潮目付近における水温分布と魚卵･仔魚分布の観測

誌名	日本水産學會誌
ISSN	00215392
著者	坂本, 亘 田中, 祐志
巻/号	52巻5号
掲載ページ	p. 767-776
発行年月	1986年5月

Bulletin of the Japanese Society of Scientific Fisheries 52(5), 767–776 (1986)

Water Temperature Patterns and Distributions of Fish Eggs and Larvae in the Vicinity of Shallow Sea Front*[1]

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(Accepted June 13, 1985)

Water temperature patterns and distributions of fish eggs and larvae in the vicinity of shallow sea front were observed at the mouth of Wakasa Bay, the Japan Sea. The front was formed between nearshore and offshore waters. The concentration per 100 m^3 of eggs and larvae of Japanese anchovy *Engraulis japonicus* in the surface layer sometimes corresponded with the direction and scale of the front. The effect of the swimming activity of a larva on distribution pattern was little during the first two days after hatching out. The front shifted horizontally with tidal cycle and its pattern was affected by the longer period wave. The wave longer than tide period was caused by typhoons and low pressure.

Convergent zones which are often observed in the vicinity of oceanic fronts play an important role in forming aggregations of marine fish larvae and eggs. The topic of oceanic fronts has attracted both biological and physical ocean scientists and in October 1977 a big conference on oceanic fronts was held.[1)] There many type of fronts were discussed from planetary scale associating with the surface Ekman transport to a small one which goes out of sight within a few minute caused by internal waves. Recently the phenomenon of convergent streak formation in the sea surface layer, which is distinguishable from the neighboring parts by sun glitter or aggregation of particulate matters, has been explained by the analogy to be connected with the progressives of internal solitary waves. Osborn and Barch,[2)] who analyzed the relation between the streak intervals and frequencies of internal solitons, reported that the phase speed of solitons are different by depth. In considering the aggregation of coastal fish larvae or variance of egg patchiness, the front shifting with semi-diurnal tidal current can not be neglected since the concentration of eggs in unit water mass are affected no matter how much the spawning area is separated from fronts.

The longer periodical waves such as shelf waves along the coast may be important because the feature and direction of tidal fronts sometimes seem to be interacted with such longer period waves. In this paper, we discuss the movement of front formed in Wakasa Bay in relation with the distribution of eggs and larvae of Japanese anchovy *Engraulis japonicus* and longer waves along the western coastal parts of the Japan Sea in summer.

Experimental Procedures

Both spatially and temporally common hydraulic and biological sampling surveys are necessary to discuss the distribution on oceanic organisms which are vulnerable to the turbulent flow in the ocean. The analyses were divided into three parts, according to the interests in the distribution of larvae and eggs in the vicinity of fronts as follows;

1) Do the organisms show distinct distribution patterns between the front and the other area?

2) Is it possible to find the causality of the formation or shifting feature of front, and how long does it last?

3) Are there any relations with the other physical factors?

Measurement of the Distribution of Japanese Anchovy Larvae and Eggs in the Front Neighbors

The temperature (T) and salinity (S) were measured from surface to 10 m depth at 9 points as shown in Fig. 1-b, where were observed several streaks, so called "slicks", about 50 m to 100 m

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wide at the mouth of Wakasa Bay on June 30, 1981. There slick zones appeared frequently in the neighboring area of the fronts in this bay and they extended from northeast to southwest; one of them came to point No. 1, while the others were observed across from Nos. 3 to 5 and Nos. 7 to 8. Nos. 2 and 9 were out of the slick during the survey. After T-S measurements we made net towing in four layers (surface, 50 cm, 100 cm and 200 cm deep) crossing the slick for ten minutes at tow speed of 0.5 m/s. These shallower layers were selected for monitering the surface distribution pattern of organisms quickly without any time lag with the physical pattern. The mesh of net was 318 μm, NGG 54 and the width of net mouth was 0.3 m $\times$ 0.6 m. The survey was carried out on the Shiranami-maru (4.5 t) of the Faculty of Agriculture, Kyoto University, and its positions were plotted on a chart by LORAN C installed in the vessel.

Determination of the Fronts

Water temperature data were collected to compare with the distribution patterns observed. A buoy station of the Kyoto Institute of Oceanic Fishery Science is moored off the Niizaki Point about 2.5 km from point No. 1. This buoy system records the underwater temperature at five depths of 1, 5, 10, 15 and 25 m every 30 min intervals through the year. These data were compared with the survey results and the process of front formation drawing the isothermal distribution patterns during, before and after 2 days of the survey.

To probe the effects of the waves longer period than the diurnal tide on the thermal distribution in the front, the surface water temperature data measured once every day were collected from four fixed sites in the western part of the Japan Sea; Izuhara, Saigo, Hamada and Etomo, and intermittent data from Goto Islands were also added. The location of each site was shown in Fig. 1-a.

Results

Distributions of Water Temperature, Fish Larvae and Eggs

The isothermal pattern of the survey is shown in Fig. 2. The difference of temperature between surface and 10 m depth was 4.8°C (28.1°C–23.3°C) and seems to be related with the egg distribution as Fig. 3 shows. In this paper any salinity data is not given since the maximum difference between surface to 10 m depth, it was only 1.00‰ that is,

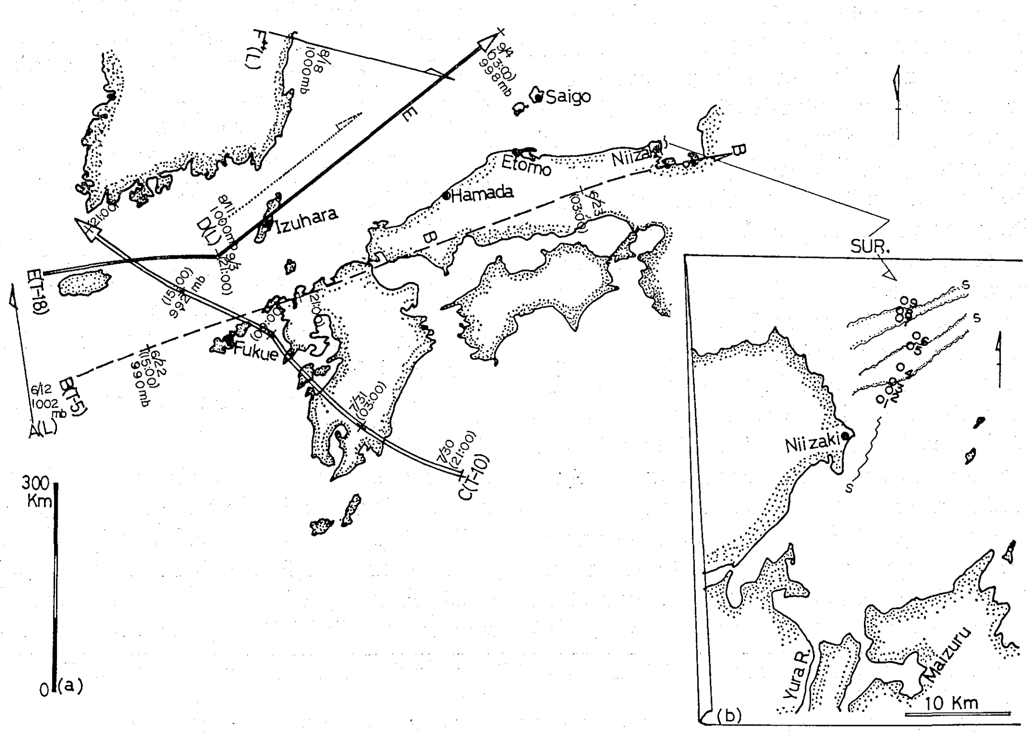


Fig. 1-a. Surface water temperature sampling stations, courses of typhoon (T) and low pressure centers (L) (upper).

1-b. Locations of survey points (lower), S is slick zone.

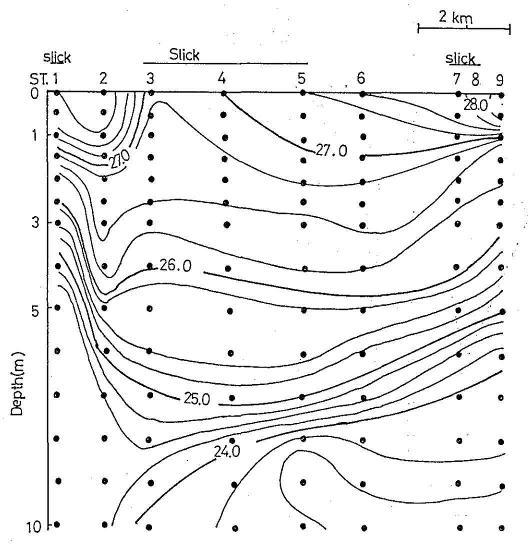


Fig. 2. Vertical temperature distribution patterns in Wakasa Bay.

surface layer 31.95‰ and 10 m depth 32.95‰. The isotherm of 25.0°C was rising toward both southern and northern ends and it formed plateau in the middle below the 5 m depth layer. Several drifting *Sargassums* and particulate matters were floating at the northern edge.

The mean concentration of egg per unit mass from points No. 1 to No. 6 was 87 per 100 m³, while it was 741 from No. 7 to No. 9 toward north and the highest value was obtained in the surface layer of No. 7 (1350 per 100 m³). The concentration of larvae, on the other hand, did not show a similar pattern as indicated in Fig. 4. The range of total length of larvae are within 3 mm to 7 mm.

Shift of Fronts and Tide Period

The temporal transitions of isothermal patterns are presented in Figs. 5-a, b. Water temperature higher than 27.0°C appeared above the 10 m depth once every day and persisted about three to ten hours. The sharp boundaries separated by 24.0°C would be fronts, and the SURVEY was the intermediate part between the boundaries. To indicate the horizontal shift of warmer water, the tide period in Maizuru Bay, which is located within Wakasa Bay, was superimposed on the time axis in Fig. 5. Appearance of warmer water in the shallower layers was almost all in accord with the time periods from high water slack (HWS) to the low water slack (LWS).

In addition a longer period wave was found from July 30 to Aug. 1 with a period of 52 h, and at noon on Aug. 1 the surface temperature became 23.5°C which was about 3.5°C lower than the previous day. The warmer water was recorded twice while the longer period wave passed; although each pattern was quite different in both time duration and depth. The internal structure of the front seems to be affected by the longer period wave. It is necessary to know the cause of this fluctuation longer than the tidal period, since its fluctuation sometimes occurred during the summer as shown in Fig. 6. The time series data of the Niizaki Point from June to September are arranged to determine the periodical frequencies at each depth. From the spectral analyses of the time series data the most common

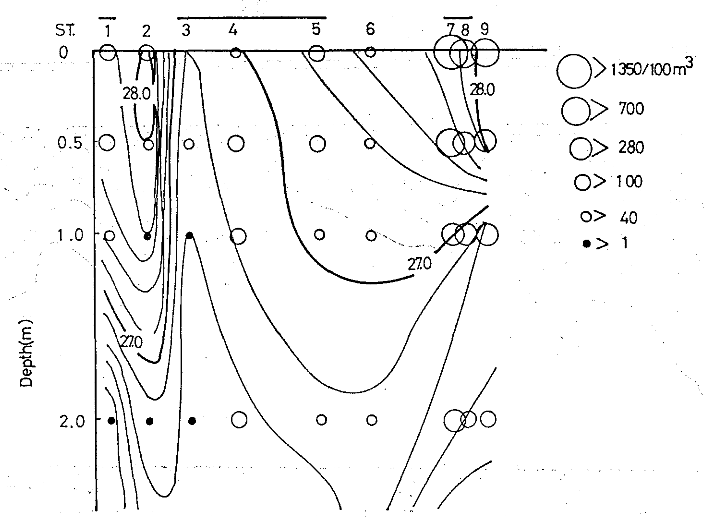


Fig. 3. Japanese anchovy *Engraulis japonicus* egg distribution in the surface layers.

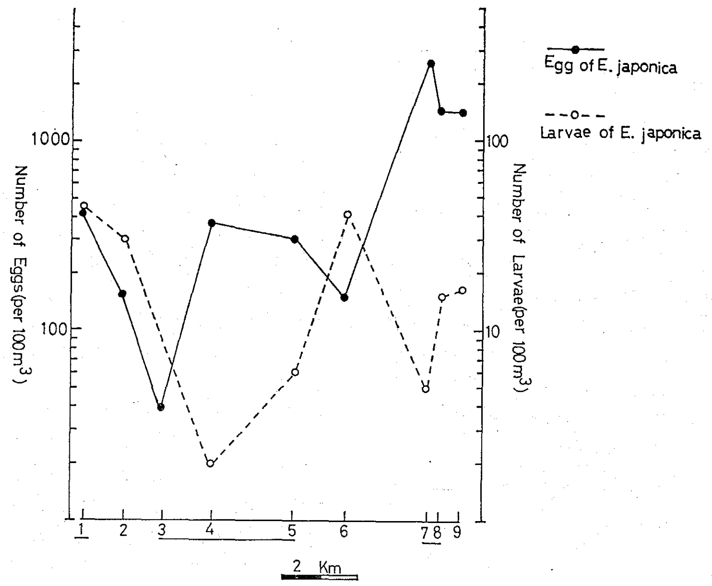


Fig. 4. Numbers of larvae and eggs per 100 m^3 at each survey point.

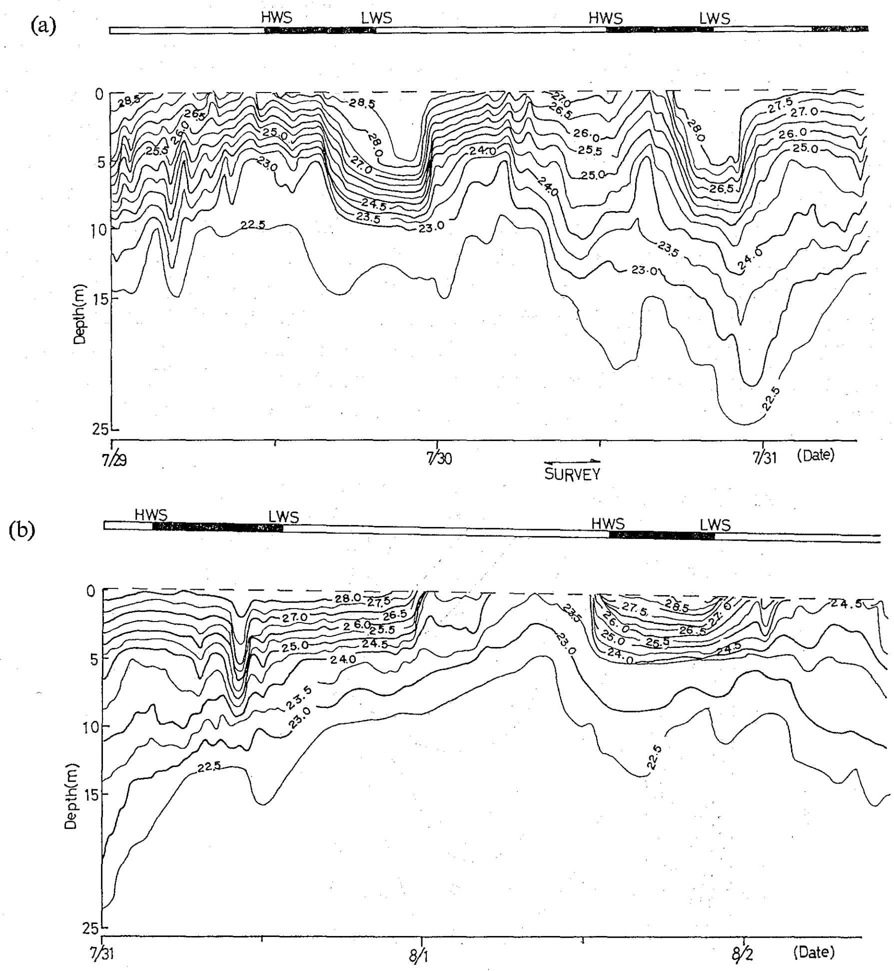


Fig. 5-a. Isotherms at Niizaki Point from June 29 to 31, 1981.
5-b. From June 31 to August 2.

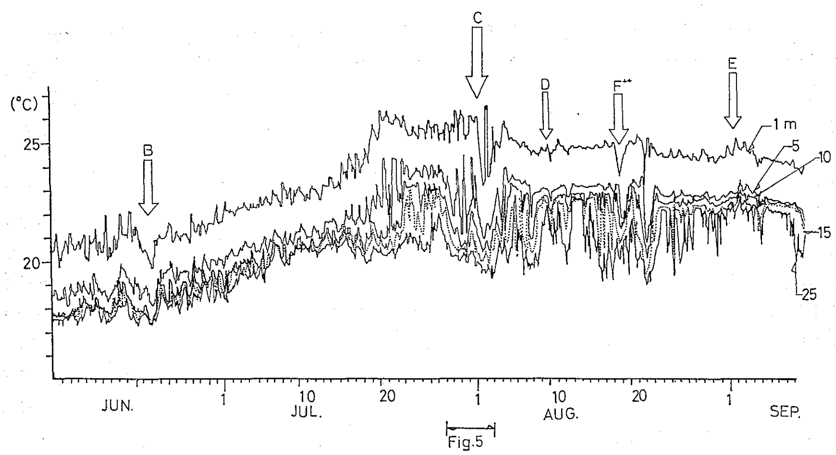
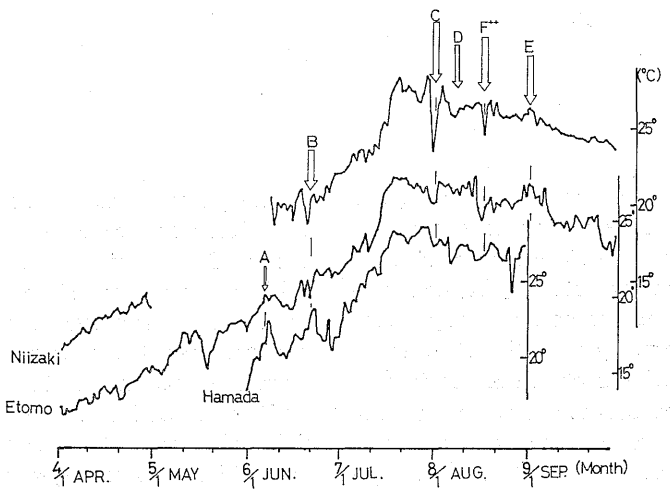


Fig. 6. Time series data of water temperature at Niizaki Point; arrows indicate typical fluctuations (see text for details).

(a)



(b)

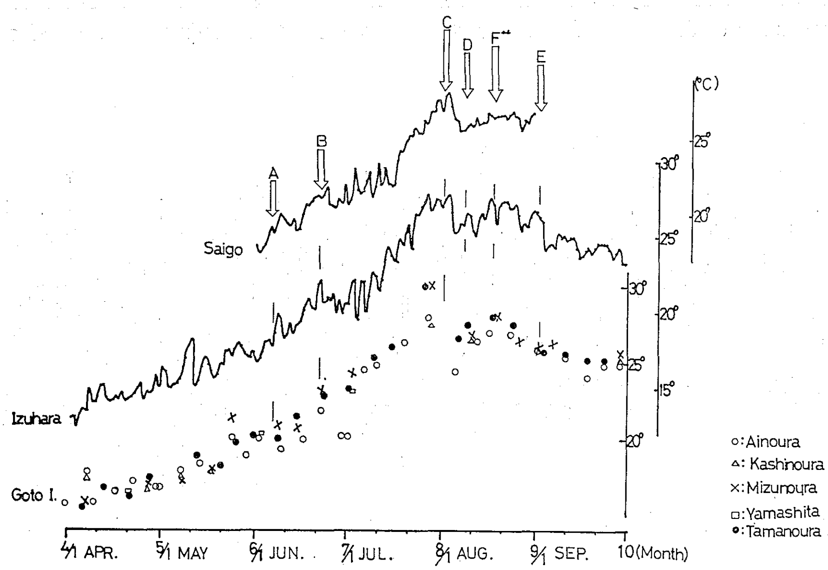


Fig. 7-a. Surface water temperature along the coast of the Japan Sea.
7-b. The same data of islands, Izuhara, Fukue and Saigo.

frequency throughout the layers was $8\times10^{-3}\,h^{-1}$ (about 5 $days^{-1}$) and this frequency was also commonly found in the time series data of surface temperature from some places along the coast of the Japan Sea. The fluctuations marked with arrows in Fig. 6 do not have any periodicity in each interval but occurred randomly from June to August. The capitals in Fig. 6 indicate typical large fluctuations observed through the whole layers and the same are given in the surface water temperature data of Fig. 7.

Discussion

Distribution of Organisms in the Vicinity of Front

Two factors may be responsible for the patchy distribution of sea organisms; one is the biological attraction due to the deterministic nature of fish and the other is mechanical aggregation due to the velocity discontinuity of neighboring fluid mass. The former occurs to larvae seeking for advantageous conditions to outlive, for example, at fronts where provide more opportunities to meet and capture the prey than the other areas. Although fronts provide good feeding area, the physical conditions in the frontal zone is not so suitable for larvae to stay since the gradients of temperature and salinity or other hydraulic conditions such as the shear of flow are larger both vertically and horizontally than the other water mass. The biological attraction may be formed on a critical balance between tolerance to physiological stress due to the physical factor gradients and the degree of demand to feed. The gradients in the fronts sometimes differ from the optimum circumstances for feeding and growth in anchovy larvae and this discrepancy may be due to the different kinds of food particles available to the larvae as Lasker[3] pointed.

The mechanical aggregation patterns vary with the spatial sampling scale. Shallow sea fronts are commonly found in boundary regions where nearshore and offshore waters tidally mix. These fronts contain several smaller demarcations alternately divided with convergence (tide rip) and divergence (oily slick).[4] The demarcation results from the discontinuous distribution of those organisms with lesser swimming power such as phytoplankton, fish larvae and nauplii or small zooplankton.

The egg distribution of Japanese anchovy in Fig. 3 seems to correspond with the physically divergent zones presented by the slick from points Nos. 3 to 6 and convergent zones from 8 to 9 distinguished by the streak of suspended matters. But it may not commonly appear around the fronts since it did not show the same pattern in our other front surveys. The distribution of eggs, which may be regarded virtually particles, depends on the physical mixing condition of nearshore and offshore waters and on the biological spawning timing of adult fish. Hunter and Macewicz[5] determined the temporal patterns of spawning for the northern anchovy *Engraulis mordax* and reported that the maximum spawning occurs between 21:00 and 02:00 with a peak between 22:00 and 23:00. The northern anchovy exhibits little locomoter activity during the first 2 days of larval existence, and occasionally larvae execute a brief but intense burst of swimming.[6] These bursts of swimming were also observed in

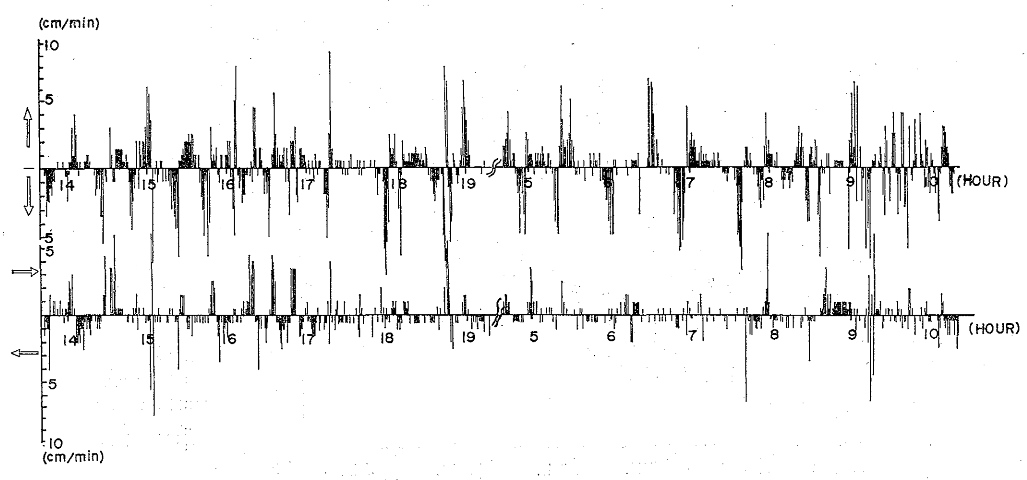


Fig. 8. Average locomoter activity during the first 2 days of *Engraulis japonicus*, measured July 5, and 6 in 1982.

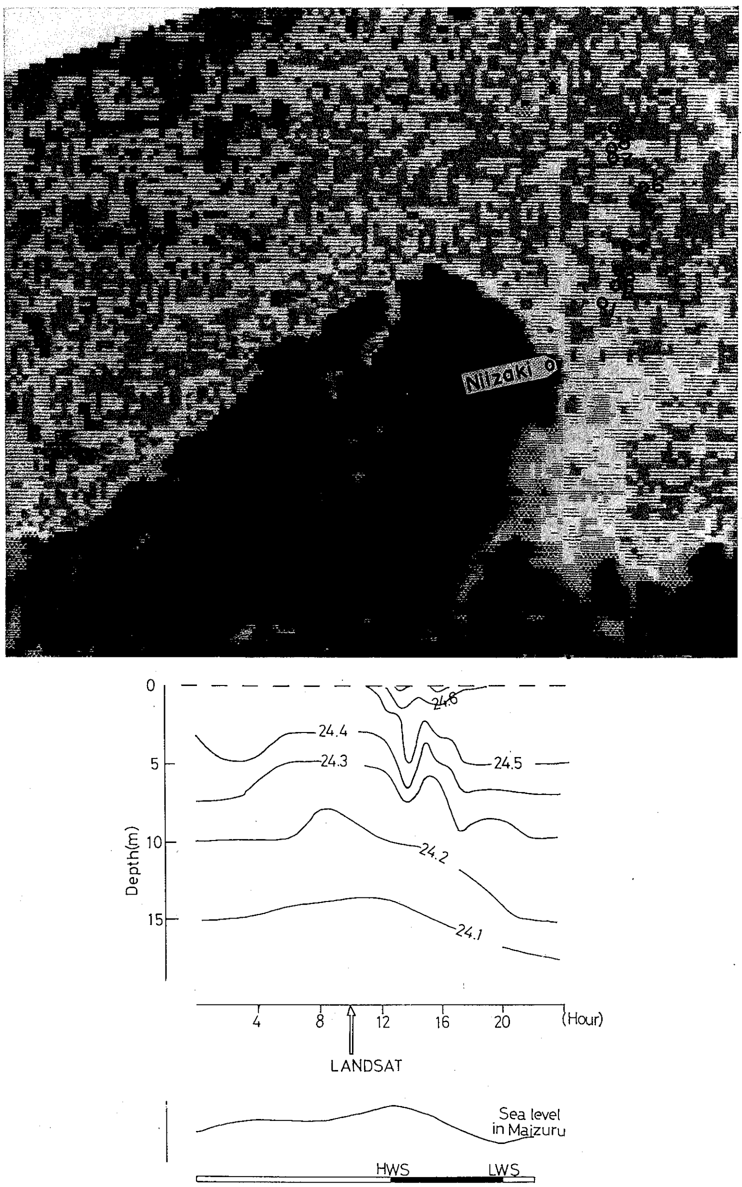


Fig. 9. Surface water color of LANDSAT processed by computer (upper) and isothermal line of Niizaki Point (lower).

the same stage of Japanese anchovy, which directed the head downward. We measured the swimming velocities of Japanese anchovy during the first 2 days using the same water basin and method as Tsuda and Sakamoto[7] reported. The result was presented in Fig. 8.

The measurement was done keeping water temperature in 26°C to 27°C, to seek the difference of distribution pattern between eggs and larvae as shown in Figs. 3 and 4, that is, to know the effect of biological rhythm of swimming power. Illuminance during the day was 1000 lx, in dusk and dawn it changed from 1000 to 1 lx. In the night we could not find the individual since the experiment was carried out under the natural light condition. It hatched out 2 h before the experiment. The intense burst of swimming observed 6 to 3 times for an hour but any clear evidence of activity rhythm could not be found. The average length to move horizontally for an hour is estimated 0.4 m, which suggests us that the maximum distance to be covered by the swimming locomotion of a larva itself is only 10 m at most in a day. The biological and physical factors to make the different distribution pattern may be as follows; spawning timing, separation distance between convergent zone and spawning ground, variance of flow and internal tide. We think that the aggregation of organisms are not always found in the vicinity of front.

Coastal Shallow Sea Front in Wakasa Bay

Some researchers have reported the existence of front at south western inner part of this bay, so called Tango-Kai.[8,9] The clearest plume front can be seen at the boundary of the Yura riverine plume discharging into the coastal water. They are visually distinguishable by the turbidity of surface water. On the whole, the water in the south western part of Wakasa Bay show lower salinity and high temperature in summer by the inflow and mixing of fresh water. Above the 10 m layer in Fig. 5, the boundary zone surrounded by the 27.0°C isotherms means the front between the coastal water and off shore water, where the surface layer influenced the "retrograde" front.[10] This front is different from the riverine plume front and the conclusion is supported by LANDSAT-2 data, which is analysed to show the scattering light intensity of CH. 5 in Fig. 9. Blue to orange coloration is used to map the optical density of monochromatic photograph.

Since the LANDSAT data was taken on September 17, 47 days after the survey, the same water temperature distribution can not be expected. The isothermal patterns at the buoy station of the Niizaki Point on the same day that the LANDSAT image was taken were plotted also in the same figure with the sea-level of Maizuru Bay. In this case the temperature was already lower than our survey period, but the isotherm of 24.4°C seems to show shifting pattern similar to that shown in Fig. 5. A critical change of temperature appears at the intermediate part of HWS and LWS just as shown in Fig. 5. When the satellite scanned Wakasa Bay at 09 : 51 in J. M. T., coastal shallow front was located in the southern part (inside of the Bay) where the coloration is green and yellow or orange. Blue and green indicate less turbid water while yellow and orange indicate more turbid water brought from river suspensions. As the ebb began from noon, the front shifted its position to the north and passed the buoy station about 13: 00. We can consider the relation between the temperature distribution change in Fig. 5 and tide by the same analogy mentioned in Fig. 9.

The direction of current changed to the south at 20: 00 on June 29 with the flood tide. The position of front moved gradually from offshore to the inner part according to the elapsed time as long as flood tide lasted. The front passed the buoy station at midnight on June 30 yet shifting to the inner part of the Bay. The period of time when we surveyed slick zones corresponded to the flood tide. As the front was located south of point No. 1 at that time, the distribution patterns of egg and temperature represented a marked concentration in the offshore side (northern part) of the front. In conclusion, the major cause of high water temperature zones appearing once a day is not the internal wave but the diurnal horizontal shifting of front which is formed by the tidally mixed nearshore water and stratified offshore water.

Long Period Wave Exerting an Influence on the Front

Time duration and depth of warmer water indicated that the 27.0°C isotherms in Fig. 5 is different from day to day. The longer period fluctuation influenced the surface temperature on Aug. 1. This long period wave was observed several times during the summer as shown in Fig. 6. Yanagi *et al.*[11] pointed out five days period wave in winter along the San-in coast of the Japan Sea and they concluded it would be shelf wave being excited by the travelling of the low pressure from west to east along the coast or the seasonal northwesterly wind.

The same frequencies as reported by them (5 $\text{days}^{-1} = 8.4 \times 10^{-3}\ \text{h}^{-1}$) can be seen in Table 1, in which the spectral analyses from June to September shows the characteristic frequencies of the Niizaki Point buoy station. They are the same data as shown in Fig. 6. Since the water temperature is vertically stratified from surface to 25 m layer, fluctuation mechanism may be different in summer from winter when vertical mixing is prominent. Yanagi and others assumed that hydraulic energy bringing from sea-level fluctuation or turbulent mixing is caused by the low pressure and seasonal wind blow. The same frequency appeared in the surface temperature fluctuation of Izuhara especially in summer from June to September. Some researchers thought that this period may be brought from the inflow of warmer water mass from outer of the Tsushima Strait intermittently (Toba *et al.*,[12] Hanawa,[13] Tawara and Fujiwara[14]). We did not make a thorough investi-

Table 1. Dominate frequencies indicated in the temperature fluctuation on Niizaki buoy recorder (h^{-1})

	1 m	5 m	10 m	15 m	25 m
June.	4.0×10^{-3}	—	—	—	—
	7.6×10^{-3}	8.0×10^{-3}	8.0×10^{-3}	8.5×10^{-3}	8.0×10^{-3}
	8.8×10^{-3}	1.6×10^{-2}	1.8×10^{-2}	1.8×10^{-2}	1.4×10^{-2}
	1.2×10^{-3}	2.4×10^{-2}	3.0×10^{-2}	2.1×10^{-2}	2.2×10^{-2}
	2.9×10^{-2}	3.4×10^{-2}	3.4×10^{-2}	2.9×10^{-2}	2.8×10^{-2}
	3.9×10^{-2}	4.3×10^{-2}	4.3×10^{-2}	3.6×10^{-2}	3.8×10^{-2}
	5.0×10^{-2}	5.5×10^{-2}	—	4.6×10^{-2}	5.1×10^{-2}
	6.8×10^{-2}	7.1×10^{-2}	—	5.4×10^{-2}	—
July	8.0×10^{-3}	1.2×10^{-2}	3.6×10^{-3}	4.0×10^{-3}	5.4×10^{-3}
	1.8×10^{-2}	1.8×10^{-2}	1.0×10^{-2}	1.0×10^{-2}	1.0×10^{-2}
	2.2×10^{-2}	2.3×10^{-2}	1.5×10^{-2}	2.1×10^{-2}	2.1×10^{-2}
	3.4×10^{-2}	2.6×10^{-2}	2.2×10^{-2}	3.2×10^{-2}	3.4×10^{-2}
	4.3×10^{-2}	3.6×10^{-2}	3.0×10^{-2}	3.8×10^{-2}	4.2×10^{-2}
	4.8×10^{-2}	4.3×10^{-2}	4.8×10^{-2}	4.9×10^{-2}	—
	6.6×10^{-2}	5.1×10^{-2}	6.2×10^{-2}	5.4×10^{-2}	—
August	8.5×10^{-3}	8.4×10^{-3}	8.4×10^{-3}	—	—
	1.5×10^{-2}	1.5×10^{-2}	1.4×10^{-2}	1.4×10^{-2}	1.0×10^{-2}
	2.6×10^{-2}	2.6×10^{-2}	1.8×10^{-2}	1.8×10^{-2}	2.1×10^{-2}
	4.2×10^{-2}	4.2×10^{-2}	3.0×10^{-2}	2.3×10^{-2}	3.2×10^{-2}
	6.2×10^{-2}	8.3×10^{-2}	4.2×10^{-2}	4.0×10^{-2}	4.2×10^{-2}
September	8.0×10^{-3}	8.5×10^{-3}	1.0×10^{-2}	1.0×10^{-2}	1.0×10^{-2}
	1.4×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
	2.3×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	3.0×10^{-2}	2.6×10^{-2}
	3.0×10^{-2}	4.2×10^{-2}	3.4×10^{-2}	3.3×10^{-2}	3.4×10^{-2}
	4.2×10^{-2}	5.8×10^{-2}	4.2×10^{-2}	5.5×10^{-2}	4.2×10^{-2}
	8.3×10^{-2}	—	—	8.3×10^{-2}	8.3×10^{-2}

gation of this frequency, but direct our attension to the large scale fluctuation which occurred in our survey period (C in Fig. 6). The same large variances as pointed with capital C are also indicated in the same figure by A to F^{++}. During our survey corresponding to arrow-C, the weather was clam and warm. On the other hand, during the same period the weather of the Tsushima Strait was rainy or cloudy since the Typhoon No. 10 was passing through.[15] The typhoon formed on June 28 and blew out to China travelling the mid part of the Strait at 03:00 June 31. The maximum instantaneous wind speed was recorded 28.4 m/s and the atmospheric pressure was 989.9 millibar at Fukue where was affected by the typhoon. But it was cloudy in Hamada with the maximum wind speed of 9 m/s (mean was 2.6 m/s) and in Maizuru it was fine with the maximum speed of 6 m/s (mean 1.3 m/s) at that time.[16] The progressive course of typhoon or low atmospheric pressure centers are plotted to compare with the large scale fluctuation in Niizaki (see Fig. 1-a).

We cannot find any direct geophysical factor on the fluctuation of water temperature within the limit of Hamada and Niizaki Point on that day. The descent of surface temperature have somewhat lag time among Hamada, Etomo and Niizaki and each of them seems to be proportional to the distance from the Strait. The phase speed from Hamada to Niizaki is about 2.4 m/s if we assume the linear distance from the chart. The existence of progressive long wave in summer can also be elucidated by comparing the daily mean sea-level adjusted for effect of atmospheric pressure according to the hydrostatic hypothesis, that is, 1 mb decrease corresponds to 1 cm sea-level rise,[16] in which is shown Fig. 10. Almost all of the fluctuations noticed above with putting arrows are accompanied by the change of sea-level. Two geophysical conditions may be thought; one is passing the typhoon or low pressure center from the Pacific Ocean to the China Sea, another is coming along the coast of the Japan Sea. The former types are A and C, the latters are B, D, E and F^{++}. These fluctuations arise from the travelling typhoon or low pressure. The long period wave is more obviously appeared along the

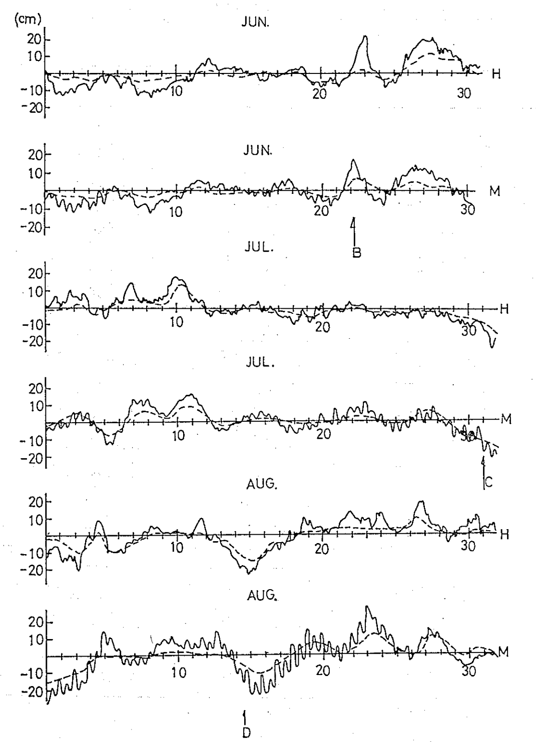


Fig. 10. Deviation of sea-level of Hamada and Maizuru (solid) and that adjusted by atmospheric effect (dash), ordinate: deviation of sea-level, H: Hamada, M: Maizuru.

Honshu side than the Islands (Fig. 7-a, b). If a diffraction occurs at the mouth of Wakasa Bay, it may be an important factor to determine the shift of front. The concentration of larvae and eggs in the front is probably affected by this diffraction.

Acknowledgements

We wish to express our gratitude to Dr. T. Shiokawa, director of the Kyoto Institute of Oceanic Fishery Science, who permitted us to refer to the water temperature data of the Niizaki Point. We also express our gratitude to Mr. T. Komatsu, who helped the data processing of LANDSAT offered from National Space Development Agency of Japan. This work was supported in part by a Grant from the Japanese Ministry of Education (No. 57560187).

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