upper 3 meter layer from 15:00 to 18:00 on the 9th, otherwise the chlorinity was retained almost homogeneously in the range from 17.8 to 17.9‰.

The change in underwater illumination is shown in Fig. 2 (below). The underwater illumination was more than 10^4 Lux above the 5 meter layer at 13:00 on September 9th as it was fine, but it dropped radically to about 10^3 Lux on the surface just before the sunset and further to as low as 10 Lux at 19:00 after the sunset. Next morning on September 10th, it was 10 Lux shortly after 5:00, and then steadily increased to 10^3 Lux at 6:00 above the 7 meter layer. No increase of illumination was observed thereafter because of the rainy weather, but it remained at the level of 10^3 Lux above the 6 meter layer.

Umbrella Diameter and Diel Change in Number of Medusae at Each Depth: Although the *Aurelia* medusae obtained by means of simultaneous horizontal tows with three plankton-nets mentioned above were often found partly broken, about 130 individuals were found intact (maximum numbers were caught from 13:00 to 15:00) and measurements of umbrella diameter were made on these. The umbrella showed a range of diameter from 4 to 12 cm, with a mode around 7 cm and the mean 7.0 ± 1.88 cm.

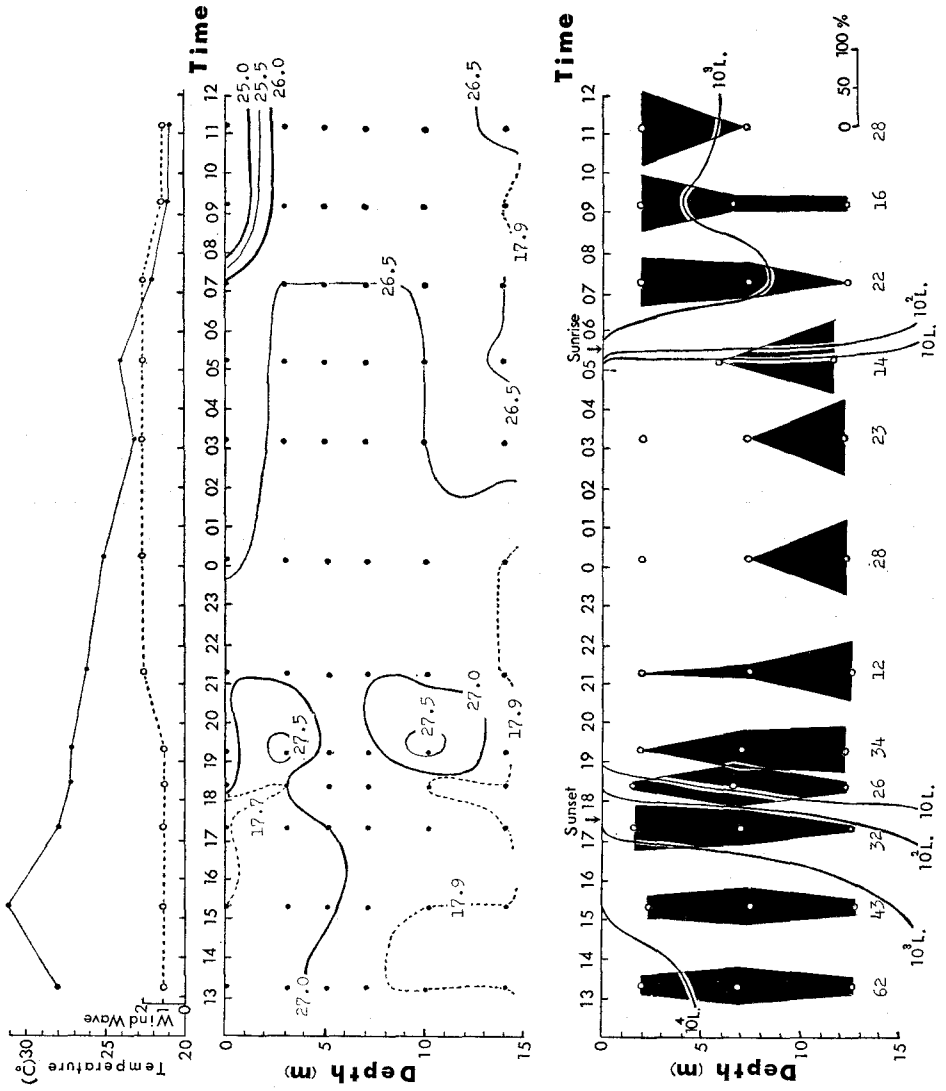

Fig. 2. Air temperature, wind wave (above), water temperature, chlorinity (middle), underwater illumination and vertical distribution of *Aurelia aurita* medusae (below) during the 24 hours from 13:00 on Sept. 9th to 12:00 on Sept. 10th, 1969.

They were all recognized as immature (YASUDA 1971). The umbrella diameter was compared among individuals from respective depths, but no significant difference was observed.

Next, the successive catches at each level are given in Fig. 2 (below) as percentages to the total of simultaneous catches by three plankton-nets. Judging from this figure, it is evident that *Aurelia* medusae show the apparent diel migration. In short, they were distributed throughout the surface to the bottom, with a slight dominance at the 7 meter layer in the daytime: but more than 50 percent of them swam up to the 2 meter layer just before the sunset. After that, they began to sink gradually to the 7 meter depth as observed at 18:10 after the sunset. Furthermore, the *Aurelia* medusae migrated down to the 12 meter layer just above the bottom in the dark hours from 19:00 to 21:00.

From midnight towards dawn (0:00 to 5:00) on September 10th, they were captured only from near the sea bottom. After the sunrise, the main distribution layer of medusae shifted from the bottom to the surface and the medusae were captured only in the surface 2 meter layer at 11:00 under the rainy condition.

Discussion

So far as the author is aware, there have been no detailed reports on the diel migration of natural populations of *Aurelia* medusae, studied qualitatively or quantitatively at different depths[1]. However, according to AGASSIZ (1862)'s observations on the Florida coast, where *Aurelia* medusae make their appearance in early spring, these medusae could be observed floating in immense numbers near the water surface as the sun rose higher above the horizon. He reported that when the sun shone brightly and the surface of the water remained smooth, they did not seem to seek the places most exposed to the glaring sun, but, on the contrary, appeared more frequently about sheltered places such as the neighborhood of wharves or prominent rocks. MAYER (1900) also reported that in Havana Harbor in February 1893, during the morning hours not one medusa was to be seen, but at about four o'clock in the afternoon *Aurelia* began to appear in great numbers, and continued to remain near the water surface until long after night-fall. BROWNE (1901) reported that around the Marine Laboratory at Plymouth in April 1898, he caught with two hauls of trawl nets only about 400 specimens of *Aurelia* medusae in the daytime. However, over 1000 specimens were taken with a hand-net in the evening.

Although the present data can not be compared directly with those obtained by above-mentioned authors because of differences in season, place and other environmental conditions, it is evident that the vertical distribution of *Aurelia* medusae changes

1) RUSSELL (1928) attempted to clarify this problem; however, he failed to obtain sufficient data about *Aurelia* and other larger scyphomedusae.

very often in a day. Most recently, the present author reported an example of diel change in the vertical distribution of this medusa. He made observations by using a closing plankton-net (51 cm in diameter of opening and 0.33 mm in mesh size) and an underwater television set (Sensuiken, Type No. 500) in the afternoon from 13:00 to 18:00 on October 17th, 1968 and elucidated that the medusae were distributed mainly in the upper 3 meter layer during the daytime in cloudy weather, but found concentrated at the surface just before the sunset.

When it became nearly quite dark, they were scattered from the surface to the middle or even to the bottom layer (15 to 20 meters) (YASUDA 1972). As shown in Fig. 2 (below), the results of the present investigation seems to agree fairly well with the observations of MAYER (1900), BROWNE (1901) and that reported previously by the present author as to the vertical distribution of *Aurelia* medusae at and after the sunset. They also show that most of the medusae are distributed near the bottom layer (about 12 meters deep) at night.

According to the author's unpublished data obtained at the same place in the middle of August 1970, about 70 to 85 percent of the *Aurelia* medusae obtained during dark hours by means of simultaneous towing of four similar plankton-nets at the surface, 3, 7 and 13 meter layers came from the deepest layer. From these, it may safely be concluded that most *Aurelia* medusae sink to the bottom after the sunset. A similar distribution pattern at night was shown by UCHIDA (1926) for the ephyrae of another scyphomedusa *Mastigias papua* L. AGASSIZ along the coast of Misaki in Japan. Also, KIKUCHI (1947) obtained a similar result for the hydromedusa *Spirocodon saltatrix* (TILESIUS) at the same locality.

The present study also shows apparently that the medusae rise towards the surface layer after the sunrise. According to the author's unpublished data obtained in the end of May 1970 by the same mentioned above, the medusae were observed mainly floating on the surface after the sunrise. This phenomenon again agrees with the observation of AGASSIZ (1862) made on the coast of Florida and also has been confirmed generally by fishermen in the Urazoko district. Further, BIGELOW (1928) mentioned that a scyphomedusa, *Cyanea* sp., often floated on the surface in the early morning. As indicated already by VERWEY (1942), UCHIDA (1961) and YASUDA (1970, 1971, 1972), on the other hand, there is a high correlation between the diel change in the vertical distribution of *Aurelia* medusa and the underwater illumination. IRISAWA et al. (1956) reported that the sense organ of *Aurelia aurita* is very sensitive to the decrease in light intensity and that the animal reacts to it by a conspicuous bell pulsation. A similar response to the decrease in light intensity, as the phenomenon of shadow reaction, has been proved for another scyphomedusa *Dactylometra pacifica* GOETTE (TAMASHIGE 1969) and the hydromedusae *Spirocodon saltatrix* (KIKUCHI 1947, HISADA 1956) and *Polyorchis karafutoensis* KISHINOUYE (TAMASHIGE & YAMAGUCHI 1967). The reports of MAYER (1900) and BROWNE (1901) and the present study clearly indicate the trend of the medusae to the dense distribution very close to the

surface towards the sunset.

As the physiological experiments mentioned above could verify only the positive relation between the bell pulsation and the sudden decrease of illumination, it is hardly possible to apply this finding directly to explain the cases observed by MAYER (1900) and BROWNE (1901) or the observations made in the present study. However, the results of hourly observations seem to support the conclusion that the want of underwater illumination may induce an increase in bell pulsation of medusae and this may have brought the animals closer to the surface when the sunset is drawing near.

In the present study, also taking the previous data into account, it was noticed that the medusae gradually sank from the surface to the middle and bottom layers from the sunset to midnight. This seems to indicate that the sense organ of *Aurelia aurita* seemingly no longer responds to any diminished light intensity, after it has become less than 10^3 Lux at the sea surface. Since there is no light stimulation at night, *Aurelia* medusae, slightly more than sea water in specific gravity (ÔSHIMA et al. 1967), may begin to sink and to be distributed towards the middle and bottom layers. KIKUCHI (1947) also made a simillar contemplation on the vertical distribution of *Spirocodon saltatrix* during dark hours. However, as well known, some moderate water current is necessary to keep the medusae, including *Aurelia aurita* medusae, alive in a good condition (BROWNE 1897, KAKINUMA 1961, ABE & HISADA 1969), and this urges to reexamine in detail the possible relation between the vertical distribution of *Aurelia* medusae at night and the direction and strength of water currents.

In previous reports, the author mentioned that *Aurelia* medusae were mainly distributed at the middle or bottom layer when the surface illumination was more than 10^4 Lux, but were floating abundantly in the surface layer less than 5 meters deep under the light condition approximately less than 10^4 Lux. This seems roughly confirmed by observations under the fine weather condition on September 9th and under the rainy condition on September 10th (Fig. 2). The following observations may be cited as supporting data: AGASSIZ (1862) found that *Aurelia* medusae often swarmed around the sheltered places of prominent rocks or in the neighborhood of wharves when the sun shone brightly, and further it is reported that the medusae gathered densely at the surface at night under the light of 900 Lux electric lamp in Uragami Bay, Kii, in the Kinki district of Japan (KINKI UNIV. 1970). It seems likely that bell pulsation of *Aurelia aurita* becomes more active at the moderate illumination around 10^3 Lux.

According to AGASSIZ (1862)'s observation, on the other hand, *Aurelia* medusae sank into deeper water when the surface of the water began to be ruffled. CHAS & HARGITT (1910) also noticed this phenomenon as to another schyphomedusa *Cyanea arctica* PÉRON.

UCHIDA (1926) also mentioned that medusae of *Mastigias papua* descend to a larger depth in rainy or strongly windy weather. Although it was not tried to collect medusae at the sea surface in the present study, no definite correlation was seemingly in all

probability found between the surface occurrence of medusae and the degree of wind waves on the surface (Fig. 2). The similar situation seems to be true as to other environmental factors such as the air and water temperature and the chlorinity. Thus, it may safely be concluded that the underwater illumination is the main factor influencing the vertical distribution of medusae of *Aurelia aurita* unless any significant halocline is existing there.

Summary

During the 24 hours from 13:00 on September 9th to 12:00 on September 10th 1969, the diel vertical migration of the population of *Aurelia* medusae was studied.

Sampling of the medusae was made at intervals of about 2 hrs. by means of simultaneous horizontal hauls at the depths 2.5, 7.5 and 12.5 meters of three plankton-nets (100 cm in mouth diameter, 220 cm in length, and stretched with gauze of 10 mm meshes), the mouth-ring of a net being fixed directly to respective wire-ropes each with a 30 kg weight. The nets were hauled for ten minutes at a speed of 0.5 meter/sec. in the outer-western part of Urazoko Bay, a small cove of Wakasa Bay near the middle of the Japan Sea coast of Honshu Island.

The results obtained are summarized as follows:

1. Collected medusae ranged from 4 to 12 cm in diameter and with the mean 7.0 ± 1.88 cm and were found immature. They were distributed fairly dominantly in the middle layer around 7 meter deep in the daytime in fair weather, but more than a half of the population seemed to move up to the surface layer around 2 meter deep just before the sunset. After that time medusae began gradually to go down into the middle layer till they reached the bottom layer around 12 meter deep in dark hours. After the sunrise in the next rainy morning, the main part of the population rose from the bottom up to the surface layer.

2. A close correlation was again confirmed between the vertical distribution of medusae and the underwater illumination, while other environmental factors such as the air and water temperature, the wave strength and chlorinity did not seem to have any significant influence on the vertical distribution of medusae. They were collected in the surface layer when the light intensity was around 10^3 Lux, but sank down in either cases when it was fairly decreased below or increased above 10^3 Lux.

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DISCUSSION

MOTODA: I would like to mention a similar diel vertical migration observed on *Chrysaora helvola*, another scyphomedusa, in Bristol Bay in the eastern Bering Sea. This species occurs in tremendously large number at the surface at night, resulting in the entanglement to salmon gill net. There is no such trouble in gill net set in daytime. The diel vertical migration of jelly-fish may supposedly be caused, as in pelagic copepods, by internal rhythm of activity of organisms and photokinetic or phototactic movements of organisms. I hope the studies of jelly-fish behavior be more progressed by accumulating field observations as well as designing suitable laboratory experiments.