Some aspects of spawning of the reared Japanese anchovy (*Engraulis japonicus* H.) in relation to the photoperiod, water temperature and starvation

Kouichi KAWAGUCHI*, Yoh YAMASHITA** and Amane HAYASHI***

Abstract

The spawning of Japanese anchovy (*Engraulis japonicus* H.) was observed for 6 months on the specimens reared in a 1.7 ton tank under the controll of lignt, water temperature, and food to confirm the previous knowledge on the spawning in the field. The spawning starts 1–1.5 hours after switching off the light and continues 3.5–4 hours. The shift of spawning time croresponds to the shift of the light period. It takes 2–3 days for the anchovy to complete the shift spawning time when the light piriod is shifted 1–2 hours earlier. The critical spawning temperature is considered to be around 14°C, since no spawning was observed at 14°C in this experiment. The well fed anchovy endures 10–20 day starvation to continue the spawning at 19°C, but regulates the spawning frequency, egg size and fecundity according to deterioration of nutritional condition. Egg size varies in accordance with the rearing temperature as seen in the field. The egg volume is rather stable, but more sensitive to the temperature change than the egg length because the egg length and width change in compensation with the decrease of the egg volume fluctuation. The egg size responds quickly to the temperature change, but size change corresponding to 1°–2°C difference took at least one week.

Current knowledge on the spawning conditions and behavior of the Japanese anchovy were obtained from mainly based on the field observations (ASAMI, 1953; NAKAI *et al.*, 1955; YAMANAKA and ITO, 1957; FUNAKOSHI and YANAGIBASHI, 1983; TSURUTA and HIROSE, 1989), and partly from the rearing data (TAKAO *et al.*, 1983; IMAI and TANAKA, 1987, TSURUTA and HIROSE, 1989). The rearing experiments, however, were usually made using outdoor flow through tanks, in which the rearing conditions are difficult to control compare with experiments in a closed system. In order to know more about the natuae of spawning, Japanese anchovy was reared in the tank of closed circulatory system kept in the laboratory. Spawning was observed almost every day for about six months and its response to water temperature, light conditions and starvation were studied to compare with the field data previously reported.

Accepted August 27, 1990

* Otsuchi Marine Research Center, ORI, University of Tokyo. Akahama, Otsuchi, Iwate-ken, 028-11, Japan.

** Tohoku National Fisheries Research Institute. Shinhama, Shiogama, Miyagi-ken, 985, Japan.

*** Marine Ecology Research Institute. Iwawada, Onjuku, Chiba-ken, 299-51, Japan.

1. Materials and methods

The Japanese anchovy. kept and fed in raft pens on the coast of Sagami Bay as live bait for skipjack tuna fishing, was used on our experiment. About 600 individuals of adult anchovy were transported in a 2.5 t-tank from Sagami Bay to the Ocean Research Institute, University of Tokyo by 2.5 hours drive on July 20, 1987. At the arrival 458 individuals survived and were transferred into a 1.7 ton tank equipped with circulatory and filtering system. They were reared untill February 25, 1988. Water temperature was adjusted from 14°C to 23°C according to the purposes of experiment. Compound pellet developed for the culture of juvenile rainbow trout was fed throughout the experiment. Average body length of the anchovy was 8.5 cm in standard length.

The amount of pellet fed was about 1 g/ind./day on the average. The pellets were offered at the rate at which when almost all pellets in the water were taken by fish; thus deterioration of rearing water due to the decomposition of food residue was kept to the minimum. Sediments on the bottom of tank were removed every day by siphoning. Quantity of food consumed and the number fish died were recorded daily. The rate of sea water circulation was maintained at 40 l/hr and the water was filtered with active coal, coarl sand and pebble. To keep good water quality, the rearing water was replaced with 150l of open sea water every day for the first 4.5 months and with 40 l for the next 2 months. Thus, a total of about 23 tons of sea water were used in 6 months. The tank was kept in a dark room for the control of light condition. Eight tubes of 36 W fluorescent lights (day light type) were hung 3 m above the water surface and controlled with a timer set at 13.5 D, 9.5 N and 1 Dim. One 5 W tungsten lamp was set 1.5 m above the water surface and time controlled to simulate 30 minutes each of dawn and dusk conditions.

Since the egg shape is elliptical the length and width of 36 eggs were measured and 30 values were averaged after discarding 6 values at both extremes to avoid the effect of the deformed egg.

2. Result

(1) Mortality

Of the 458 individuals transfered into a tank on July 21, 418 individuals died during the first 5 months (Fig. 1). Of the 418 individuals, 297 (71%) died in the first 10 days. This high mortality rate (29.7 inds./day) is deemed mainly from the damage during the transportation and and also probably from the overcrowding in the 1.7 ton tank. The mortality rate decreased to about 2 inds./day during the next 40 days when 74~161 individuals were kept in the 1.7 ton-tank (Fig. 1). Thereafter, the mortality rate decreased to 0.37 inds./day in the following 100 days untill Dec. 17 and further decreased to 0.15 inds./day untill the end of the experiment, Feb. 25, 1988. The main cause of mortality after the first 10 days were difficulties in feeding due to the damages of eye and mouth, the change of the small wound for the worse and jumping out of the tank. Twenty six individuals survived at the end of experiment, (February 25, 1988).

(2) Spawning

The spawning started 30 days after the start of rearing when the mortality rate stabilized at the level of 2 inds./day or lower (less than 2%) and continued onwards for 6 months. Some

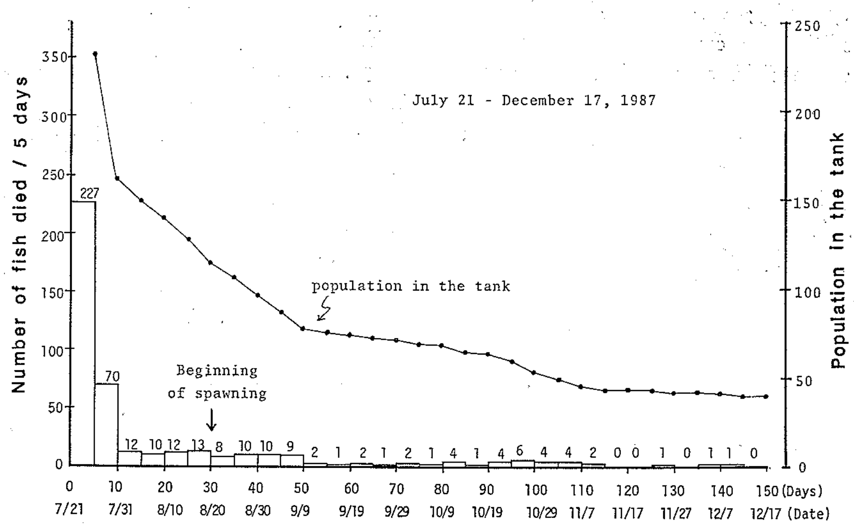

Fig. 1. Number of the anchovy died and its population in the tank summed up every 5 days during the first 150 days of rearing.

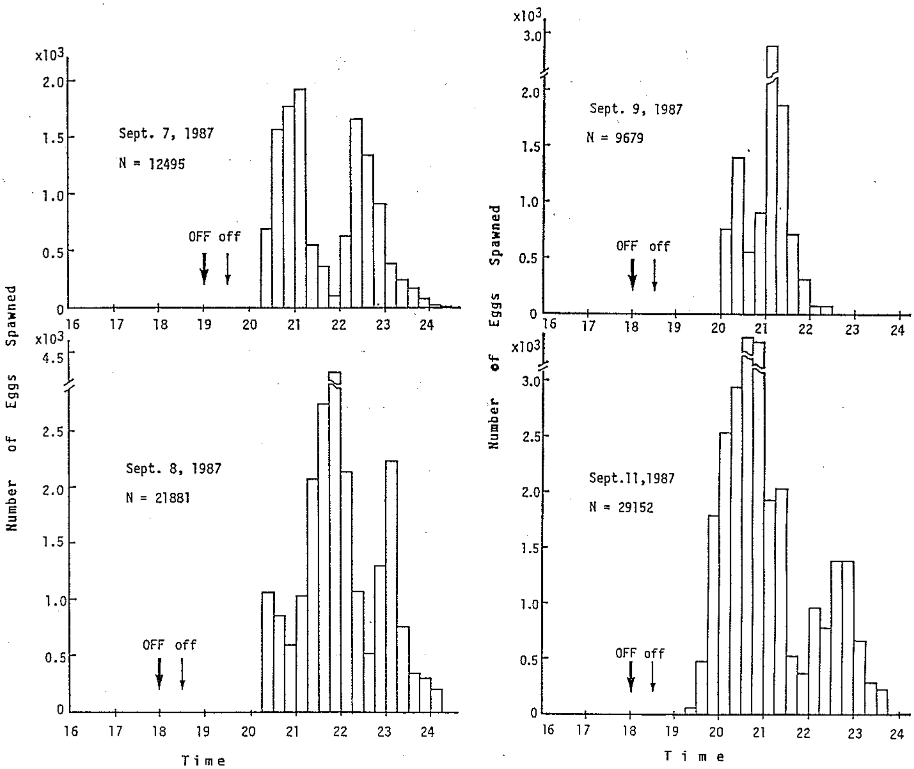

Fig. 2. The shifting process of the spawning time corresponding to the one hour shift of lighting time and the bimodal or trimodal spawning patterns. The period between two arrows indicates twilight condition. Egg number was counted every 15 minutes. N indicates total number of eggs spawned.

features of spawning were studied under the controlled conditions to compare with the results reported from the field observation or outdoor tank experiment.

① Spawning time in relation to photoperiod: The experiments were carried out from September 7 through 28, 1987 by advancing the switch-off time of light. The eggs spawned were collected every 15 minutes by plankton net set in the circulatory system to confirm the start and end of spawning. The switch-on time was also shifted forward in accordance with the shift of switch-off time without changing the lighting hours.

Fig. 2. shows the result of the first experiment in which both switch-on and -off times were shifted 1 hour earlier than the original photoperiod. The start of spawning did not change in the first day (Sept. 8), but shifted 15 minutes earlier in the next day and 1 hour in the third day to synchronize with the shift of sun set.

The experiment of 2 hour shift showed no shift in the spawning time on the first day (Sept. 18) as in the experiment of 1 hour shift. The observation was not made in the next 2 days, but on the fourth day (Sept. 21) the start of spawning advanced 1 hour 45 minutes, almost in synchrony with the switch-off time (Fig. 3). The result of these experiments are summarized in Fig. 4 indicating that spawning in the Japanese anchovy starts 1 to 1.5 hours after the switch-off time of lighting. The end of spawning also shifted with the change of start, *i. e.* the spawning duration of 3.5~4 hours was not affected by the shift of photoperiod (Figs. 2, 3).

② Spawning in relation to water temperature: Response of the spawning to the change of rearing temperature was observed in various ranges between 14°C and 23°C. The rearing temperature was kept at 23°C for the first 42 days as the anchovy had been kept around 23°C in the sea and the spawning there occurred at about 10,000 to 30,000 eggs/day (Fig. 5). The water temperature of 23°C is thought to be optimum for this species to spawn in the sea, for it has been reported spawn in the field within the range of 14～28°C with its optimum from 17 to 24°C (NAKAI *et al.*, 1955; IMAI and TANAKA, 1987).

To elucidate the effect of temperature change on the spawning, the rearing temperature was lowered from 23°C to 22°C in one hour when 10,000～30,000 eggs were spawned every day at 23°C (see Fig. 5). The temperature was lowered at 10:00 AM and maintained at 22°C for the next 2 days and put back to 23°C in the morning of the third day. The 2 repeated experiments showed a similar result. The temperature lowered in the morning showed no effect on the spawning at night of the same day, but the number of eggs released abruptly decreased at the next night (Fig. 5). Its effect seemed to continue untill the night of the third day when the water temperature was raised again to 23°C in the morning. Similar pattern of response was also observed in two cases when the temperatures were lowered from 21°C to 19°C and from 19°C to 17°C in the morning of Nov. 2, Nov. 10 respectively (see Fig. 5). In both cases the number of spawned eggs did not change in the first two days, but the spawning stopped on the

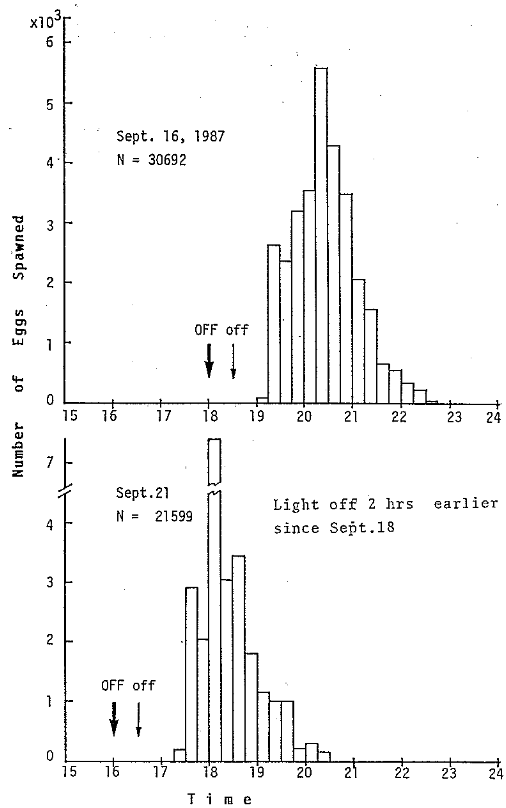

Fig. 3. The shifting process of the spawning time corresponding to the 2 hour shift of lighting time and the spawning patterns.

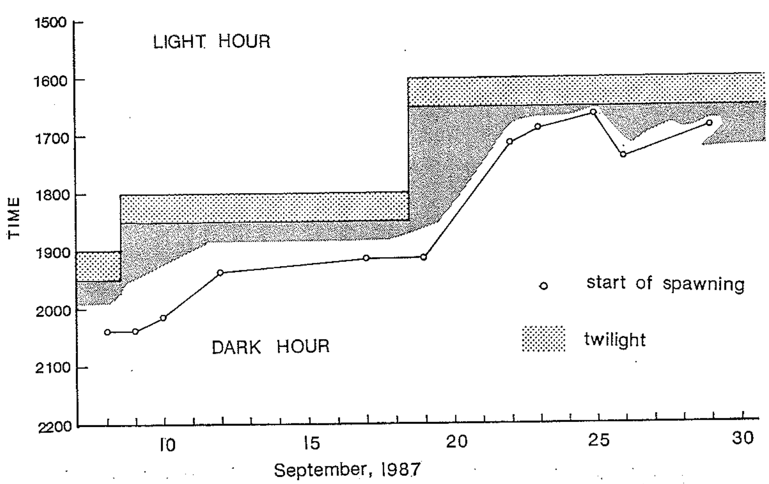

Fig. 4. The relationship between the sun set and spawning time and the shifting process of the spawning time in accordance with the shift of photoperiod.

third day and recovered on the fourth day. The temperature was also lowered from 23°C to 21.5°C at the night of Oct. 27, but no clear response was observed, probably due to rahetr unstable spawning condition in the period of Oct. 15~26. The first 4 observations, however, suggest that the shock of lowering temperature at the rate of 1~2°C/hour decrease the fecundity even in the optimum range of temperature (higher than 17°C). The suppressed spawning was recovered in 2~3 days after adapting to the lowered temperature within the optimum temperature range of 17~22°C.

③ Critical spawning temperature: To elucidate the critical spawning temperature, the rearing temperature was gradually lowered from 19°C to 14°C in November (Fig. 5). As mentioned above, the lowering temperature from 21°C to 19°C (Nov. 2) and from 19°C to 17°C (Nov. 10) caused the stop of spawning in the third day, but it recovered very quickly showing the quick adaptability to the lower temperature. When the temperature was changed from 17°C to 15°C in the morning of Nov. 15, the spawning stopped during 4 consecutive days from the night of the first day. At 15°C the spawning stopped during 5 of the next 7 days, although a small scale spawning observed at the 5th and 7th day nights (Nov. 19 and 21). No spawning was observed at 14°C from Nov. 23 to 29 (Fig. 5).

The rearing temperature was gradually raised from 14°C to 19°C in the next one month to confirm the critical spawning temperature and the effect of raised temperature (Fig. 6). The temperature was shifted from 14°C to 15°C in Nov. 30, and further up to 17°C in the next day and maintained at 17°C during a week. The spawning recovered on the first day at 17°C and was observed in 5 of the next 6 days, although spawning level is not so high as observed at 21°C or higher (Fig. 6). The water temperature was again lowered and maintained at 16°C for 8 days from Dec. 8 to 15. No spawning was observed in 6 of the 8 days, but small scale spawning occurred in the 5th and 6th days. The temperature was shifted back to 17°C on Dec. 16 with no spawning at night of the day and shifted further up to 18°C to be maintained in the next 12 days. At 18°C the spawning was recovered again and occurred in 9 of the 12 days. After Dec. 29 the anchovy were kept at 19°C untill the end of the experiment of Feb. 25, 1988. At 19°C spawning rate was maintaihed at the

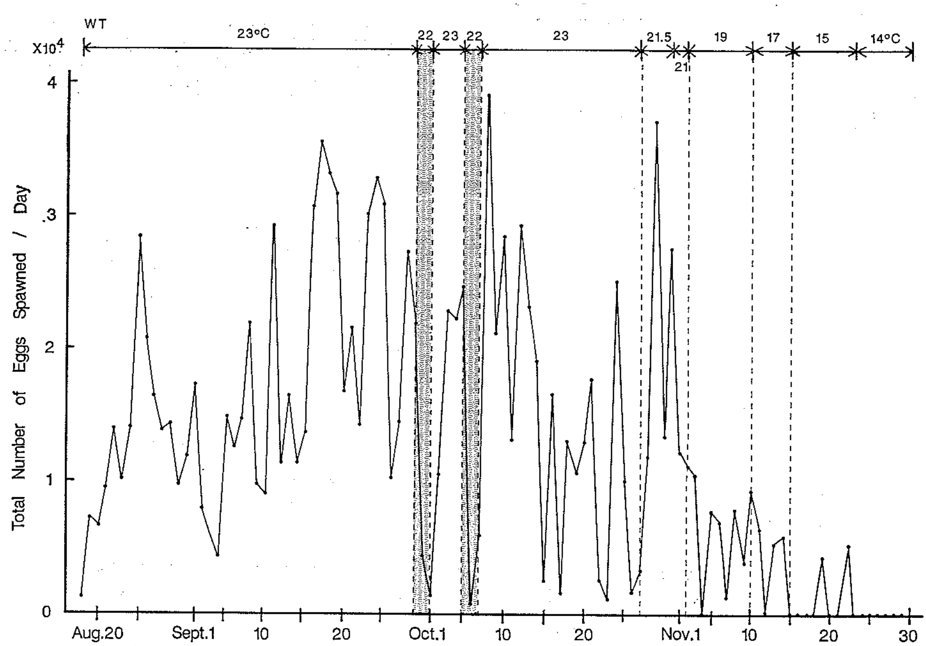

Fig. 5. The total number of egg spawned per day in relation to the rearing temperature from Aug. 20 to Nov. 30, 1987.

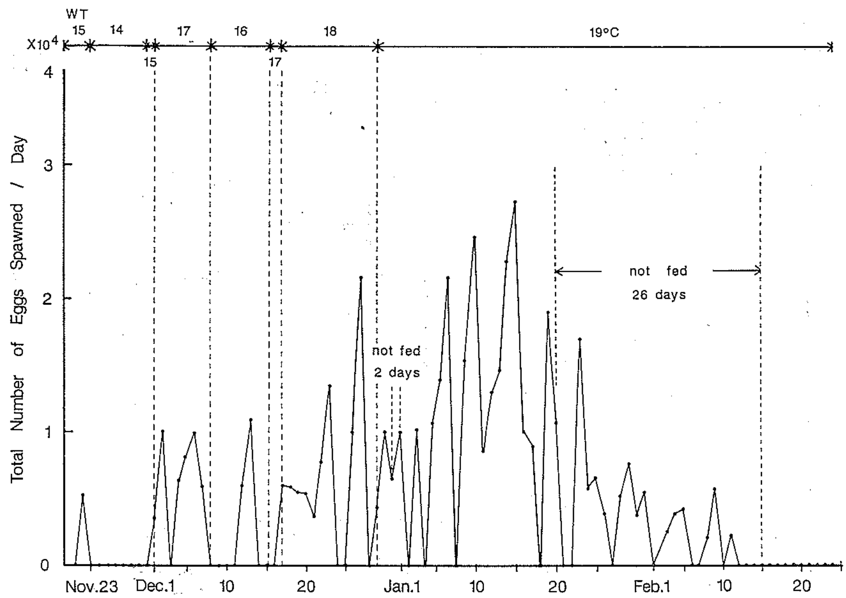

Fig. 6. The total number of eggs spawned per day in relation to the rearing temperature and the starvation.

level of 10,000~20,000 eggs per day, although no spawning was observed on certain days, probably due to the decrease of population to about 30 individuals in the tank. This experiment shows that the minimum critical spawning temperature of Japanese anchovy is 15~16°C and no spawning takes place at 14°C.

④ Starvation: The spawning continued at the level of 10,000~20,000 eggs/day for 15 days from Jan. 5 to 19 when the anchovy was well fed at 19°C, although no spawning was observed in 2 days, probably due to the decrease of population as metioned above. To examine the effect of starvation on spawning, feeding was stopped for 27 days from Jan. 20 to Feb. 15. It is obvious that as the starvation progressed the fecundity decreased gradually and the days of no spawning occurred more frequently. After 23 days of starvation the spawning stopped for 4 consecutive days and fail to recover in spite of 10 days of feeding untill February 25 when the experiment was terminated (Fig. 6). This starvation experiment suggests that anchovy regulates the frequency and fecundity of spawning according to its state of nutrition and can endure 10~20 day stravation with no effect on the spawning at 19°C.

⑤ Egg size in relation to rearing temperature: The relationship between average egg size and rearing temperature is shown in Fig. 7. The change in egg size is not significant under the water temperature of 21~23°C from Aug. 20 to Nov. 3. The changes in the length and width tend to be compensatory with each other to lower the fluctuation of egg volume, *i.e.* egg volume shows less fluctuation relative to size. When the rearing temperature was gradually lowered to 14°C from Oct. 27 to Nov. 22, egg size became gradually larger and the spawning stopped at 14°C for 7 consectuive days. Thereafter, when the temperature was raised to 15°C for one day, and further up to 17°C in the next day, the spawning recovered and produced the eggs largest in volume. The temperature was maintained at 17°C for a week, during which egg volume decreased quickly to the corresponding level. Furthermore, the temperature was lowered again to 16°C for 8 days and shifted up to 17°C for one day, 18°C for 12 days and 19°C for 22 days. During these expenment egg size and volume changed according to temperature change. Egg volume seems to be more sensitive to the temperature change than egg size, since egg length and width fluctuate compensately as mentioned above. It takes at least one week for the egg to complete the size change corresponding to 1~2°C difference.

The starvation at 19°C promtly caused the

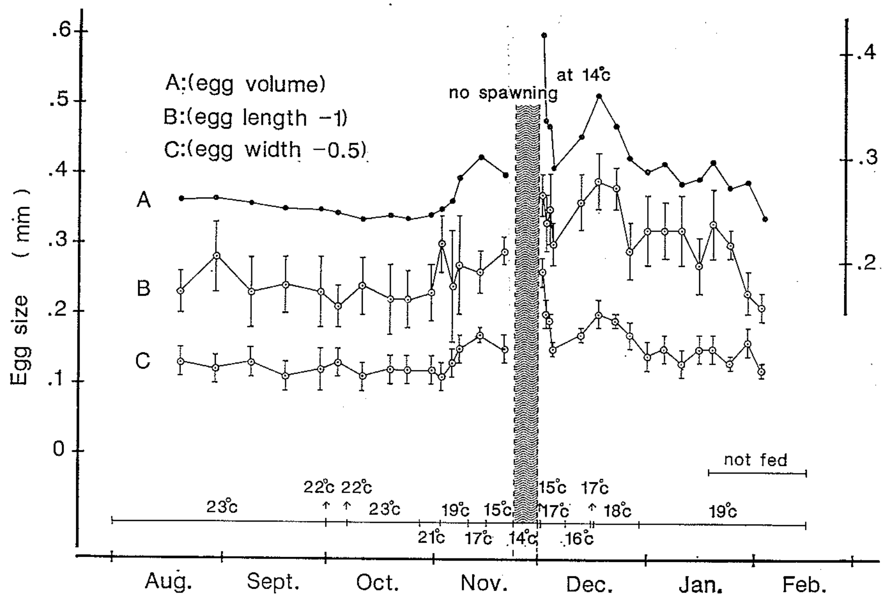

Fig. 7. The change in the egg size and egg volume according to rearing temperature and starvation at 19°C. Egg volume was calculated as $\pi/6 \times \text{length} \times (\text{width})^2$.

decrease in egg volume, although egg quality was not checked in this experiment.

3. Discussion

Based on the results of our experiments on the light period shift, it is concluded that the spawning begins 1∼1.5 hour after switching off the main light and the peak is reached 1∼1.5 hours later, *i.e.* 2∼3 hours after sun set. It has been reported from the field observation or outdoor tank experiment that the peak of spawning occurrs between 3∼5 hours after sun set (NAKAI *et al.*, 1955; YAMANAKA and ITO, 1957; TAKAO *et al.*, 1983; KUWABARA and SUZUKI, 1984; IMAI and TANAKA, 1987). The peak of spawning after the sun set occurred at about 2 hours earlier in this experiment than those reported from the field observation. This difference is mainly due to the fact that in our experiments the dusk was not well simulated by illuminating 30-minute lighting of 5 W tungsten lamp, *i.e.* dusk time is much more longer in the sea. The more precise simulation of dusk, based on the field observation of underwater light condition, is necessary for the future laboratory experiment. In northern anchovy the peak spawning time is reached 4∼5 hours after sun set (PIQUELLE and STAUFFER, 1985).

The end of spawning also shifted in accordance with shift of photoperiod, *i.e.* the spawning finishes within 3.5∼4 hours from the start. This spawning behavior well explains the patchy distribution of the same stage of egg in the field (AZETA, 1981; FUNAKOSHI and YANAGIHASHI, 1983; SEKIGUCHI *et al.*, 1988), if the transport by the current is considered.

The shifts of sun set did not affect the spawning time in the beginning but its effect appeared at the second night and the shift of spawning time was almost completed at the fourth night (Fig. 4). This suggests that the internal physiological process of the spawning is initiated based on the previous day's light condition and the process, once initiated, is not affected by the shift of photoperiod. As to the sun set or sun rise it is not certain which one affects the spawning time, since both sun rise and sun set time was altered in the same way in this experiments. IMAI and TANAKA (1987) reported that the strong lighting during the night inhibits the spawning. This suggests that the spawning time depends on the sun set time.

Even within the range of the optimum spawning temperature the sudden downward shift (1°C∼2°C/hour) of water temperature could cause the decrease in the fecundity or stop of spawning, but the spawning is recovered quickly within 2∼3 days. No spawning was observed at 14°C in our experiment, which agrees with the field collected data (IMAI and TANAKA, 1987) and other rearing experiment (TSURUTA, 1987). In addition to the temperature, it is reported that light period longer than about 12.5 hours is essential for gonadal maturation and spawning (TSURUTA, 1987).

It is well known that egg size of anchovy decreases linearly corresponding with the increase of sea water temperature from 14°C to 20°C, *i.e.* egg length is around 1.4 mm or more at 15°C and around 1.2 mm at 20°C (IMAI and TANAKA, 1987). Adaptive aspects of shift in egg size corresponding to the sea water temperature were discussed in detail by IMAI and TANAKA (1987). The size shows no significant change above 20°C. The egg size-temperature relationship in this experiment shows no significant difference from the field collected data previously reported. Egg size also decreased during starvation. Temperature and state of nutrition seem to affect the egg size independently.

It is noted that spawning continued for 22 days under starved condition at 19°C, though fecundity and egg size gradually decreased from the beginning of starvation. According to TSURUTA and HIROSE (1989), anchovy continued spawning for about 25 days even at 1% ration level (food/body weight) which is below the level of body maintenance, though spawning frequency, fecundity, and egg size decreased. They inferred that the maximum use of energy in spawning was important for the short-lived anchovy. The reproductive characteristics of this species, which are adaptable and responsive to the quick change of ambient facters, may play an important role in maintaining an fairly stable anchovy population in the pelagic fish community.

4. Acknowledgement

We thank to Drs. I. MITANI and N. NAKATA of Kanagawa Prefectural Fisheries Experimental Station for providing us with live anchovy and valuable advice for rearing. Dr. Y. TSURUTA of Tohoku National Fisheries Research Institute offered us the valuable information on the rearing experiment in the outdoor flow through tank. Misses H. SHIMIZU, A. TADA and T. OKAYA of Ocean Research Institute, University of Tokyo helped us with data processing and drafting. We are also indebted to Prof. J. Ho of California State University for improving our english manuscript.

References

ASAMI, T. (1953) Studies on the spawned eggs of anchovy, *Engraulis japonicus* T. et S. Contribution Nankai Reg. Fish. Res. Lab., **1**, 1-7.

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 Japanese anchovy. Gyogyou Shigen Kaigi-ho (Rep. Fish, Resour. Conf.), **22**, 7-28.

FUNAKOSHI, S. and S. YANAGIBASHI (1983) Environmental characteristics during the spawning period and in the spawning area of the Japanese Sardine, *Sardinops melanosticta* in the coastal waters off Enshu-nada, the Pacific coast of central Honshu. Bull. Japan. Soc. Fish. Oceanogr., **44**, 29-43.

IMAI, C. and S. TANAKA (1987) Effect of sea water temperature on egg size of Japanese anchovy. Nippon Suisan Gakkaishi, **53**, 2169-2178.

KUWABARA. A. and S. SUZUKI (1984) Diurnal changes in vertical distributions of anchovy eggs and larvae in the western Wakasa Bay. Bull. Japan. Soc. Sci. Fisher., **50**, 1285-1292.

NAKAI, J., S. USAMI, S. HATTORI, K. HONJO and S. HAYASHI (1955) Progress report of the cooperative IWASHI resources investigation. Apr. 1949 - Dec. 1959. Tokai Reg. Fish. Res. Lab., Fisheries Agency, pp. 1-116.

PIQUELLE, S. and G. STAUFFER (1985) Parameter estimation for an egg production method. *in* "An egg production method for estimating spawning biomass of pelagic fish: Application to the northern anchovy *Engraulis mordax*". NOAA Tech. Rep. NMFS, **36**, 7-16.

SEKIGUCHI, H., S. ITOKAWA and T. IKEDA (1988) An example of of anchovy egg patches. Bull. Japan. Soc. Fish. Oceanogr., **53**, 1-5.

TAKAO, K., T. KISHIDA and K. UEDA (1983) Number of eggs of Japanese anchovy produced per female per year estimated by a rearing experiment. Bull. Nansei Reg. Fish. Res. Lab., **15**, 1-11.

TSURUTA, Y. (1987) Notes on the reproduction of the Japanese sardine and anchovy as related to population fluctuation. Bull. Japan. Soc. Fish. Oceanogr., **51**, 51-54.

TSURUTA, Y. and K. HIROSE (1989) Internal regulation and reproduction in Japanese anchovy (*Engraulis japonica*) as related to population fluctuation. Canadian Spec. Pub. Fish. Aquatic Sci., **108**, 111-119.

YAMANAKA, I. and ITO (1957) Progress report of the cooperative IWASHI resources investigations 1954. Japan Sea Reg. Fish. Res. Lab., 1-177.

飼育条件下におけるカタクチイワシの産卵特性

川口弘一*・山下　洋**・林　　周***

人工的に管理された光・水温条件下でカタクチイワシを7ヶ月間飼育し，種々の条件下で6ヶ月間にわたり産卵特性の変化を観察し，天然で報告された産卵特性と比較検討した。産卵は，消燈後1～1.5時間後に始まり，3.5～4時間後に終了する。照明時間を変えずに消燈時刻をずらすと産卵時刻もそれに応じてずれる。1～2時間のずれを2～3日間で修復する。ただし光条件を変えた日の産卵時刻は変化しないので，産卵時刻は当日の光条件には影響されない。産卵可能な最低水温は，14°C付近にある。栄養状態のよいカタクチイワシは水温19°Cで10～20日間程度の飢餓にさらされても，産卵を続けることが可能である。しかし栄養状態の低下に応じて，産卵頻度，産卵数，卵径を縮少させる。卵径は飼育水温で変化し，1°～2°Cの水温変化に対応して卵径が変化，安定するのに約1週間を要した。一般的に飼育条件下での観察は自然での産卵習性をよく説明し，その理解を深めるのに役立った。

* 東大海洋研究所大槌臨海研究センター
〒028-11 岩手県上閉伊郡大槌町赤浜 2-106-1
** 東北区水産研究所　〒985 塩釜市新浜町 3-27-5
*** 海洋生物環境研究所　〒299-51　千葉県夷隅郡御宿町岩和田