水産海洋研究 第59巻 第1号 19-31, 1995

Fine-scale Spatial Distribution of Anchovy Eggs in Ise Bay, Central Japan

Hideo SEKIGUCHI* and Hideaki SUGISHIMA*

Abstract

Fine-scale spatial patterns of the distribution of anchovy eggs in Ise Bay were investigated by continuously towing submersible pumping gears at depths of 1 m and 3 m just above the halo- and/or picno-cline. Towed distance and filtered volume of seawater were 300 m and 260-300 liters per sample, respectively. Egg counts were in the range of 0-419 eggs/sample, and samples with 0-19 eggs accounted for ca. 55% of all samples. As the first step in analyzing the spatial patterns of egg distribution, the background density, 'patch' and 'high-density patch' were defined. Sizes of the 'high-density patch' were ≦0.3-6.3 km, with an average value of 1.82 km. Distances between the 'high-density patches' were ≦0.3-12.3 km ; the most frequent distance between patches was 0.3 km and less. Using MORISHITA's (1959) index of dispersion, it was made clear that the eggs are contagiously distributed and composed of small patches. However, the eggs are randomly distributed within these small patches. Estimation of anchovy egg mortality was difficult because daily egg production was not always constant and the death rate was different between daily cohorts of eggs.

1. Introduction

Recently, many studies have been done on fine- (1 m-1 km) and micro-scale (less than 1 m) spatial distributions of planktonic organisms (SEKIGUCHI, 1984). Biological oceanographers have focused on a patch, because a patch is a general phenomenon in the sea and there is no question of its ecological importance (STEEL, 1976 ; MACKAS *et al.*, 1985). Consequently, patches, which may be generated by the organisms themselves and also by interactions of behavior of the organisms and dynamic physical factors of the environment, are a normal feature in the sea and are vital for understanding the dynamics of plankton assemblages and also pelagic ecosystems (DENMANN and POWELL, 1984 ; MACKAS *et al.*, 1985 ; HAURY, 1986). A patch is defined by MAUCHLINE (1980, p. 613) as follows : a patch is an aggregation within a defined environment.

On the other hand, the studies as stated above are still with meager for pelagic eggs and fish larvae (MATSUSHITA *et al.*, 1982 ; SAKAMOTO and TANAKA, 1986). However, it is believed that information on distributions on such a spatial scale are vital for estimating abundance of eggs and larvae and for clarifying the dynamics of fish populations (HUNTER and THOMAS, 1974 ; NORCROSS and SHAW, 1984).

According to previous studies done on anchovy eggs (*Engraulis japonicus*) in Ise Bay (SEKIGUCHI *et al.*, 1988), the following facts are known : (1) In general, eggs are abundant in May and June, and are aggregated above the halo- and/or picno-cline at 5 m depth, (2) eggs are not found in the innermost part of the bay where freshwater from the Kiso Rivers excerts a major influence on the oceanographic conditions, and (3) abundance of the eggs in bay fluctuates remarkably from year to year.

Based on this background information, we examined fine-scale spatial distributions of anchovy eggs in the bay, focusing particularly on the size, abundance and statistical characteristics of egg patches. The production and mortality of the eggs

Accepted Nov. 15, 1994

* Faculty of Bioresources, Mie University, 1515, Kamihama-cho, Tsu, Mie, 514, Japan.

in the bay are then discussed using the patch distribution data.

2. Materials and Methods

Ise Bay, covering a surface area of 1,600 km² with a mean depth of 19.5 m, is located along the Pacific coast of central Japan and is separated from the Pacific by a passage 13 km wide and 73 m deep. Freshwater from the Kiso Rivers (Ibi, Nagara, Kiso) which flow into the innermost part of the the bay exerts a major influence on the oceanographic conditions (SAIJO and UNOKI, 1977).

Investigations were made from the T/V Seisui-Maru in the central and southern parts of the bay in June 1990. Sampling of anchovy eggs (*Engraulis japonicus*), starting at 1:41 PM on June 8 and finishing at 6:01 PM on the following day, was done continuously along several transect lines in the bay (Fig. 1) by using submersible pumping gears. Distance of the transect was 28.5 km for A (Matsusaka)-B (Morozaki), 27.0 km for C (Kamishima)-D (Shiroko), 15.0 km for D (Shiroko)-E (Noma), and 27.0 km for E (Noma)-A (Matsusaka).

On board the vessel running along the transects, seawater was taken from both depths of 1 m and 3 m by using two submersible pumping gears which were towed with a ship speed of 3.6 km/hr, and then were continuously filtered with a mesh-opening of 0.33 mm renewed at 5 min intervals. The tempera-

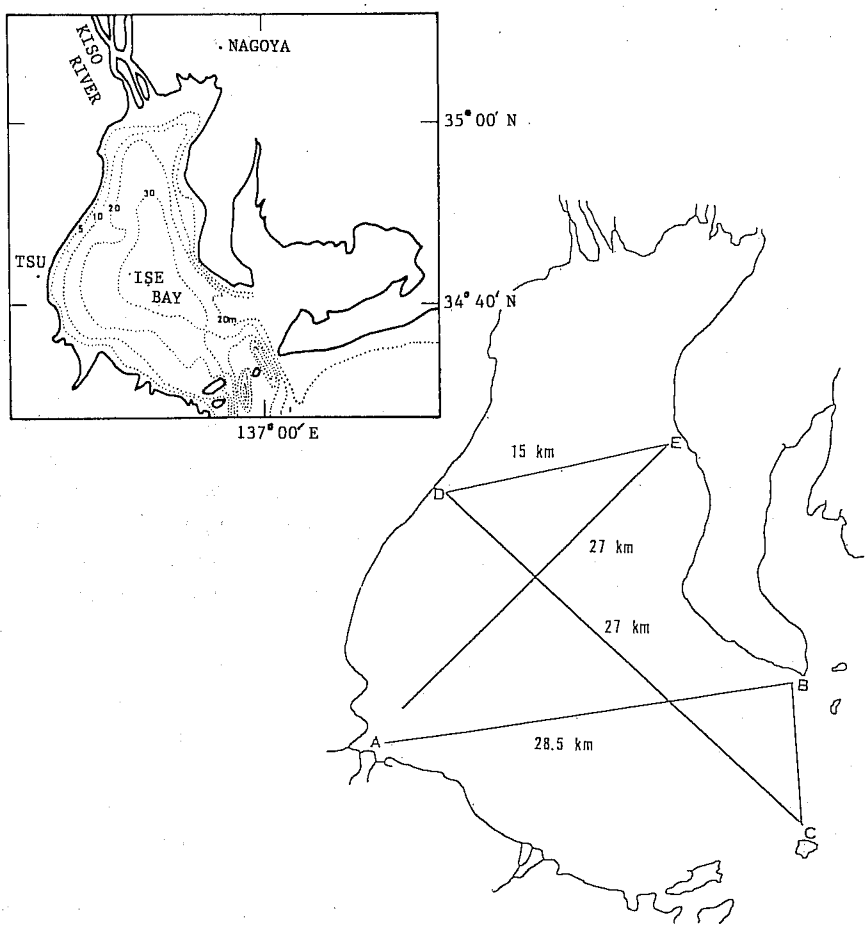

Fig. 1. Ise Bay and transect lines where submersible pumping gears were towed. Numericals with dotted lines indicate depth of the bottom.

ture and salinity were simultaneously monitored using a CTD system. Since anchovy eggs are usually aggregated above the halo- and/or picno-cline at 5 m depth in the bay in May and June (SEKIGUCHI *et al.*, 1988), the pumping gears were kept above 5 m depth. The gears were set separately at both depths of 1 m and 3 m in order to monitor the differences in horizontal distributional patterns of the eggs between these depths.

We took a total of 650 samples; towed distance and filtered volume of seawater were 300 m and 260-300 liters per sample. All samples were immediately fixed on board with 5% neutralized seawater formalin.

In the laboratory, all anchovy eggs were sorted, and the developmental stages of the eggs were identified according to MORSER and AHLSTOROM (1985), who described in detail the eggs of the northern California anchovy (*Engraulis mordax*). Unfortunately, detailed descriptions of the developmental stages of *Engraulis japonicus* eggs have not yet been published. Anchovy eggs, collected in the present study, were classified into 11 developmental stages.

3. Results and Discussion

Distributional patterns of the abundance of anchovy eggs at 1 m depth were very similar to those at 3 m depth, as indicated in Fig. 2. Accordingly, we mainly analyzed the data set collected from 1 m depth. As the first step in analyzing the spatial patterns of egg distribution, densities of the eggs inside and outside the patches were determined. A 'high-density patch' was defined as a concentration exceeding the average egg density in the data set. A sample was thus considered to have been taken from a 'high-density patch' if it has an egg density exceeding the average. The background density (the density of eggs not in the 'patch') was defined as the average egg density in the data set excluding the samples taken from the 'high-density patches'. Next, a 'patch' was defined as a concentration of eggs exceeding the 'background density'. The average and the background densities of the eggs obtained from 1 m depth were 34.86 and 10.86, respectively. Thus, a sample with

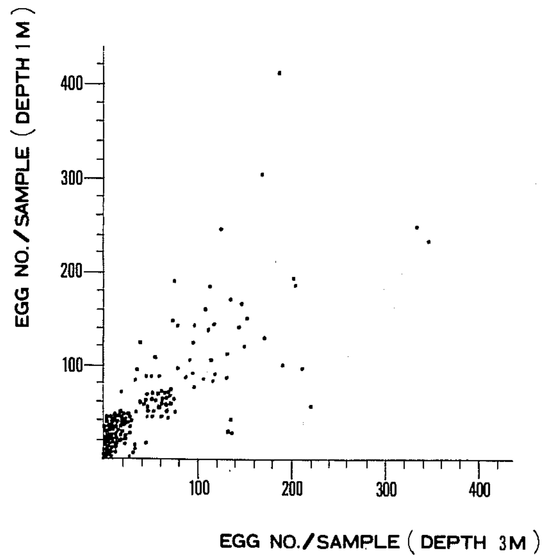

Fig. 2. Relationship between densities of anchovy eggs collected at depths of 1 m and 3 m in Ise Bay.

an egg density exceeding 34.86 was considered to have been taken from a 'high-density patch', while that with an egg density exceeding 10.86 was considered to have been taken from a 'patch'. The background density and the 'high-density patch' defined here would correspond to the background density and patch referred into WIEBE (1970), respectively.

3-1. Distributional patterns of anchovy eggs in relation to oceanographic conditions in Ise Bay

'High-density patches' of anchovy eggs were mostly located in the central part of the bay (Fig. 3), while eggs were rarely found in the innermost part of the bay, where the influence of freshwater discharged from the Kiso Rivers was noticeable, or in the southern part where coastal (saline) water was detected. 'Patches' and 'high-density patches' of eggs were found within a defined range of temperature and salinity as illustrated in Fig. 4. This would not be caused by dispersion and/or transport of the eggs due to tidal curents etc., but rather by behaviors of spawning anchovies as referred in SMITH and HEWITT (1985), because the early stage eggs at several hours after fertilization showed

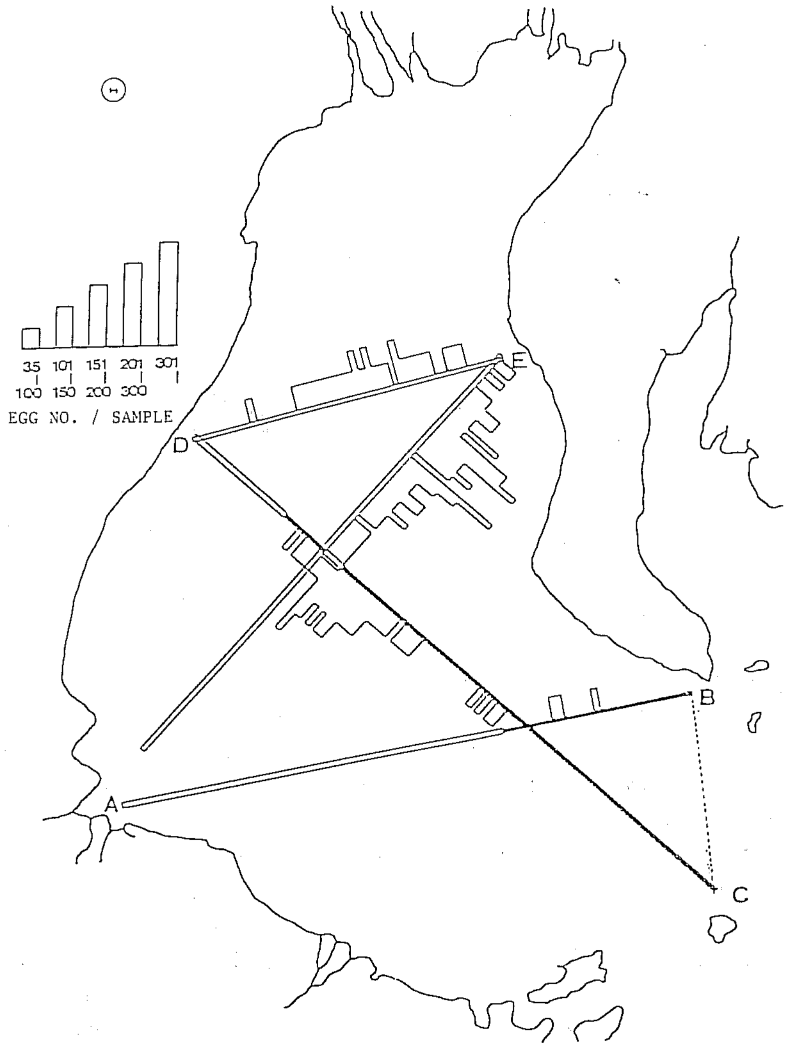

Fig. 3. Distribution of the abundance of anchovy eggs in Ise Bay. Dark transect lines indicate that the sampling was performed at night, while the white lines indicate that the sampling was during the day. The dotted line indicates no sampling. Bar scale shows the distance a sample covers.

similar distributional patterns to those at the other developmental stages, as referred later in detail.

Fine-scale spatial distributions of the eggs on the transects are shown in Figs. 5-8. Abundance of the eggs fluctuated remarkably on such a fine-scale and also on a coarse scale (more than 1 km), and 'high-density patches' of eggs were clearly distinguishable on each transect: samples with a concentration exceeding 100 eggs/sample were often obtained, and there was one sample exceeding 400 eggs/sample (equivalent to 1,435 eggs/m^3). The egg density became lower at the both ends of the transects close to shore, where the water was less saline.

Relative abundance of each developmental stage of the eggs was quite similar between the samples taken from 1 m and 3 m depths: the 2nd stage eggs accounted for ca. 50%, while the 11th stage eggs accounted for ca. 40% (Fig. 9). Within 'high-den-

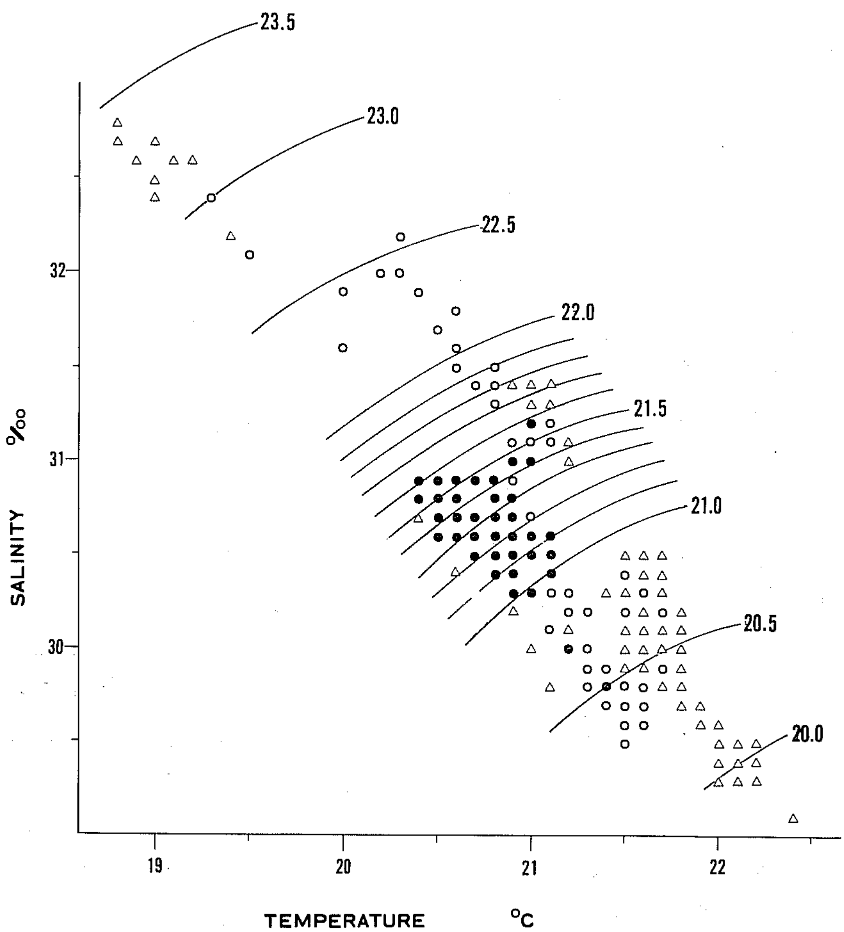

Fig. 4. T-S diagram in relation to anchovy egg patches in Ise Bay. Solid and open circles indicate 'high-density patch' and 'patch' of anchovy eggs, respectively, open triangles indicate stations with the background density of eggs, and lines indicate specific gravity of seawater.

sity patches', these two developmental stages were predominant as shown in Figs. 5-8. These two stages belong to different daily cohorts, because the 2nd and 11th stages occur at ca. 3-4 hours and ca. 27-38 hours after fertilization, respectively, based on Lo (1985)'s calculation at water temperature of 19-21°C at the surface of the bay. This indicates that spawning anchovies shed their eggs within the 'high-density' produced by the previous day's spawning. This problem will be discussed later in relation to estimation of anchovy spawning time and egg mortality in the bay.

3-2. Statistics of number of eggs per sample, and size and egg abundance of patches in Ise Bay

Egg counts were in the range of 0-419 eggs/sample, and samples with 0-19 eggs accounted for ca. 55% of all samples (Fig. 10). The larger the number of eggs, the fewer the number of samples. The average number of eggs per sample was 34.86, and the dispersion index (variance/average) was 74.8, indicating that the eggs are contagiously distributed.

Statistical characteristics of the 'patches' and 'high-density patches' in the bay are summarized in

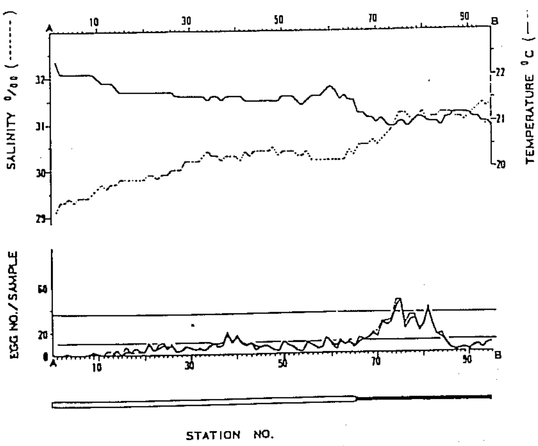

Fig. 5. Abundance of anchovy eggs on the A-B transect. Dark bar indicates that the sampling was performed at night, while the white bar indicates that the sampling was performed during the day. Upper and lower lines in the lower figure indicate densities of 'patches' and 'high-density patches', respectively. Outer and inner lines of anchovy egg abundance indicate densities of whole stage and the 11th developmental stage eggs, respectively. Numbers between A and B indicate sample numbers.

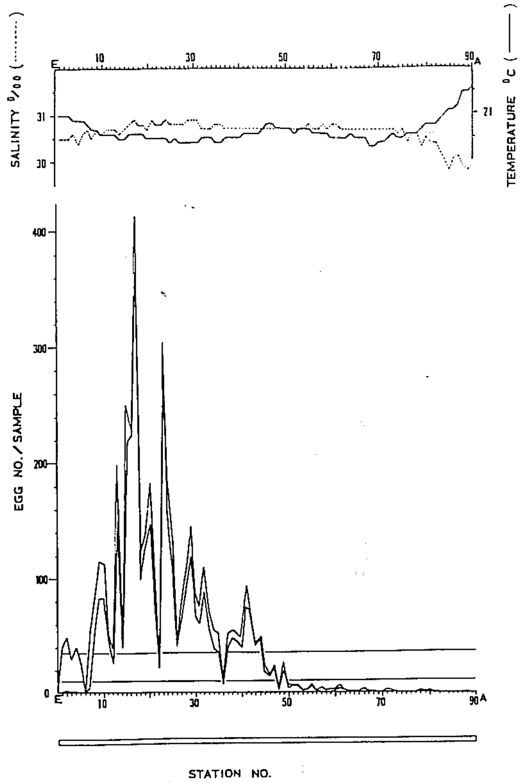

Fig. 6. Abundance of anchovy eggs on the C-D transect. Outer and inner lines of anchovy egg abundance indicate densities of whole stage and the 2nd developmental stage eggs, respectively. Other symbols are same as in Fig. 5.

Table 1. Sizes of 'patches' of the eggs were in the range of ≦0.3-15.0 km, while those of 'high-density patches' were in the range of ≦0.3-6.3 km. Most frequent sizes of 'patches' and 'high-density patches' were both 300 m and less, accounting for 41% and 38%, respectively, of those patches. The average size of 'patches' was 11.20 km, and the dispersion index was 18.5, while the average size of 'high-density patches' was 1.82 km, and the dispersion index 25.3. This indicates that sizes of 'patches' and 'high-density patches' are contagiously distributed. This was also the case for the sizes of 'patches' and 'high-density patches' of 2nd and 11th stage eggs.

Distance between 'patches' was in the range of ≦ 0.3-21.9 km. The most frequent distance between 'patches' was 300 m and less. The average distance was 7.39 km, and the dispersion index was 11.5, indicating that the distance is contagiously distributed. Distance between 'high-density patches' was in the range of ≦0.3-12.3 km, and the most frequent distance was less than 300 m. The average distance was 11.30 km, and the dispersion index was 29.5, indicating that the distance is contagiously distributed. This was also true of the distances between 'patches' and between 'high-density patches' of 2nd and 11th stage eggs.

Using MORISHITA's index of dispersion I_δ (MORISHITA, 1959), we were able to determine whether the eggs disperse in a random distribution ($I_\delta=1$), or in an even distribution ($I_\delta<1$), or in a contagious distribution ($I_\delta>1$). Then, based on the type of response curves of I_δ according to variations in sample size, we were able to determine distributional patterns of eggs and their patches.

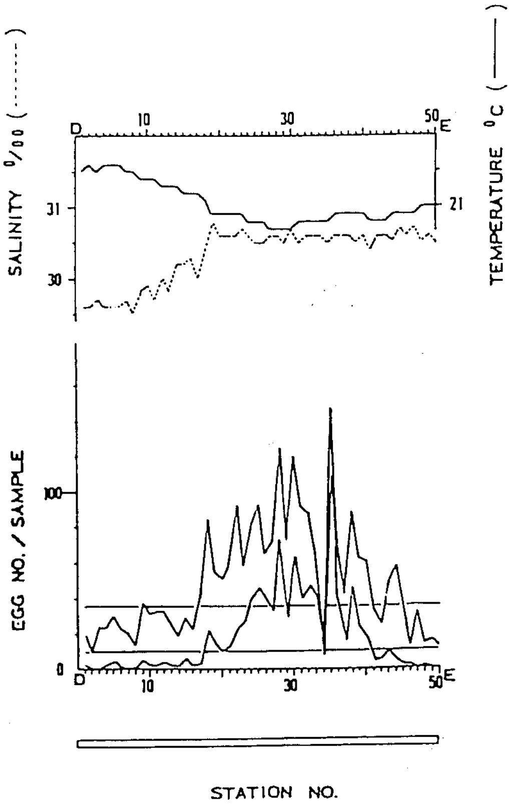

Fig. 7. Abundance of anchovy eggs on the D-E transect. Symbols are same as in Fig. 6.

Response curves of I_δ for anchovy eggs according to variations in sample size are shown in Fig. 11: very similar results were obtained for eggs between the 2nd and 11th stages. These curves indicate that the eggs are contagiously distributed and composed of small patches, within which the eggs are randomly distributed.

In the present study, the detectable minimum size of egg patches was 300 m. Thus, the size of the patches would be overestimated if that of the real patches in the bay were smaller than 300 m. According to MATSUSHITA *et al.* (1982), who investigated the fine-scale spatial distributions of anchovy eggs in Sagami Bay by continuously towing nets renewed at 1 min intervals with a ship speed of 3.6 km/hr, patches with a size of less than 300 m were also observed, although they were not as numerous as patches of larger sizes.

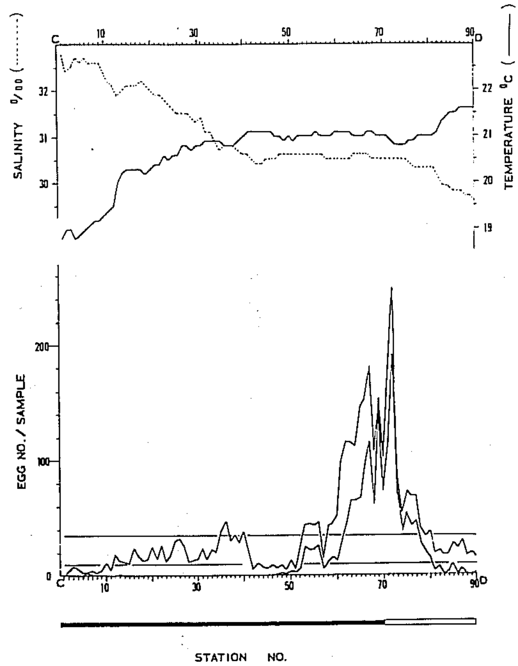

Fig. 8. Abundance of anchovy eggs on the E-A transect. Symbols are same as in Fig. 6.

The present study differed from previous work done using towed nets (MATSUSHITA *et al.*, 1982; SMITH and HEWITT, 1985; SEKIGUCHI *et al.*, 1988) in that we employed submersible pumping gears to enable exact monitoring of the filtered volume of seawater and to gain many samples, so we were able to observe remarkable fluctuations of the egg density on a fine-scale and also on a coarse scale. Statistical characteristics of the egg density, and abundance of the egg patches are illustrated in Figs. 5-8. Accordingly, the present study suggests that estimation of the size and abundance of anchovy eggs would result in larger error if the patchy distribution of the eggs is not taken into account.

3-3. Spawning time and mortality of anchovy eggs in Ise Bay

AZETA (1981) examined average age (hours) from fertilization to hatching of the eggs of the Japanese anchovy (*Engraulis japonicus*) depending on water temperature, but unfortunately he did not average the age of each developmental stage of the eggs, whereas LO (1985) did average the age of each

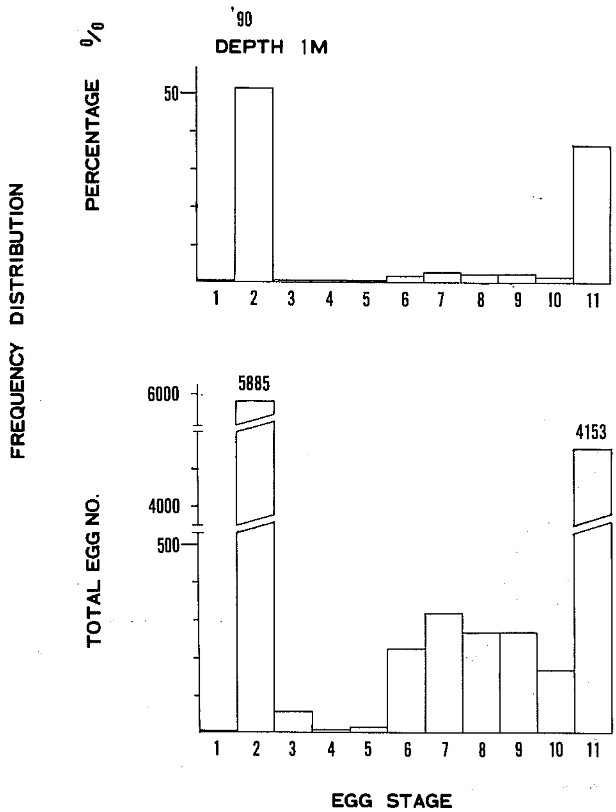

Fig. 9. Relative abundance of each developmental stage of anchovy eggs collected in Ise Bay.

developmental stage of the eggs of the northern California anchovy (*Engraulis mordax*). Therefore, we estimated average age of each developmental stage of the eggs at 19-21°C at the surface of the bay (Fig. 4) according to LO (1985).

In order to examine spawning time of anchovy in the bay, number of each developmental stage of the eggs in a sample was ordered according to the sampling time without regard to sampling location. Then, based on the average age of each developmental stage of the eggs, anchovy spawning habits in the bay was clarified as shown in Fig. 12. Peaks of spawning were observed at 5 : 00 to 6 : 00 AM, 8 : 00 to9 : 00 AM and 11 : 00 PM to 0 : 00AM. Average age from the fertilization to hatching of eggs of the Japanese anchovy at 19-22°C is ca. 33-44 hrs according to AZETA (1981), while the time is longer by ca. 2-3 hrs for the northern California anchovy, according to LO (1985). Even after taking this difference into account, anchovy eggs in the bay would have been shed at night as well as at dawn to morning, as clearly indicated in Fig. 12. Based on previous studies, the Japanese anchovy spawns mainly during the first half of the night (ASAMI, 1961 ; AZETA, 1981 ; LO, 1985 ; SEKIGUCHI *et al*., 1988). This has also been confirmed under laboratory conditions (KAWAGUCHI *et al*., 1990).

In previous studies which postulated that there would not be daily variation in egg production and that eggs would die at a constant rate according to age (hour) after fertilization, egg mortality was calculated using egg densities by age after fertilization (SMITH and HEWITT, 1985), since in most cases densities of the earlier stage eggs were greater than those of later stage eggs. Sometimes, such a method is not applicable because densities of later

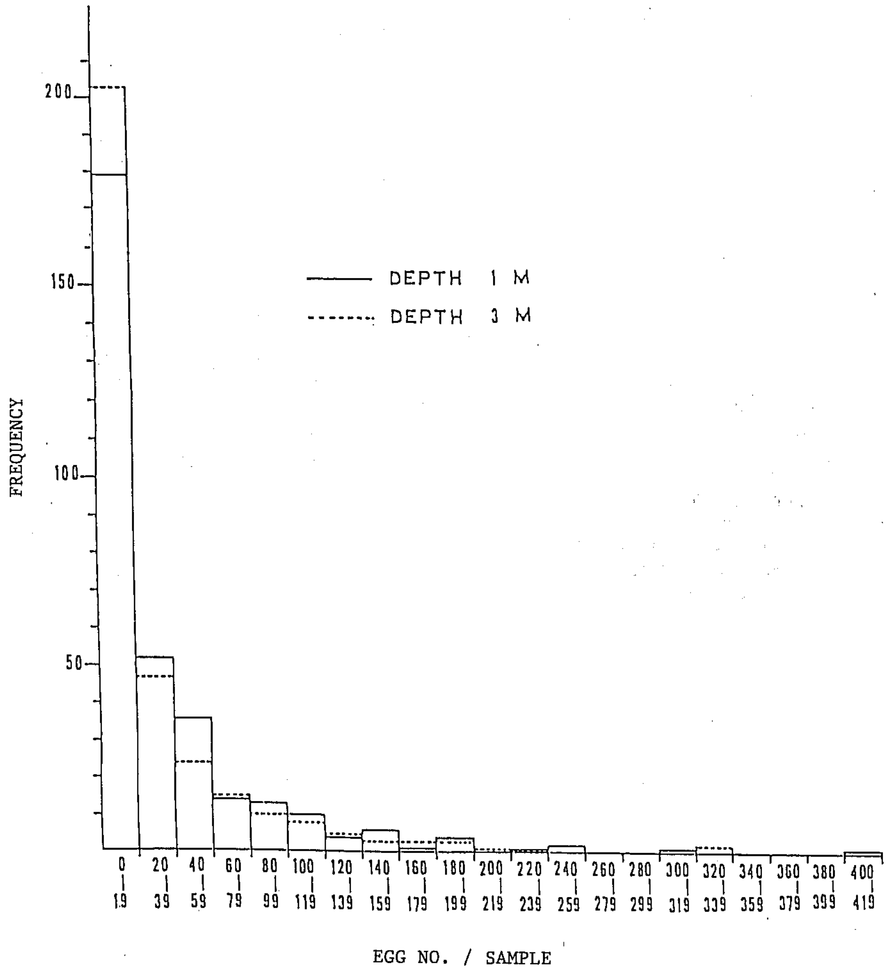

Fig. 10. Frequency distribution of number of anchovy eggs per sample in Ise Bay.

stage eggs are greater than those of earlier stage eggs, which has been regarded as being caused by bias in sampling (SMITH and HEWITT, 1985; SHIBATOMI and OZAWA, 1990).

However, in the present study, the earlier and later developmental stages (2nd and 11th stages) of anchovy eggs were most abundant, while the intermediate stages were very scarce (Fig. 9). Judging from the densities and relative abundance of each developmental stage of the eggs at 1 m depth being very similar to those at 3 m depth (Figs. 2 and 9), this relative scarcity of the intermediate stages is a fact in the bay, and was not caused by bias in sampling. Furthermore, according to TANAKA (1990) specific gravity of the intermediate stage eggs is not very different from that of the other stages.

The 2nd and 11th stage eggs are ca. 3-4 hrs and ca. 27-38 hrs after fertilization, so these would belong to different daily cohorts. Dominance of the later (11th) stage eggs (Fig. 9) indicates that daily variation in egg production by spawning anchovy in the bay occurs, or that egg mortality varies for each daily cohort of eggs, as shown in Fig. 13. Accordingly, estimation of anchovy egg mortality was difficult, because it appears unjustified to assume constant daily egg production and no difference in death rate between daily cohorts of anchovy eggs in the bay, as illustrated in Fig. 13.

Table 1. Features of the 'patches' and 'high-density patches' of anchovy eggs in Ise Bay

Sizes of the patches

	'patch'	'high-density patch'
Most frequent size	≦0.3 km	≦0.3 km
Range	≦0.3-15.0 km	≦0.3-6.3 km
Average	11.2 km	1.82 km
Dispersion index	18.5	25.3

Distance between the patches

	'patch'	'high-density patch'
Most frequent distance	≦0.3 km	≦0.3 km
Range	≦0.3-21.9 km	≦ 0.3-12.3 km
Average	7.39 km	11.30 km
Dispersion index	11.5	29.5

* Dispersion index indicates variance/average.
** See the text for explanation of the definitions of 'patch' and 'high-density patch'.

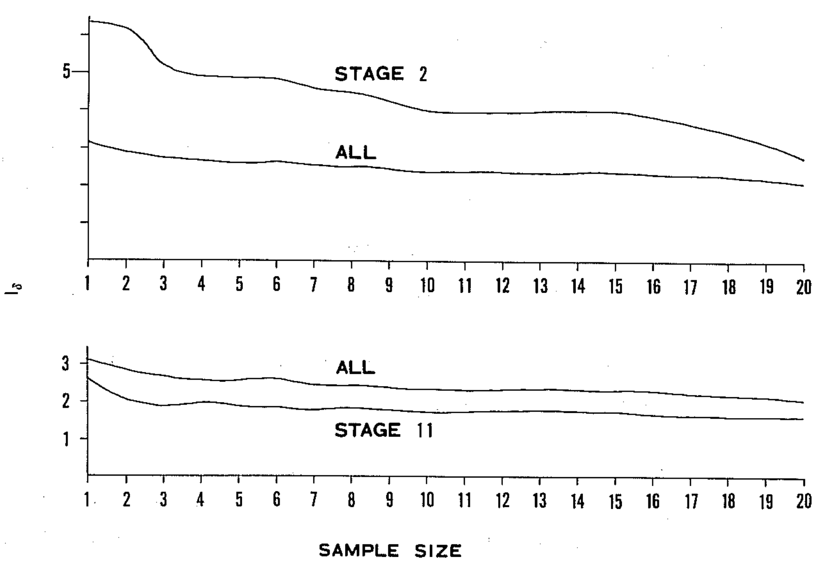

Fig. 11. Response curves of MORISHITA's index of dispersion (I_δ) according to increasing sample size.

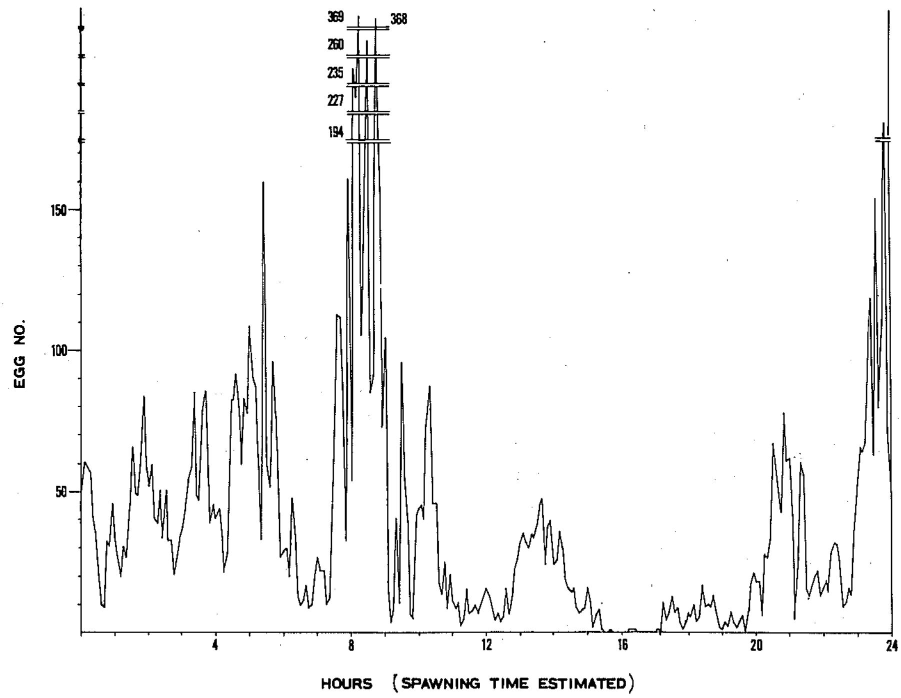

Fig. 12. Spawning time of Japanese anchovies in Ise Bay. Spawning time was estimated based on the number of eggs of each developmental stage at different sampling times. See the text for further explanations.

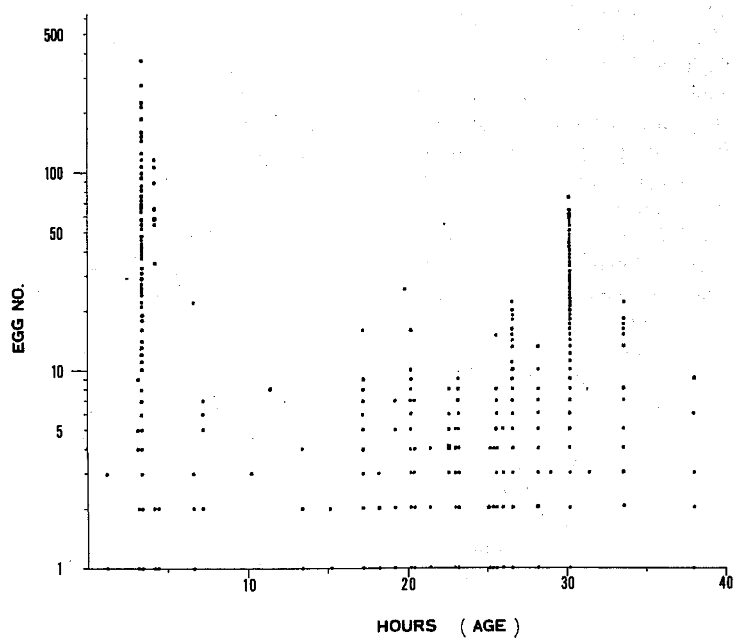

Fig. 13. Relationship between number of anchovy eggs and hours (age) passing after fertilization in Ise Bay. See the text for further explanations.

Acknowledgements

We wish to express our thanks to Dr A. KAWAMURA, Mie University, for his encouragement and assistance in sampling on board the T/V Seisui-Maru. Thanks are also due to the captain and his crew for their assistance in sampling.

References

ASAMI, T. (1962) Studies on the Japanese anchovy, *Engraulis japonicus* (HOUTTUYN), along the coast of Nankai region of Japan. Rep. Nankai Reg. Fish. Res. Lab., **16**, 1-56.

AZETA, M. (1981) Some considerations on the high mortality during the larval stage of fish with special reference to the fluctuation of population-based on the population dynamics investigations of early life history of anchovy-. Rep. Fish. Resour. Invest., Fish. Agency, **22**, 7-28. (in Japanese)

DENMANN, K.L. and T.M. POWELL (1984) Effects of physical processes on planktonic ecosystems in the coastal ocean. Oceanogr. Mar. Biol. Ann. Rev., **2**, 125-168.

HAURY, L.R. (1986) Patches, niche and oceanic biogeography. *In*. Pelagic Biogeography, ed. A.C. PIEOTT-BULTS *et al*., UNESCO, 16-132.

HUNTER, J.R. and G.L. THOMAS (1974) Effects of prey distribution and density on the searching and feeding behaviour of larval anchovy *Engraulis mordax*. In The Early Life History of Fish, ed. J.H.S. BLAXSTER, p. 559-574, Springer-Verlag, Berlin.

KAWAGUCHI, K., Y. YAMASHITA and A. HAYASHI (1990) Some aspects of spawning of the reared Japanese anchovy (*Engraulis japonicus*) in relation to the photoperiod. water temperature and starvation. Bull. Jap. Soc. Fish. Oceanogr., **54**, 364-372.

LO, N.H. (1985) A model for temperature-dependent northern anchovy egg development and an automated procedure for the assesment of age to staged eggs. *In*. An Egg Production Methods for Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy, *Engraulis mordax*, ed. R. LASKER, NOAA Tech. Rep., NMFS36., 43-50.

MACKAS, D.L., K.L. DENMANN and M.R. ABBOT (1985) Plankton patchiness: biology in the physical vernacular. Bull. Mar. Sci., **37**, 652-674.

MATSUSHITA, K., M. SIMIDU and Y. NOSE (1982) Micro-distribution of anchovy eggs and larvae in Sagami Bay. Bull. Jap. Soc. Sci. Fish., **48**, 355-362.

MAUCHLINE, J. (1980) The biology of mysids and euphausiids. Adv. Mar. Biol. Ann. Rev., 18, 1-680.

MORISHITA, M. (1959) Measuring of the dispersion of individual and analysis of the distributional patterns. Mem. Fac. Sci. Kyusyu Univ. Ser. E (Biol.), **2**, 215-235.

MORSER, H.G. and E.H. AHLSTORM (1985) Staging anchovy eggs. In. An Egg Production Methods for Estimating Biomass of Pelagic Fish: Application to the Northern Anchovy, *Engraulis mordax*, ed. R. LASKER, NOAA Tech. Rep., NMFS36., 37-41.

NORCROSS, B.L. and R.F. SHAW (1984) Oceanic and estuarine transport of fish eggs and larvae: a review. Trans. Amer. Fish. Soc., **113**, 153-165.

SAIJO, Y. and S. UNOKI (1977) Oceanographic conditions and phytoplankton production in Ise and Mikawa Bays. Bull. Coast. Oceanogr., **14**, 10-18. (in Japanese)

SAKAMOTO, W. and Y. TANAKA (1986) Water temperature patterns and distributions of fish eggs and larvae in the vicinity of shallow sea front. Bull. Jap. Soc. Fish., **5**, 767-776.

SEKIGUCHI, H. (1984) Distributional ecology of marine planktonic copepods. Bull. Plankton. Soc. Japan, 30th Ann. Volume, 40-43. (in Japanese)

SEKIGUCHI, H., S. ITOKAWA and T. IKEDA (1989) An example of anchovy egg patch. Bull. Jap. Soc. Fish. Oceanogr., **53**, 1-5.

SHIBATOMI, K. and T. OZAWA (1990) Examination of the methods to estimate total egg production in fishes. Bull. Jap. Soc. Fish. Oceanogr., **54**, 438-445. (in Japanese)

SMITH, P.E. and R.P. HEWITT (1985) Sea survey design and analysis for an egg production method of anchovy biomass assesment. *In*. An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy, *Engraulis mordax*, ed. R. LASKER, NOAA Tech. Rep., NMFS36., 17-26.

STEEL, J.H. (1976) Patchiness. *In*. The Ecology of the Seas, ed. D.H. CUSHING, Blackwell Sci. Publ., Oxford, 98-115.

TANAKA, Y. (1990) Change in the egg buoyancy of Japanese anchovy Engraulis japonicus during embryonic development. Bull. Jap. Soc. Sci. Fish., **56**, 165.

WIEBE, P.H. (1970) Small-scale spatial distribution in oceanic zooplankton. Limnol. Oceanogr., 15, 205-217.

伊勢湾におけるカタクチイワシ卵の微細分布

関口秀夫*・杉島英樹*

6月に伊勢湾において，2台の水中ポンプを数本の測線に沿って曳航し，塩分(密度)躍層以浅の水深1mと3mの海水を連続的に汲み上げ，カタクチイワシ卵を採集した。1試料は航走距離にして300m，ろか海水量にして260-300リットルに相当した。1試料当たりの卵数は0-419個であり，0-19個の卵数をもつ試料が全試料の約55%を占めた。これらのデータをもとに，カタクチイワシ卵の微細スケールの空間分布の諸特徴を解析するために，卵の環境密度，卵のパッチと高密度パッチを定義した。高密度パッチのサイズは≦0.3-6.3kmの範囲にあり，平均サイズは1.82kmであった。また，高密度パッチ間距離は≦0.3-12.3kmの範囲であり，もっとも頻度が高かったのは，0.3km以下であった。森下のI_δ指数を使ってデータを解析した結果，カタクチイワシ卵は小集団からなる集中分布をしているが，これらの小集団内では機会分布であることが分かった。また，カタクチイワシ卵期の死亡率の推定を行おうとしたが，伊勢湾のカタクチイワシ卵の産卵量には日間変動がない，daily cohort によって卵期の死亡率が相違しない，といった2つの前提が満たされていなかったので，推定は困難であった。

* 三重大学生物資源学部
〒514 三重県津市上浜町1515