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Early Development and Reproductive Behavior of the Gobiid Fish, *Mugilogobius abei*

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Abstract Reproductive behavior, spawning season and development of eggs and larvae of *Mugilogobius abei* were studied. Materials used in this study were taken periodically from Takahama Channel, Tokyo Bay, during the period from April to October, 1979. The spawning season seems to continue from April to August, with a peak in May. Spawning was accomplished at least more than one time during the spawning season. The oval eggs were 0.98 mm (mean) in length, 0.45 mm (mean) in breadth. Eggs hatched 97 hours after their discovery at 24.0°~24.6°C. The larvae reached the juvenile phase and wholly abandoned their planktonic mode of life 44 days after hatching at 22.5°~29.1°C. It was assumed that larvae in the field return, not immediately, but rather gradually to the native habitat, after completing the planktonic mode of life.

Mugilogobius abei (Jordan et Snyder) is a very common goby, reaching 5~6 cm in total length, which not only inhabits sandy and muddy bottoms in estuarine waters, but also occasionally enters freshwaters. This species is known to occur from the Kanto district (middle part of Honshū) southward to the Ryukyu Islands in Japan and the southern part of China including Hainan Island (19.00N, 109.30E) (Okada et al., 1965; Nakamura, 1975; Aoyagi, 1957). Its northern range seems to extend to Miyagi Pref., northern Honshū, Japan (Nakamura, 1976).

There is little information concerning the life history of this species except for observations of the egg shape (Dotsu, 1979) and estimation of the spawning season (Iwata et al., 1979).

In this paper the spawning season, reproductive behavior and the development of eggs and larvae are described and discussed based on specimens collected from Takahama Channel near the Tokyo University of Fisheries.

Materials and methods

The sampling area is located near the mouth of Takahama Channel, Tokyo Bay. Sea water enters the channel at high tide (13.49‰ in salinity at low spring tide in April). The bottom of this area consists mainly of sandy mud and small gravel. Discarded tires, broken concrete blocks, pieces of glass and cans lie scattered about the bottom.

A total of 150 males, 157 females and 71 individuals of unknown sex were caught (Table 1) using dip nets once a month at low spring tides, during the period from April to October, 1979. The spawning season was estimated from the gonad index of female specimens and the appearance of egg masses in the surveyed area. The gonad index was obtained by the following formula: gonad weight (g)/body weight (g)$\times 10^2$.

Five pairs of mature males and females of 58 individuals captured on 26 April were maintained to 1 November, 1979 in an aquarium, 114 cm$\times$30 cm$\times$43 cm, 120 *l* in capacity, containing 50% sea water (15.19‰ in salinity) with a closed water circulation system. Water temperature during the period ranged from 20.8° to 29.8°C. Natural and fluorescent light was used during day time. The fish were fed chopped bivalves and midge larvae, *Chironomus prasinus*.

During six months of rearing, curved slate plates were placed on the bottom as spawning beds. The reproductive behavior was observed and fertilized eggs were obtained.

Some of the fertilized eggs from one spawning were transferred to a 13 cm diameter glass basin, containing the same water as their parents were kept in, where observations of the development of eggs were carried out. The water temperature for eggs was kept at 24.0°~

24.6°C. The remaining fertilized eggs were separated from the guarding male immediately before hatching and transferred to a round plastic tank 3 *l* in capacity for hatching.

Hatched larvae were transferred again and reared in another tank of 30 *l* capacity containing full-strength sea water (37.09‰ in salinity) with a closed circulation system. Water temperature during the rearing experiment ranged from 22.5° to 29.8°C. The aerated rearing water was partly changed with 3 *l* of clear new water everyday for the first nine days.

Nine days after hatching, the water was circulated from another filter tank during night time and the rearing water was partly changed with 3 *l* of clear new water once every two days. Thirty-six days after hatching, the larvae were transferred to another aquarium, 39×25×23 cm, 25 *l* in capacity, with a closed water circulation system.

During the first 15 days after hatching, the larvae were fed fertilized oyster (*Crassostrea gigas*) eggs as an initial food item. According to the growth of larvae, the rotifer *Brachionus plicatilis* was also given from 16 days after hatching. From the 28th to the 43th days, the larvae were fed only with *Brachionus plicatilis* and the food items were changed to chopped bivalves and midge larvae after the 43 day. Dead larvae and left-over food were removed by a siphon everyday.

Sizes of eggs, larvae and juveniles were measured after anaesthetizing with MS 222, using an ocular micrometer attached to a dissecting microscope.

Periodical observations

Fertilized eggs and guarding males were observed during the period from April to

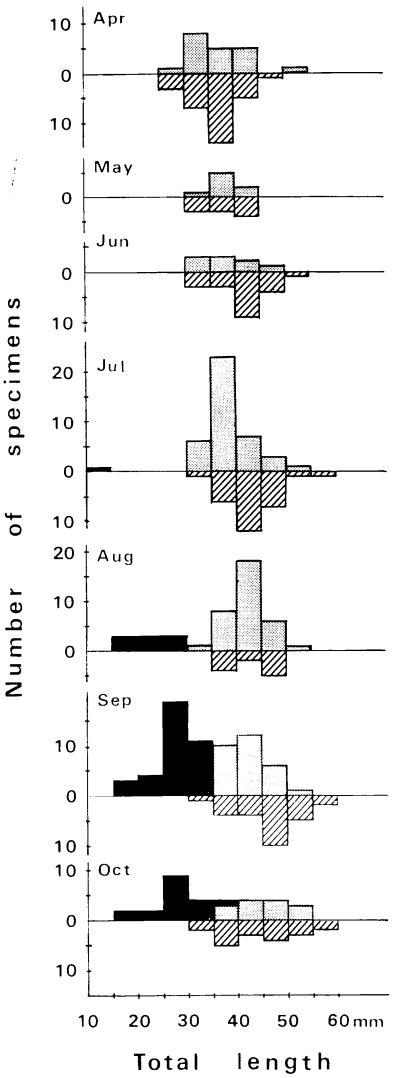

Fig. 1. Monthly change in size frequency of *Mugilogobius abei*. ▨ male; ▩ female; ■ indeterminable.

Table 1. Number of individuals collected and appearance of egg mass in the field.

Collecting date	Male	Female	Sex indeterminable	Egg mass
April 26, 1979	35	23		rare
May 24, 1979	10	8		abundant
June 25, 1979	20	9		rare
July 26, 1979	29	40	2	rare
August 25, 1979	11	34	9	none
September 21, 1979	26	29	42	none
October 27, 1979	19	14	18	none

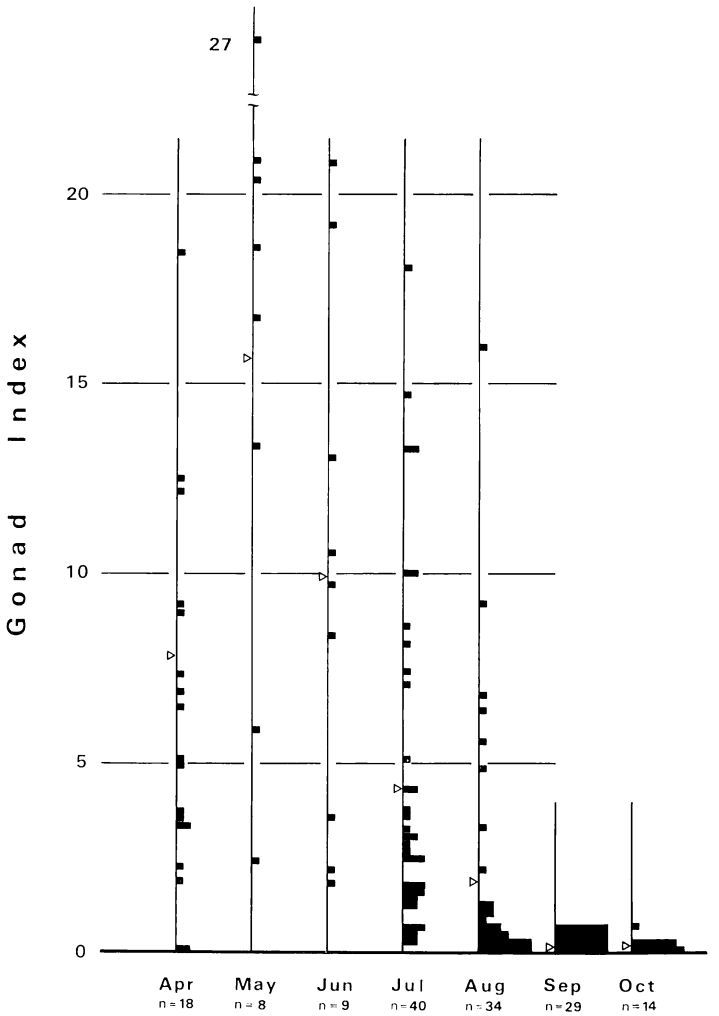

Fig. 2. Monthly change in the distribution of gonad index. A black square represents one individual, white triangle indicates mean index.

July, with a peak in May, in nests between stones and sandy bottom on the sampling area. After July, eggs were not observed. These nests were generally located in the water, but during the low spring tides many nests were exposed above the surface of the water. Individuals of unknown sex appeared from July to October, and were especially abundant in September and October (Table 1, Fig. 1).

During the period from April to August, ripe eggs were observed in the gonads. Ripe gonad weight was almost equal on both the right and left sides. The highest gonad index was obtained in May. The mean index gradually decreased from June to August (Fig. 2). In September and October, ripe eggs were not found in the gonads and one of 29 individuals in September and four of 14 individuals in October were observed with only a few unripe eggs in their gonads.

Eggs in the gonads of five females were measured and counted. The size of eggs in the gonads was not uniform and varied between individuals. The size combinations of eggs in the gonads are represented as large; large and small; large, medium and small; and small and extremely small. All large eggs seemed to be ripe and ranged from 0.30～0.49 mm in diameter. Small eggs ranged from

0.08～0.20 mm in diameter and were not ripe. Counts of large eggs ranged from 1,407 to 6,920 in four females.

Spawning behavior

For nest preparation, gravel was carried from inside to the entrance of the nest in the mouth of the male in order to increase the space of the spawning area. The entire procedure of nest preparation was accomplished by the male. The single male usually stayed in the nest during most of the day. After the completion of the nest, tne courtship display of the male was occasionally observed. At this time, the body color of the male darkened and the margin of the dorsal fin became yellow. The female's body color faded.

In pre-spawning, the male started his courtship behavior towards a selected female. The response of the estrous male to an approaching gravid female was represented by two characteristic movements, circling around the female by the male and a trembling display.

Circling of the male around the female: The circling movement starts as the male approaches the female. He circles around her in a spiral and leads her to the nest.

Trembling display: The male approaches the female near the bottom, turns his body a little away from her and trembles his body and caudal fin against her, attempting to lead her to the nest. This display was only rarely observed.

Even when the male was successful in leading the female into the nest, spawning was not always observed. Some females fled from the nest after a short stay. These patterns were repeated if the initial display of the male was unsuccessful.

In spawning, the estrous female pushed her urogenital papilla to the undersurface of the nesting plate and moved slowly by fanning the caudal fin. Eggs were extruded from the erected and swollen urogenital papilla and laid in a one-layer mass on the undersurface of the nesting plate. The male followed the female and ejected sperm by pushing his urogenital papilla to the laid eggs.

After spawning, the male and female usually stayed for some hours in the nest, and then the female left the nest. On the other hand, the male remained in the nest, took care of the eggs by fanning the fins, and aggressively guarded the nest against intruders. Gravel was sometimes carried by the male to the entrance of the nest to shield it from invasion. The guarding male only rarely left the nest for feeding and quickly returned after he captured food.

Spawning activity was observed 21 times during the period from 10 May to 2 August, but the frequency of spawning by one individual in one season is not clear because the five females were not distinguished from each other.

Egg development

Egg development was observed from a series of eggs taken from an egg mass spawned in the aquarium on 22 May, 1979. The eggs were spawned in a one-layer mass, hanging from the underside of the spawning bed, with some lying on the gravel at the bottom. At the time of the discovery, the egg mass consisted of eggs in various stages, from one-cell to eight-cell stages.

1) One-cell stage, immediately after discovering the egg mass (Fig. 3A): Eggs were elliptic, 0.93～1.00 mm in length (mean 0.98 mm) and 0.40～0.47 mm in breadth (mean 0.45 mm), with adhesive threads at their bases. Some large and several small oil globules were observed in the yolk.

2) Morula stage, 1 hr. 30 min. after discovering (Fig. 3B).

3) Gastrula stage, 4 hr. 15 min. after discovering (Fig. 3C): The blastdermal cap began to spread over the surface of the yolk. The oil globules merged to form a large globule.

4) 12 hr. after discovering (Fig. 3D): The optic vesicles and Kupffer's vesicle appeared.

5) 16 hr. 20 min. after discovering (Fig. 3E): The lenses were clearly observed in the eyes and the elliptic auditory vesicles were recognized on the lateral sides of the nape. Nine pairs of myotomes were visible. Kupffer's vesicle had disappeared.

6) 21 hr. after discovering (Fig. 3F): The heart was recognized pulsating anterior to the yolk. The embryo sometimes wagged its tail. The notochord was clearly observed. A constriction appeared at the part where the mouth

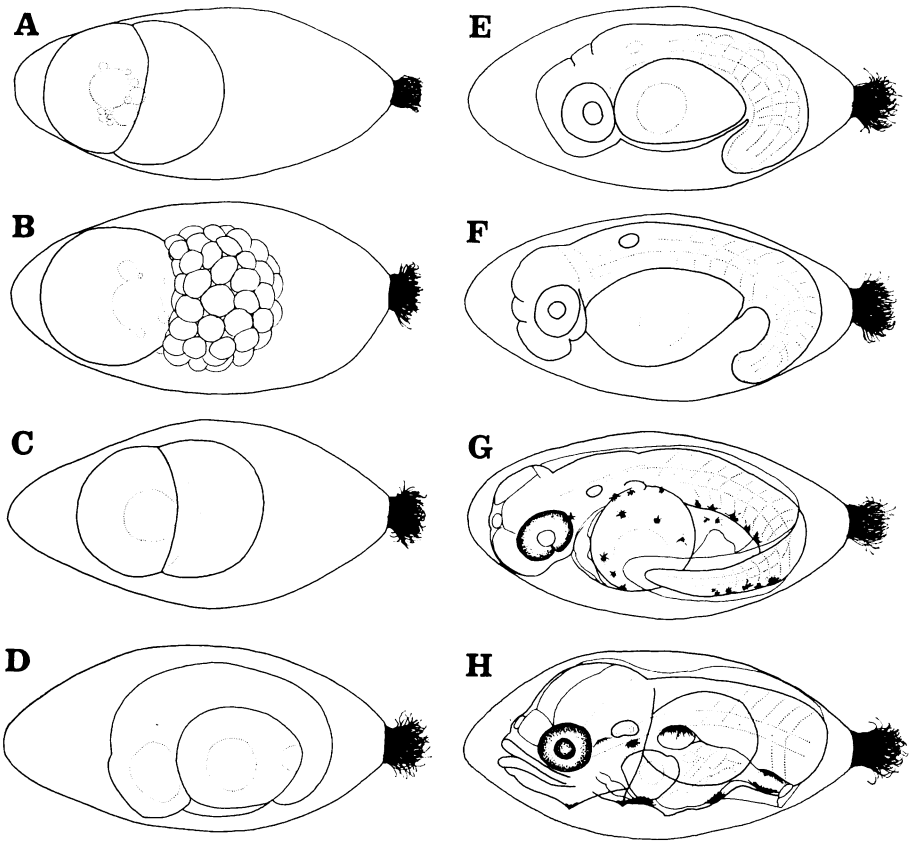

Fig. 3. Egg development of *Mugilogobius abei*. A: One cell stage, immediately after discovering. B: Morula stage, 1 hr. 30 min. after A. C: Gastrula stage, 4 hr. 30 min. after A. D: 12 hr. after A. E: 16 hr. 20 min. after A. F: 21 hr. after A. G: 31 hr. after A. H: 96 hr. 30 min. after A, immediately before hatching.

was expected to open.

7) 31 hr. after discovering (Fig. 3G): Larval fin membranes were enlarged on the dorsal and ventral sides. The tail was lengthened and looped to reach middle of the yolk. Melanophores had already appeared along the ventral side of the tail and on the yolk. The eyes were pigmented. Rudiments of pectoral fins were developing over the yolk. The placode of the gut was recognized.

8) 96 hr. 30 min. after discovering the eggs, and immediately before hatching (Fig. 3H): The embryo was folded in three parts, its tail covering its face (the posteriormost part of the tail is not shown in the figure). The yolk had decreased in volume. The mouth had opened on the terminal end of the head. The alimentary canal was straight. The small gas bladder was observed above the yolk. The embryo was vigorously moving and finally hatched, breaking the distal tip of the egg capsule. Enzyme glands, which must have existed before hatching, were not clearly observed under our binocular microscope.

Development of larvae

1) Immediately after hatching, 2.0～2.2 mm (4 individuals) in total length (TL) (Fig. 4A): Myotomes numbered 25(7+18). The preanus length (the distance from the anterior mid tip of lower jaw to the center of anus) was 32.9% of TL in the specimen shown in the figure. The yolk still remained and was larger than the eye. The gas bladder was not yet expanded. A single large dendritic melanophore was observed on both middorsal

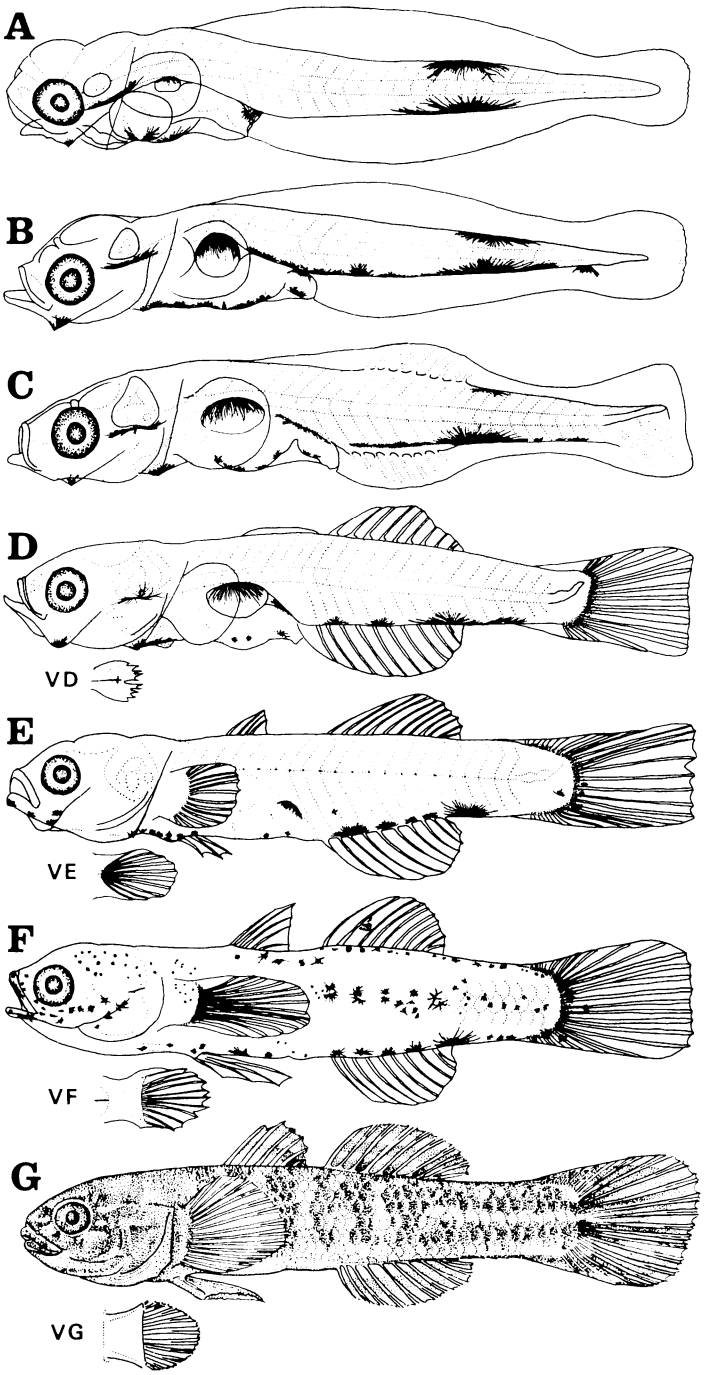

Fig. 4. Larvae and juvenile of *Mugilogobius abei*. A: Immediately after hatching, 2.0 mm in total length (TL). B: 11 days after hatching, 3.3 mm TL. C: 16 days after hatching, 4.0 mm TL. D: 24 days after hatching, 5.5 mm TL. E: 33 days after hatching, 6.6 mm TL. F: 36 days after hatching, 9.4 mm TL. G: 44 days after hatching, 19.5 mm TL. VD, ventral fins of D; VE, ventral fins of E; VF, ventral fins of F; VG, ventral fins of G.

and midventral sides of the caudal region. Smaller ones were also distributed under the auditory vesicle, over the gas bladder and rectum, on a median line of the abdominal part and on the lowest end of the preopercle. Yellow pigments were observed over the malanophores on the caudal region. The larvae tended to float on the surface of the water and showed positive phototaxis.

2) 11 days after hatching, 2.8～3.3 mm in TL (5 individuals) (Fig. 4B): The anus moved backward, the preanus length was 44.8% of TL in the specimen shown in the figure. The yolk had already been absorbed. The auditory vesicle became triangular. The lower jaw projected. Melanophores developed almost entirely on the ventral side of the body.

3) 16 days after hatching, 3.2～4.0 mm in TL (5 individuals) (Fig. 4C): The preanus length was 48.3% of TL in the specimen indicated in the figure. The end of the notochord slightly bent upwards and rays of the caudal fin were not developed. Eight weakly developed rays were recognized in both the second dorsal and anal fins. The auditory vesicle increased in size.

4) 24 days after hatching, 4.9～6.2 mm in TL (5 individuals) (Fig. 4D): Larval fin membranes disappeared except for the rudiment of the first dorsal fin. The adult complement of 9 (I, 8) rays in the second dorsal fin and 10 (I, 9) rays in the anal fin had been completed. The rudiments of ventral fins had also appeared on the breast (Fig. 4, VD).

5) 33 days after hatching, 6.6～7.9 mm in TL (3 individuals) (Fig. 4E): Four spines were counted in the first dorsal, 14 rays in the pectoral, and 5 rays in the ventral fins. The caudal fin was truncate. Some melanophores newly appeared on the lower jaw.

6) 36 days after hatching, 9.4～14.5 mm in TL (2 individuals) (Fig. 4F): Five spines were completed in the first dorsal fin. The ventral fins were completely united together to form a sucking disc. Several scales appeared on the side of the caudal peduncle. Secondarily developed asteroid melanophores were distributed on the jaws, along the lateral and ventral sides of the body, on the base of the caudal fin, and sparsely on the head and along the dorsal side of the body. Larger individuals began to abandon the planktonic mode of life.

7) 44 days after hatching, 15.0～19.5 mm in TL (3 individuals) (Fig. 4G): The adult complement of 6 spines was completed in the first dorsal fin. The body was wholly covered with ctenoid scales except for the head and belly. Melanophores extended all over the body, showing the specific color pattern of this species. About this day, almost all the larvae wholly abandoned their planktonic mode of life.

The largest young grew to about 40 mm in TL by the ninth month.

Discussion

From monthly changes of the gonad index, appearance of natural egg masses in the field, and spawning observed in the aquarium, the spawning season of *Mugilogobius abei* in Takahama Channel was estimated to continue from April to August. However, it may reasonably be deduced that the spawning of this species takes place mainly from the end of April to the beginning of July, because the highest gonad index and the most numerous egg masses in the field were observed in May. Iwata et al. (1979) reported that the spawning of this species in the Tsurumi River was carried out from May to August with a peak in June and July. The gap between these spawning seasons may be caused by some abiotic conditions such as geographic factors, water temperature, salinity, etc.

The condition of eggs in the gonads and the number of spawnings observed in the aquarium indicate that females of *M. abei* spawn more than one time during a spawning season. This fact agrees well with studies of *Aboma lactipes* (Hilgendorf) by Dotsu (1959), *Pterogobius elapoides* (Günther) by Dotsu and Tsutsumi (1959) and *Zonogobius boreus* Snyder by Shiogaki and Dotsu (1974).

The results of our rearing experiments show that the larvae live a planktonic life for more than a month (about 40 days). In the field, the larvae must also remain planktonic for about the same time span.

During this study, we were able to collect specimens of only juvenile and adult phases of *M. abei*. Individuals of unknown sex

(juvenile) appeared numerous in September and October. On the other hand, egg masses were observed frequently in May, four months before the peak of the appearance of juvenile fishes. Iwata et al. (1979) reported that many juveniles, the smallest 6 mm in length, were captured from July, on the estuary of the Tsurumi River, where adult fish were also present. The differences in size and in the period of appearance of juveniles between the two localities (Tsurumi River and Takahama Channel) may be caused by geographic factors, sampling methods, etc.

The gap between the appearances of the fertilized egg masses and juveniles indicates that the larvae of this species flow out with outgoing tides after hatching, and return rather gradually to the native habitat after completing the planktonic mode of life. Shiogaki and Dotsu (1972) discussed this type of early life history which is shared by tide pool fishes and amphidromous fishes.

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アベハゼ *Mugilogobius abei* の卵および仔魚の発育と産卵行動

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アベハゼ *Mugilogobius abei* の産卵行動，産卵期，卵および仔魚の発育を観察した．産卵期は4月から8月にわたり，5，6月が盛期であった．産卵は1個体の雌によって，複数回行われることが判った．卵は楕円形で，平均長径 0.98 mm，短径 0.45 mm であった．卵発生の観察開始後，卵は97時間（水温 24.0°～24.6°C）で孵化した．飼育した仔魚は，孵化後 44 日頃（水温 22.5°～29.1°C）にすべて底棲生活に移行した．野外における仔魚は，浮遊生活を終えた後，徐々に本来の生息地に帰ってくることが推察された．

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