The Journal of the Shimonoseki University of Fisheries 27 (1) 89 — 100 (1978)

Transportation Model of Japanese Anchovy in Yuya Bay Based on Current Pattern*

By
Satoru TAWARA

Recently, echo-survey for estimating fish stocks has been developed in many countries. In Japan, the echo countings for individual fish[1,2,3,4,5] or fish schools[6,7,8,9] are now showing remarkable advance. In Yuya bay, OKAWA and MISU[8] estimated the stock of Japanese anchovy, *Engraulis japonica* (HOUTTUYN), comparing the echo counting with the catch from the detected schools. The catch records of boat seine, which is the exclusive commercial fishing aiming at surface and midwater swimmers in this bay, showed that abundant fish were adult and larvae of anchovy. It is natural that there is a basic difference between them in the mechanism of change in population density : the former has a sufficient ability of free swimming and its density depends mainly on its own preference but is partly modified by fishing activities, while the latter has negligible ability to swim and it is possible to regard that the change in its population density depends on current drift. The present report dealt with the daily change of the stock condition of the latter during the period from June 4 to 19 in 1977 in Yuya bay in relation to the current at 5-m layer measured by self-recording current meter, with the intention of clarifying whether it would be possible to explain the change in the population density of anchovy larvae by current drift or not.

Material and Method

Current at 5-m layer of the three stations was measured by moored self-recording current meters. The location of these stations and the mooring system are shown in Figs.1 and 2, respectively. The direction and velocity of tidal stream at St. A and St. B were recorded at 7.5 minute intervals (8 frames/hour) by film-recording current meter (manufactured by General Oceanic Co.Ltd.), and those of St. C at 5-minute intervals. The current records were converted into the 25-hour running means of the north- and east-components, and used in the present report, for the purpose of excluding the change due to tidal rhythm.

Wind was recorded at 2-hour intervals at Kawaziri misaki, 5 km north of Yuya bay. Its 24-hour running means of north- and east-components were used, for the purpose of corresponding the records of wind to those of current.

* Contribution from the Shimonoseki University of Fisheries, No. 831. Received July 31, 1978.

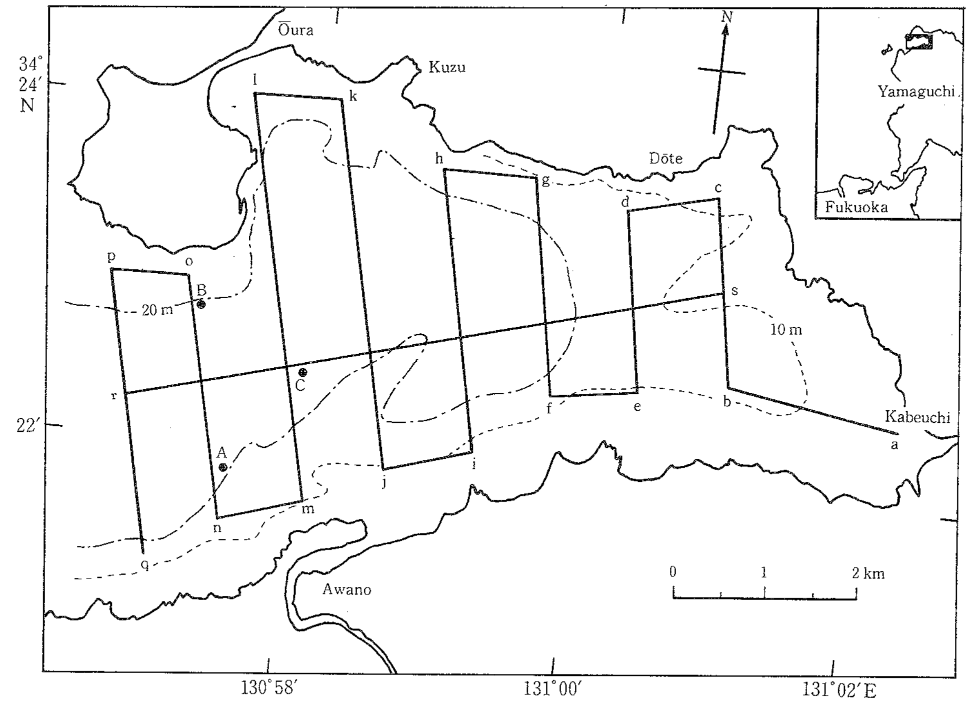


Fig. 1. Echo-survey line and positions of current measurement in Yuya bay (June, 1977).

Echo-survey was conducted daily over 13 consecutive days along eight parallel transects spacing at about 1,000 m intervals (*abc .... qrs* and *bcd .... qrsa* in Fig. 1, *i.e.* each of the parts was sounded twice a day, consecutively). The echo traces along each of the survey lines were transferred on 1 mm mesh parchment, and their sizes were read to the nearest mm^2. And the density of fish population was estimated from this reading through the proportional method proposed by OKAWA and MISU[8] after correction for the sailing speed during recording. The boat seine was chartered for two days during the echo survey in order to detect the organism responsible for echo traces.

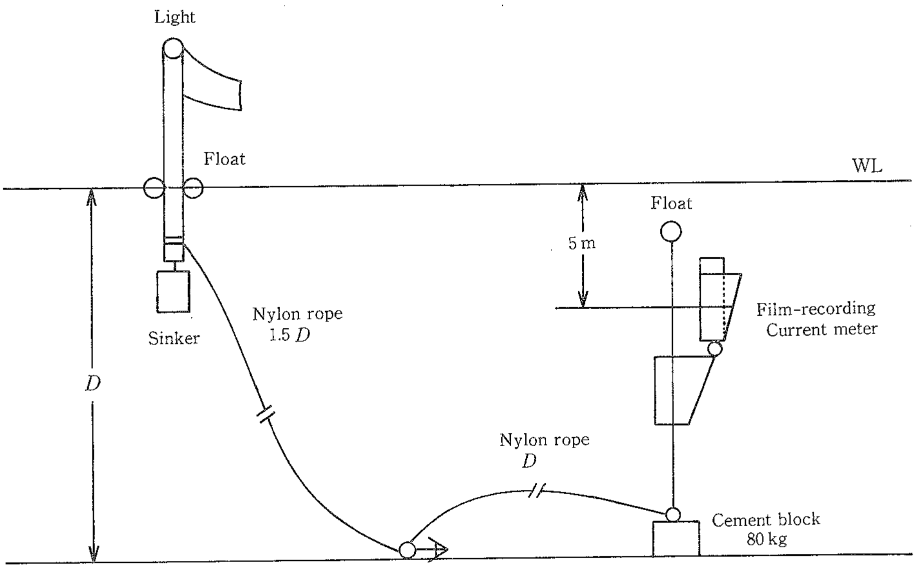


Fig. 2. Current meter mooring system at Sts. A and B.

Results

1. Horizontal distribution of larval population and its daily change

The amount of fish population in this bay was estimated from echo traces in the range from 600 to 1,200 tons, showing an increasing trend with fluctuation of 3-5 day periodicity as shown in Fig. 3. Here attention should be paid to the following finding of the catch records of the chartered seiner : it is necessary to treat the echo traces separating according to their size, for those smaller than 10 mm^2 were derived from the patch of larvae of Japanese anchovy while those larger than this size limit were from its adult. The traces larger than this size limit were excluded, and it was found out that the larval population showed a decreasing trend during the surveyed period with the fluctuation of the same periodicity. The horizontal distribution of larval population was illustrated in Fig. 4. In this figure, the following method was adopted to draw contours : 1) the densities of echo trace in every 250 m of surveyed course were read from the echogram transferred on 1 mm mesh parchment, 2) a pair of data for each of the 250 m sections (for each of the sections was sounded twice a day) was averaged, and 3) the averaged readings were smoothed by estimating the 3-section running means.

The leading patterns of distribution shown in this figure were :

1. On the days of increasing phase of density, concentrated population was found frequently in the head of the bay, while on the days of decreasing phase, the pattern suggested that the dense population in the northern head should be drifted to the northern half of the mouth.
2. In the northwest corner concentration of fish could be detected at every survey, indicating the stay of fish probably due to a stagnation of water as suggested by topography.
3. At the mouth of the bay, isolated school(s) could be frequently detected at both or one of the northern part and southern one.

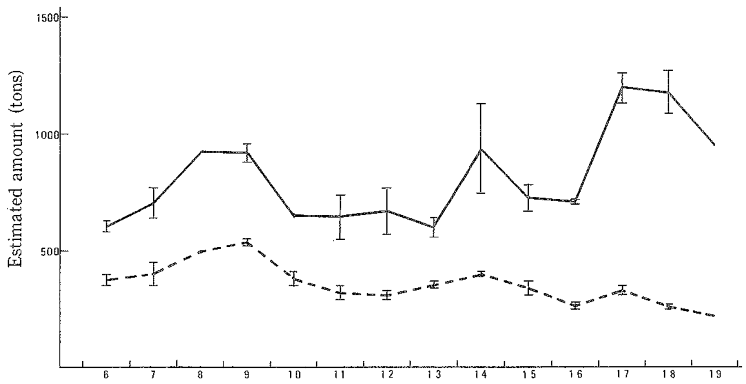


Fig. 3. Daily change of the estimated amount of fish population.

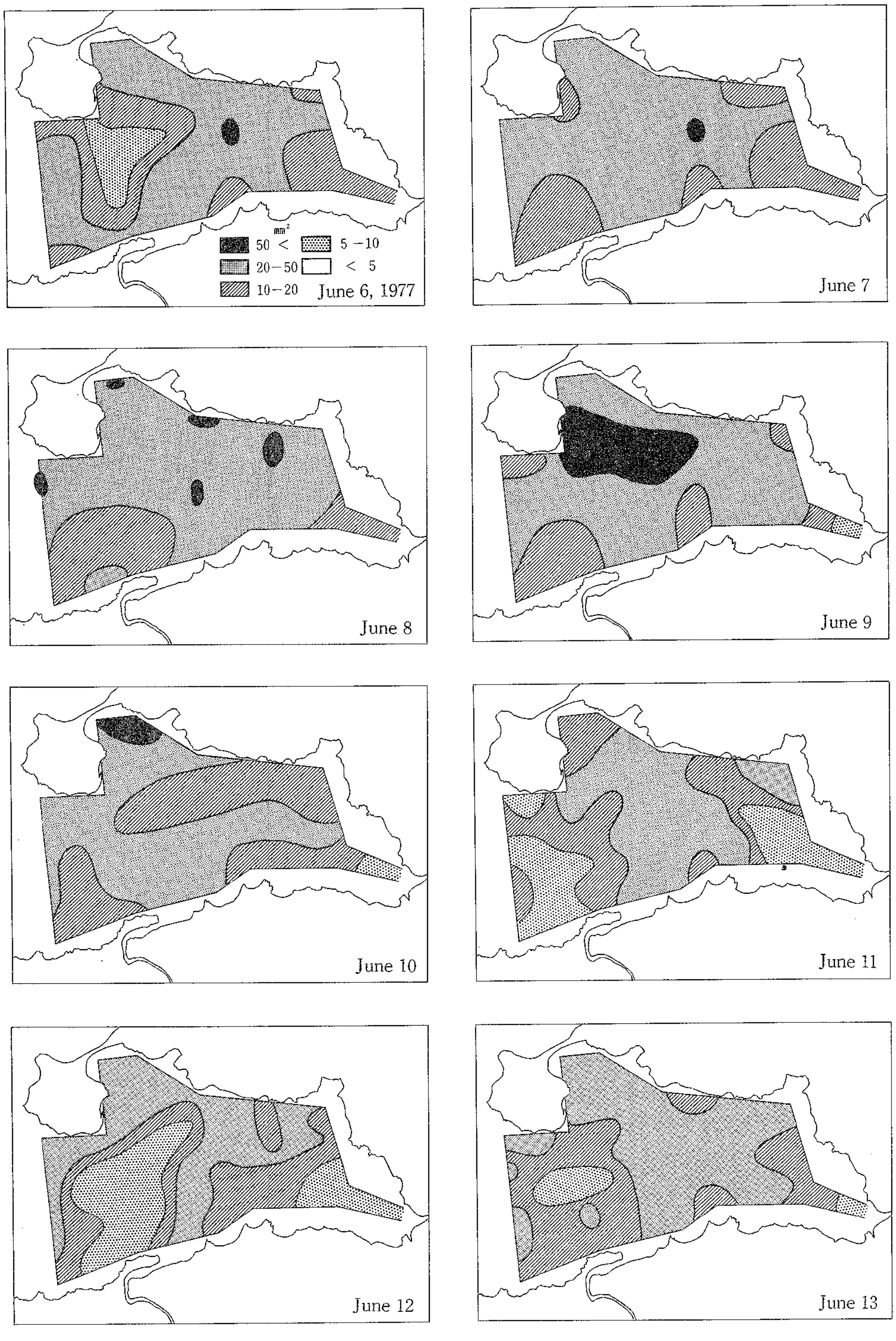
Solid line......... Total amount of fish population
Broken line....... Amount of larval population

2. Current pattern and its modification by wind

A continuous counterclockwise circulation of less than 10 m/sec (25-hour running mean) could be pointed out as the basic pattern of the current regardless of wind drift. And the water flowed into the bay along the southern coast and flowed out along the northern one intermittently with a 3-4 day periodicity. The wind modified slightly this basic pattern : the wind was within 2 m/sec till June 14. During this phase, the sea water first flowed into the bay along the southern coast then flowed out along the northern one. The NE'ly wind became noticeable after June 14 and attained the level of 4 m/sec on June 18 as shown in Fig. 5. During this phase, the inner water was driven out along the northern coast at first, and then the water from out side flowed in along the southern one. During this 15-day current observations, two peaks of flowing-in (over 20 cm/sec) and a peak of flowing-out were recorded as shown in Fig.6, although each of them continued for not longer than 4 to 4.5 hours. No strong current was recorded at St. C, suggesting that this station be located near the center of the area surrounded by the above-mentioned circulation.

3. Basis of transportation model of larval population proposed in the present report

Based on the above-mentioned pattern of daily fluctuation of horizontal distribution of fish larvae and the current patterns, it is reasonable to assume that the swimming ability of larva is negligible, and its transference is due to current drift especially in consideration of the horizontal distribution. In consequence, the daily fluctuation of its horizontal distribution depends on that of current. Then, it is possible to caluculate quantitatively its transportation based on the following simple model. The current pattern shown in the preceding section suggested that the larvae should be transported according to the current into the bay along the southern half, then drifted along counterclockwise circulation of constant flow. To express the transportation between adjacent parts in the bay, the bay is divided into the four sections as shown Fig.7. Set that $Z_{1 \cdot i}$ is the amount of larvae transported from Section 1 to Section 2, $Z_{2 \cdot i}$ from Section 2 to


mm²
50 <
5 −10
20−50
< 5
10−20
June 6, 1977
June 7
June 8
June 9
June 10
June 11
June 12
June 13

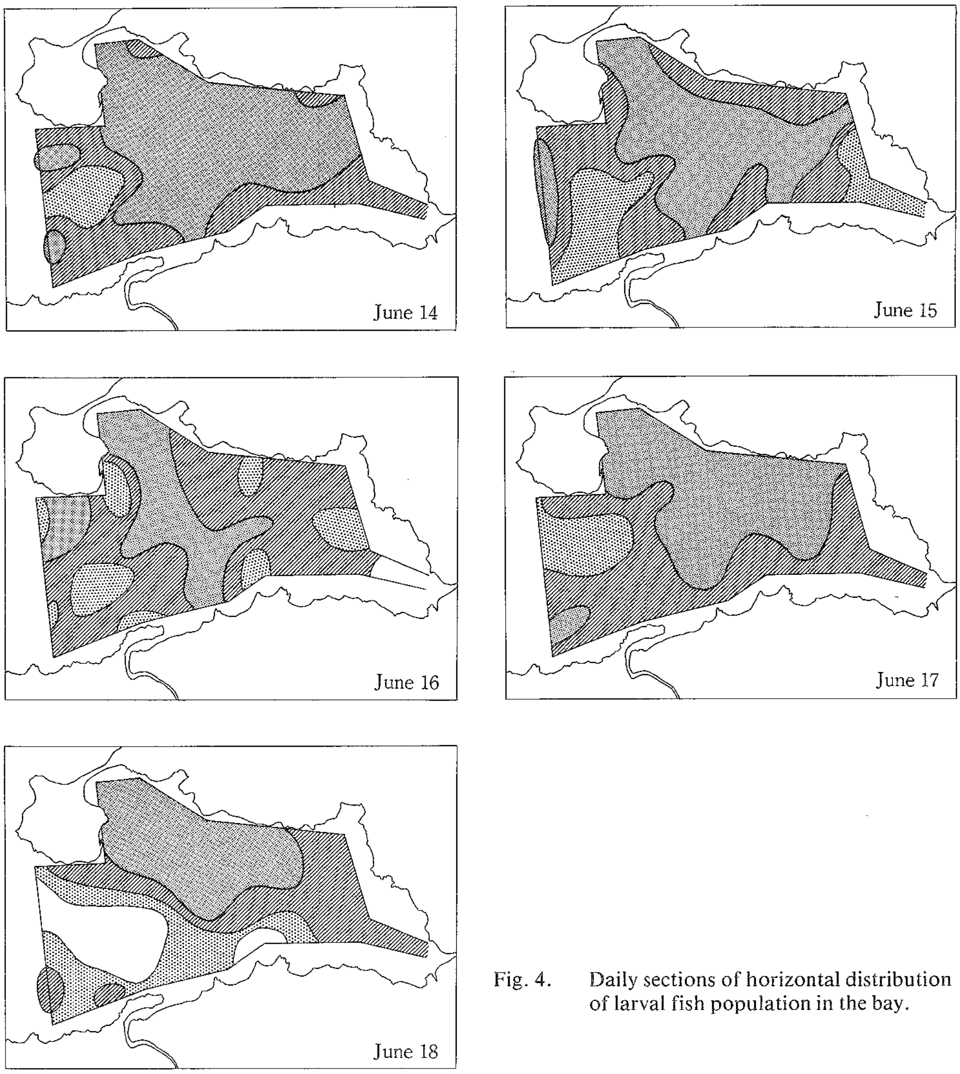


Fig. 4. Daily sections of horizontal distribution of larval fish population in the bay.

Section 3, $X_{1 \cdot i}$ from Section 3 to Section 4, $X_{2 \cdot i}$ from Section 3 to Section 2, and Y_i from Section 4 to Section 1. In the case of "drifted in", the amount of larvae drifted from Section 3, X is divided into $X_{1.i}$ (to Section 4) and $X_{2.i}$ (to Section 2) with the ratio of $\frac{u}{u+v} \cdot X$ and $\frac{v}{u+v} \cdot X$, *i.e.* according to the ratio of the east- and the north-vector (u and v) of constant flow at St. A. Then the change in abundance of larvae on the Day i in the Section j, $\Delta n_{i \cdot j}$, is expressed as follows:

$$\begin{cases} \Delta n_{i \cdot 1} = Y_i - Z_i \\ \Delta n_{i \cdot 2} = Z_i + X_{2 \cdot i} \\ \Delta n_{i \cdot 3} = \Delta N_i - X_{2 \cdot i} - X_{1 \cdot i} \\ \Delta n_{i \cdot 4} = X_{1 \cdot i} - Y_i \end{cases}$$

where

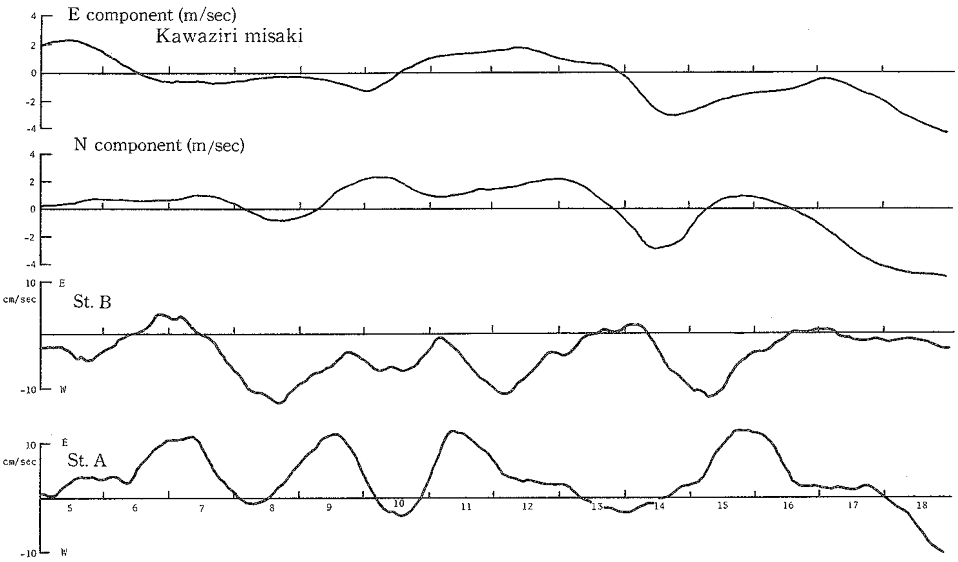


Fig. 5. 24-hour running means of the east and north components of wind at Kawaziri misaki and 25-hour running means of the east components of current at St. A and St. B in the mouth of the bay.

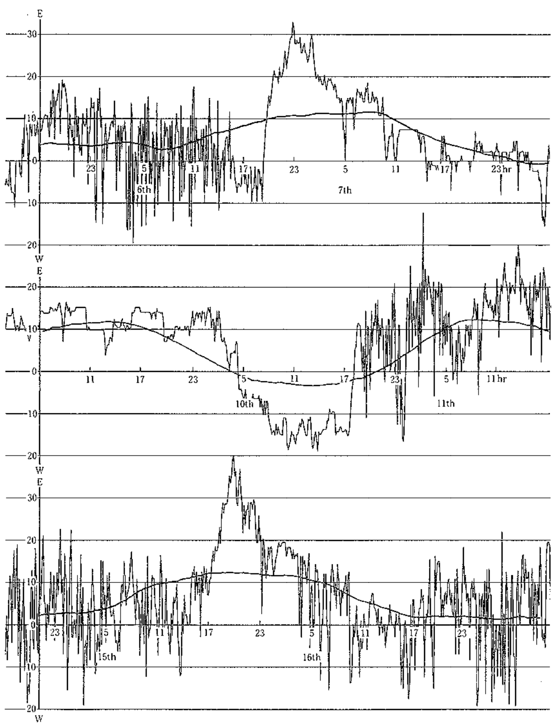


Fig. 6. East component of current at St. A with its 25-hour running mean.

$$\Delta n_{i\cdot j} = n_{i+1,j} - n_{i\cdot j}$$

$$\Delta N_i = \sum_{j=1}^{4} \Delta n_{i\cdot j}$$

In the case of "drifted out", similary, the amount of larvae drifted into Section 2, Z, is divided into $Z_{1\cdot i}$ and $Z_{2\cdot i}$ with the ratio of $\frac{u}{u+v}\cdot Z$ and $\frac{v}{u+v}\cdot Z$, according to the ratio of the east-and north-vector of constant flow at St. B.

$$\begin{cases} \Delta n_{i\cdot 1} = Y_i - Z_{1\cdot i} \\ \Delta n_{i\cdot 2} = Z_{1\cdot i} - Z_{2\cdot i} - \Delta N_i \\ \Delta n_{i\cdot 3} = Z_{2\cdot i} - X_i \\ \Delta n_{i\cdot 4} = X_i - Y_i \end{cases}$$

4. Findings through the transportation model

Using $\Delta n_{i\cdot j}$ estimated from the echogram, X_i, Y_i, and Z_i were calculated and illustrated in Fig. 8. The series of this figure showed the following pattern : counterclockwise

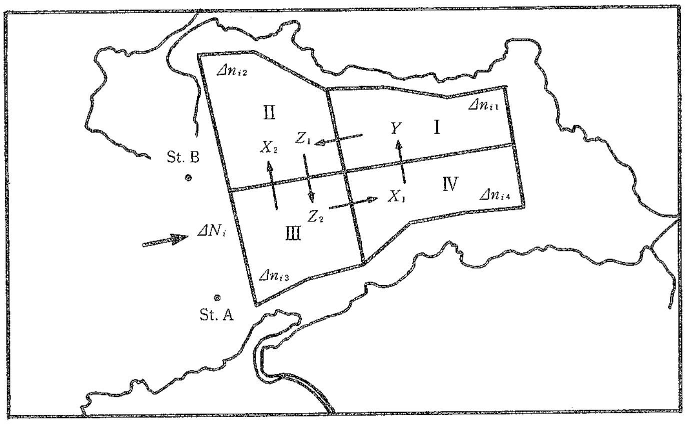


Fig. 7. Transportation model with abbreviations employed.

drift of larvae could be found in the eight examples out of the 12 ones, while clokwise drift was in an example, although there were three examples showing the different patterns (accumulation of larvae into Section 1, into Section 2, and northward drift). The importance of the present modeling in evaluating the population density should be laid in the fact that the present model can give quantitative information of renewal.

The horizontal distribution of larvae detected with the echo-sounder is nothing but that of standing stock, and, exactly speaking, the difference between the contoured charts (Fig.4) on the adjacent days can not show the migration of larvae. If the abundant fish was detected through echo survey, this population is of low value from pratical point of view, when it is slow renewal. In contrast with this, the population of somewhat low density should be given high evaluation, when it is renewed (or recruited) with a short cycle. In regard to this point, the analysis through the present model revealed that the larval population in this bay was of the latter type :

1) Six sub-figures out of the 12 ones showed unnegligible "drifted in" of larvae, the average being *ca.* 53 tons a day corresponding to 15.4 % of the average of standing stock.

2) The other 6 sub-figures showed "drifted out" of larvae, the average being *ca.* 67 tons which corresponded to 19.4% of the average of standing stock.

3) In the section showing a decrease of standing stock, the population comparable to the decrease (or sometimes far larger amount) was drifted therein, but more larvae than those drifted in were drifted out, which resulted in the decrease of standing stock.

Discussion

Results of the current observation at the mouth of the bay showed that the sea water flowed into the bay along the southern coast showing 3-4 day periodicity and the inner water flowed out along the northern one. During the present survey, wind was generally not so strong, although NE'ly wind of over 4 m/sec blowed during the last quarter. Regardless of the wind drive, the current pattern was kept in counterclockwise over the period. So, it may be presumed that counterclockwise circulation was persistent regardless of the wind. Daily abundance of larvae

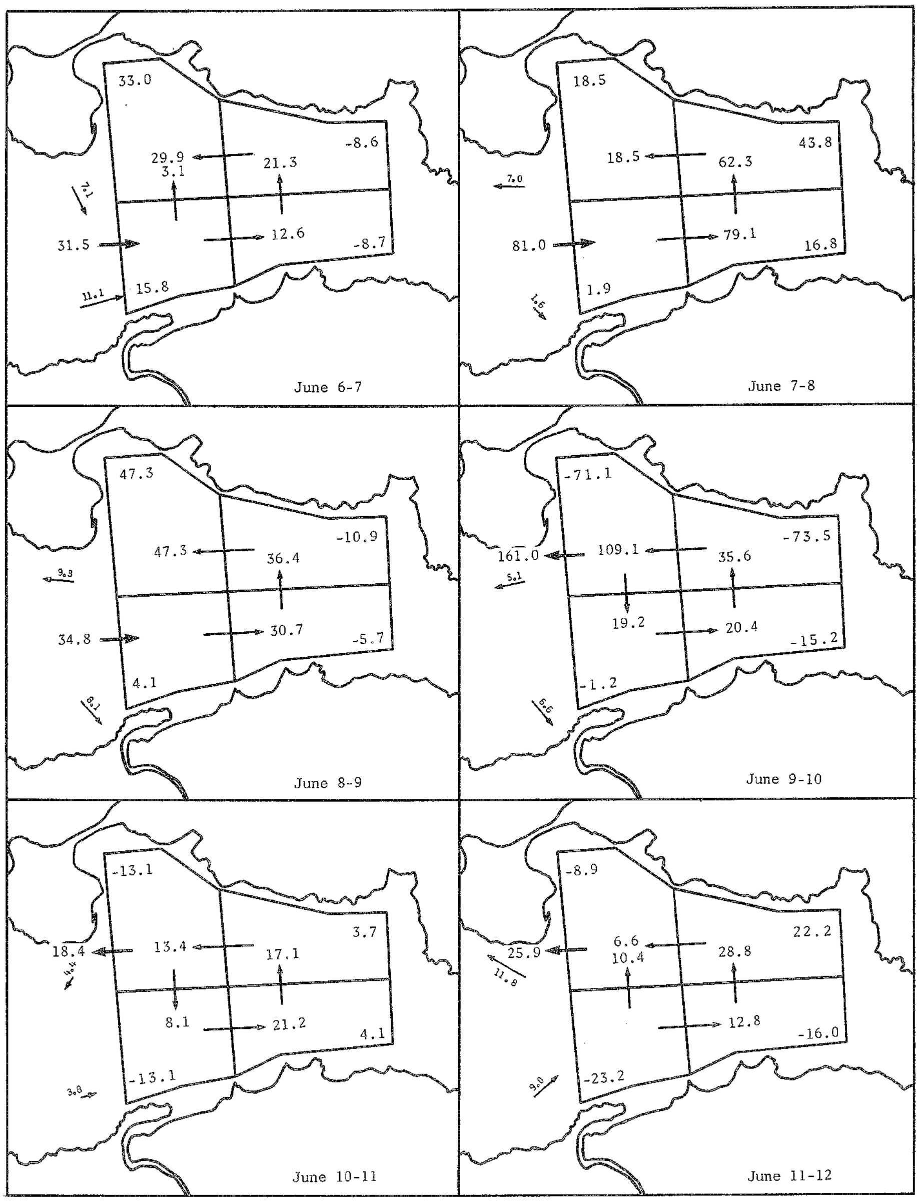


Fig. 8—1. Budget model of larval fish population (ton/day) in respective sections, based on constant flow (cm/sec) at the mouth of the bay.

varied with the same periodicity as that of sea water. For the purpose of simplifying the problem, in the present model, it is set that the larval population equivalent to the difference between the amounts estimated on the succeeding two days, $\varDelta N_i$, is drifted into (or out from) the bay. Usually the east component of current at St.A inclined to be positive and that at St. B to be negative. In consequence, the larval population equivalent to the difference is set

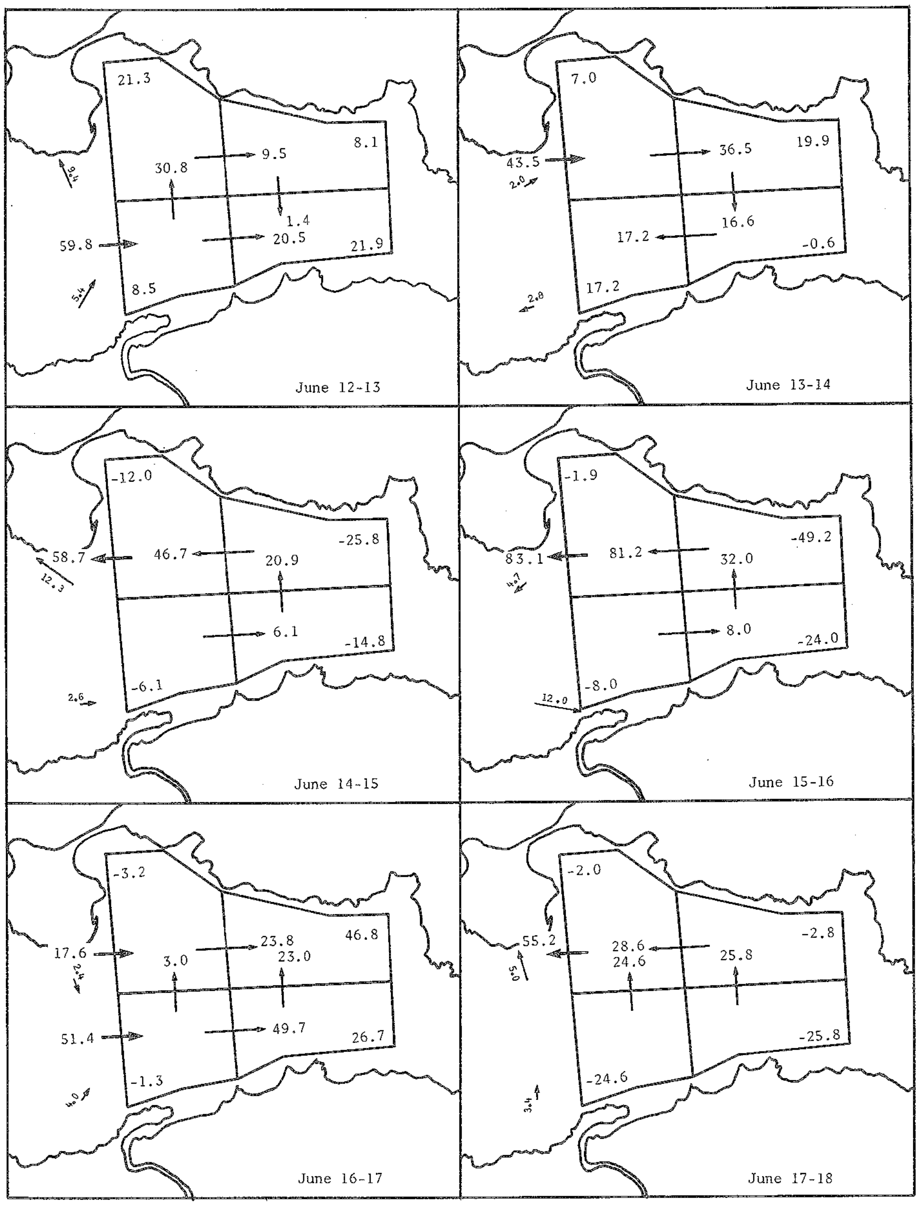


Fig. 8—2.

to be drifted in the bay first Section 3 during the increasing phase of the standing stock, while that equivalent to the difference is drifted finally out of the Section 2 during the decreasing phase. It is, however, difficult to deny completely the drift-out of a part of population through Section 2 during the increasing phase and drift-in of the population into Section 3 during the decreasing phase. This fact meant that the amount of population drifted into a section or out of it should be estimated too low. Namely, the rate of renewal should be higher than that shown in Fig.8. If the amounts of population drifted in or out of the bay could be detected, it is not difficult to reconstruct the model and to give more accurate estimation than that by the present model. Based on the above-mentioned amount of renewal, although this value is estimated to be too low, it is possible to estimate the average staying of a population in the bay: during this 13 days of survey period, there were two days of low density, the average of standing stock being 260 tons. On the other hand, the average of the standing stock during this survey period was estimated through the echogram to be 345 tons. It is set that the population of the former amount is a staying part in this bay and the population equivalent to the difference of the latter from the former level is the part of population showing a short periodic fluctuation and that these population do not mix with each other. As already mentioned, larval population was supplied by the 6 flowings-in during survey period, the average being 53 tons. And the same number of drift out of the same amount was observed, too. This fact meant that 30 tons of larvae was supplied and drifted daily on the average. Consequently, the population size of the part showing the short periodic fluctuation (345−260 = 85 tons) corresponded to 2.8 times of the amount of larvae supplied and drifted out daily. Namely, it may be said that the larvae may stay in this bay 2.8 days on the average. The validity of this estimation was supported by the following facts: the east-components of the current at St.A and St.B were measured to be 3.02 cm/sec and −3.40 cm/sec, respectively, and the current in the inner part of the bay was to be 2 to 3 cm/sec[10]. Deducing from these velocities, it is estimated that it takes 3 days to circle the water round this bay. The local fishermen also point out that the fishing spot is found first at the southern part of the bay, shifts counterclockwisely, then vanishes at 3 day periodicity from Section 2. And the extremely low fishing mortality (1.5% per day) estimated by OKAWA and MISU[8] could be cited here as a collateral evidence supporting quick renewal, too.

Conclusion

From the above-mentioned results and discussion it may be concluded that: it is possible to explain the fluctuation of the population density and its horizontal distribution of the larvae of Japanese anchovy, *Engraulis japonica* (HOUTTUYN), in Yuya bay through a simple model based on the drift by current. This model revealed that the larval population was quickly renewal and was supplied 30 tons a day (corresponding to 8.7% of standing stock) along the southern coast, staying as short as 3 days, and drifted out along the northern coast.

Summary

In Yuya bay at the northwest tip of Honshu, a 15-day echo-survey and current observations were conducted from June 4 to 19 in 1977. Based on the results of this survey, a simple model was constructed for the purpose of explaining the fluctuation of the density and distribution of larval population of Japanese anchovy, *Engraulis japonica* (HOUTTUYN), and the results obtained from the survey and the modeling were summarized as follows:

1. The standing stock of fish population in this bay (including the adult) was estimated through the echo-survey to be 600 to 1,200 tons, showing an increasing trend with 3-5 day

periodic fluctuation.

2. That of the larval population was to be 345 tons on the average showing a decreasing trend with the same periodicity.

3. A continuous counterclockwise circulation of water of less than 10 cm/sec (25-Hour running mean) could be pointed out as the basic pattern regardless of wind drift.

4. Based on these results of the observations, a transportation model was constructed under the supposition that larval population was supplied by current and drifted according to the circulation of water.

5. This model can explain the fluctuation of fish density and its horizontal distribution, and added the following information: the larval population was quickly renewal and was supplied 30 tons a day (corresponding to 8.7% of the standing stock) along the southern coast, stayed 2.8 days in the bay, and drifted out along the northern coast.

Acknowlegements

The auther expresses his sincere thanks to Prof.Dr.H. Misu of the Shimonoseki University of Fisheries for his valuable discussions, and thanks to Dr. T. Kamimura, Mr. A. Ouchi and their staff of the Seikai Regional Fisheries Research Laboratory for their collaborations and financial assistance throughout the survey. He also wishes to express his thanks to Prof.Dr.H. Maéda of the Shimonoseki University of Fisheries for his kindly reading and improving the manuscript.

References

1) Ishii, T., 1976: *Bull.Jap.Soc.Sci. Fish.*, **43** (3), 251-264.
2) Ishii, T., 1976: *ibid.*, **42** (10), 1065-1076.
3) Ishii, T., 1976: *ibid.*, **42** (11), 1251-1261.
4) Ishii, T., 1977: *ibid.*, **43** (1), 19-30.
5) Ishii, T., 1977: *ibid.*, **43** (2), 151-161.
6) Shibata, K., 1971: *ibid.*, **37** (8), 711-719.
7) Shibata, K., 1971: *ibid.*, **37** (9), 825-830.
8) Okawa, H. and H.Misu, 1978: *Bull. Seikai Reg. Fish. Res. Lab.*, **51**, 141-157.
9) Mimoto, K. and T. Aoyawa, 1978: *ibid.*, **51**, 159-166.
10) Fisheries Agency, 1975: Report of Propagation of Fishing in Yuya Bay (translated from Japanese title) 23-28.