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Ovarian Maturation and Spawning of the Japanese Common Mackerel *Scomber japonicus*[*1]

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The ovarian maturation and spawning process of Japanese common (chub) mackerel *Scomber japonicus* was studied on the basis of three years samples. The degree of maturity of ovaries was judged by the external appearance, gonad maturation index and frequency distribution patterns of egg diameters. Frequency distributions of egg diameter of ovaries were classified into 10 profiles. Ovarian maturation begins with enlarging of the egg diameter and increasing of the amount of yolked eggs. When the mean size of the most advanced egg group reaches about 0.6 mm, its increasing seems to stop and only the number of yolked eggs continues to increase. When the mean KG value exceeds 4–5, hydration occurs in a fraction of yolked eggs and these are rapidly released as a batch. It is difficult to find clear relationship between the distribution profiles of egg size and the mean KG of mature ovaries owing to the multispawning trait. The minimum sizes at the first maturity was estimated to be approximately 30 cm.

The Japanese common (chub) mackerel *Scomber japonicus* is one of the most important pelagic species for Japanese fisheries. The Pacific subpopulation of this species ranges from Hokkaido to the Tokai region of the Pacific coast (see Fig. 1). The sexual muturation process has been studied by several authors[1–6] but not since the mid-70's. In this paper we report on the ovarian maturation and spawning process of the Pacific subpopulation of Japanese common mackerel.

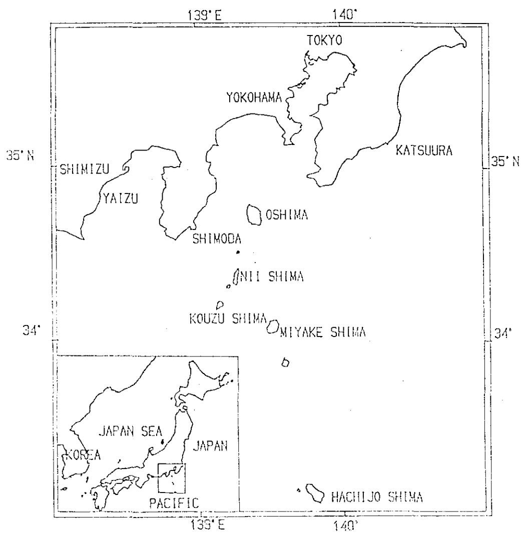

Fig. 1. Location of sampling areas.

Materials and Methods

Over a period of three years, March 1977 through June 1979, a total of 1069 female mackerel were sampled from the fish landed at Kogawa fishing port, Yaizu, Sizuoka Prefecture (Fig. 1 and Table 1). These mackerel belong to the Pacific subpopulation and aggregate to the sea around the Izu islands during the spring spawning season. The fish are caught by dip net or pole fishing. Fork length was measured to nearest 0.1 cm and body weight to 0.1 g for all fish. The smallest female mackerel in the samples was about 27 cm. Ovaries were extracted from the female mackerels and preserved in 10% formalin. The KG for each fish was calculated as KG=(Gonad Weight in g)/(Fork Length in cm)$^3\times10^4$.[7] After more than one month from the preservation, no appreciable change in the size of eggs occurs.[1] The frequency distributions of the ovarian egg

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Table 1. Japanese common mackerels sampled in 1977-79

Date		Numbers of female fish examined	Date		Number of female fish examined
1977				24	29
Mar.	1	78	Jun.	7	19
	9	37		16	22
	16	35	1979		
	22	29	Jan.	12	11
Apr.	4	24		25	17
	12	31		26	17
	18	41		29	24
	28	46	Feb.	1	38
May	10	41		6	49
	18	42		8	4
Jun.	2	25		14	42
	7	43		22	48
1978			Mar.	2	52
Mar.	7	24		7	31
	16	27		14	31
	25	24		28	53
Apr.	10	27	Apr.	19	20
	17	26		20	31
	25	27		26	19
May	2	20	May	7	50
	5	20		16	28
	11	34		21	25
	19	28	Jun.	1	21

diameters were then estimated by the method using an image processor[8] to serve as fundamental data for this study.

The analysis of the polymodal frequency distributions of the ovarian egg diameter of mackerels have been made by a computer FACOM M-180 IIAD.[9]

Results

External Appearance by Naked-eye Observation

An examination of the gonad condition by naked-eye observation was made, because this method is the easiest and most labor-saving. To determine the maturity stage of an ovary with this method, it is necessary to classify the characteristics of the sexual organ. According to some former works for the Pacific mackerel and the Atlantic mackerel[1,10-12] the criterion of gonad maturation for naked-eye observation were established, but suitably modified for the special features exhibited by the Japanese common mackerel (Table 2).

It is important to be careful in the application of this criterion that only after spawning or ovaries that have experienced spawning must be categorized in the maturity stage E or E′ according to their external appearances. Wrinkles, thinness and empty follicles are good evidence for the judgment of the spent

Table 2. Criteria of maturation for naked-eye observation

Matutity	General characteristics
A	Ovaries very small evidently immature. White, beige or light pinkish color. Individual eggs are not visible.
A′	Intermediate between the stages A and AB. Individual eggs are distinguishable by naked-eye.
AB	Yolked eggs and nonyolked eggs exist together.
AB′	Intermediate between the stages AB and B. Large yolked eggs are contained but their sizes not uniform.
B	An ovary consists mainly of yellow large yolked eggs. Egg size becomes uniform. Large eggs are jamming and easily observed through the ovary surface. Ovaries heavier and round shape.
C	Containing translucent hydrated eggs. The stage C is divided by the proportion of hydrated eggs into following three substages.
C-1	A few.
C-2	Less than 20% of total amount of mature eggs.
C-3	More than 20% of total amount of mature eggs. So called "plum-pudding" stage.
E	Spent ovaries. Ovaries are similar to the stages AB, AB′ and B. Ovaries are thinner than the developing or the ripe ovaries for their length and width, but still containing large yolked eggs. Normally shrinks and wrinkles on the ovary surface.
E′	Completely spent ovaries. Ovaries exhausted most of eggs; apparently degenerated. Reddish color.

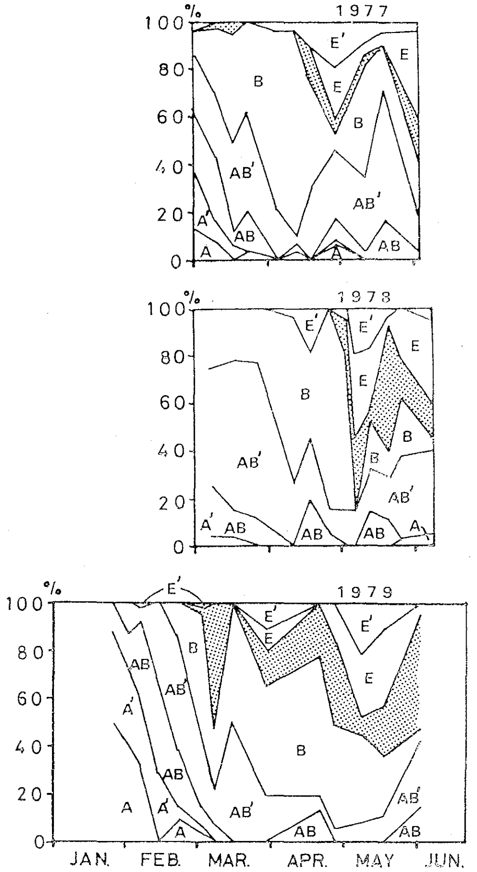

Fig. 2. Monthly variations of the proportion of ovarian maturity stages for three years; 1977–1979. Shaded parts indicate the C stage.

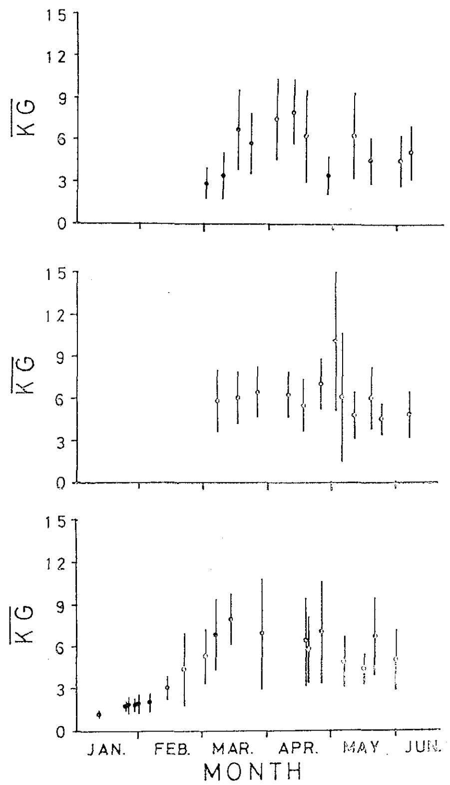

Fig. 3. Monthly variations of the mean KG and its standard deviation for three years; 1977–1979.

condition.

The preserved ovaries were examined by naked-eye observation. Fig. 2 shows the monthly variation of the proportion of ovarian maturity stages for those three years. For the years 1977 and 1979 the C stage ovaries first appeared in early March, but for 1978 they appeared lately on May 2. The E and E′ stage ovaries that had experiences of spawning tended to appear in the latter half of the spawning season and to increase as the decreasing of the percentage of the B stage ovaries through the entire spawning period.

Generally it has been suggested that sampled common mackerels caught by the fisheries don't have hydrated eggs in their ovaries, but fortunately we could get some C stage ovaries in the samples. In early April the B stage ovaries were dominant. As they decreased in mid- or late-April, the number of E, E′, AB and AB′ stage ovaries increased.

Seasonal Change of Maturation Index

Generally, to estimate the maturity of fish gonad, indices which were based on the size or the weight of gonad have been used.[13] This method has an advantage of analyzing the sexual maturity of gonad easily and quantitatively. The KG[14] and the GSI (Gonad Somatic Index) are very frequently used in this field of study. Though many arguments on the superiority of one maturation index over others have been presented,[15,16] in this paper we employed the KG as the maturation index of common mackerel to be able to compare it with some previous studies which treated the species.

Fig. 3 shows the change of the mean KG for each sample. In 1977 the mean KG was 2.9 on March 1 but increased to the highest peak 8.1 on April 12. Thereafter it decreased gradually. In 1978 it has already recorded the high value 6.0 in the beginning of March and formed the highest peak 10.0 on May 2. It then decreased slowly with small increment and de-

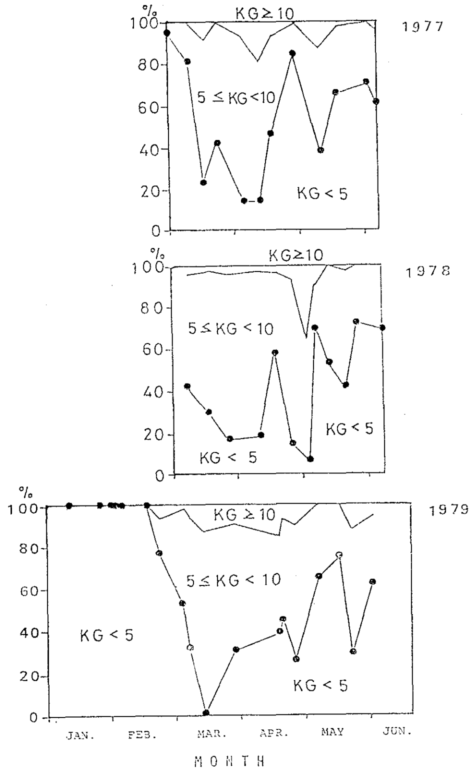

Fig. 4. Monthly variations of the proportion of stratified KG groups for three research years; 1977–1978.

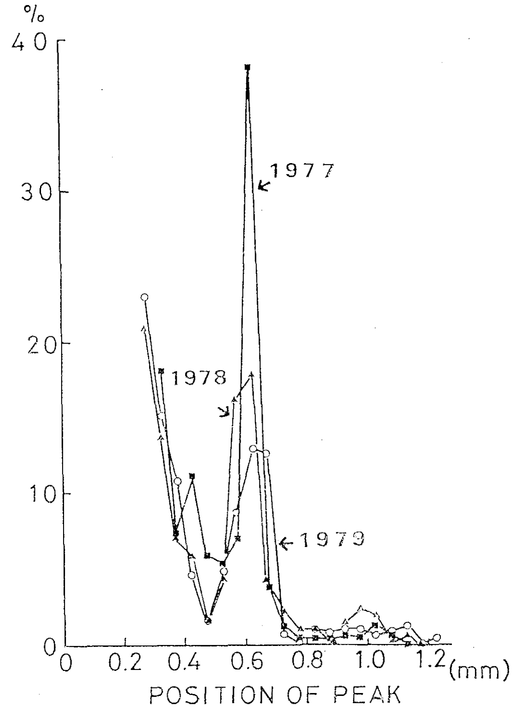

Fig. 5. Distributions of the peaks which appeared in the frequency distribution of egg diameter (for all peaks). Numerals show the sampling years respectively.

crements. In 1979 it was then very low value of less 2.0 during January but began to increase markedly at the middle of February. It recorded 7.9 as a peak on March 14. After that it tended to decrease fluctuating but remained in comparatively high level of 5.0–7.0.

To examine the seasonal variation of the distribution ratio of the KG values, the KG was conveniently divided into three groups with its value; (1) KG$<$5.0, (2) 5.0$\leqq$KG$<$10.0 and (3) KG$\geqq$10.0. The KG$=$5 is a critical value because Watanabe[17] has shown that the occurrence of egg and larva of common mackerels in the sea had started to clearly correspond with the period when the gonad index KG had increased up to 5.0 and this has not changed significantly over the period of the study.[18–20] An ovary with KG$\geqq$10.0 is really large and may be most active for spawning. The results of this stratification are shown in Fig. 4. In 1977 ovaries of KG$<$5 were 80–90% in early March, but decreased down to near 20% on March 16. Ovaries of KG$\geqq$5 lasted to be more than 50% until May 10 except April 28. Thereafter ovaries of KG$<$5 increased again to about 60%. In 1978 ovaries of KG$\geqq$5 already has exceeded 50% on March 7 and increased in late March and in early April. This tendency continued to May 2 except for April 17 and maintained a high level of more than 80%. After that ovaries of KG $<$5 began to increase and were about 70% at the beginning of June. In 1979 ovaries of KG$<$5 were 100% until February 14. Ovaries KG$\geqq$5 suddenly increased in early March and reached 100% on March 14. Thereafter ovaries of KG$<$5 steadily increased again but on the contrary, ovaries of KG$\geqq$5 decreased.

Developing Speed of Egg

The developing ovary of common mackerel usually had a few peaks in the egg size distribution. This suggests that all eggs neither mature nor spawn together. As the eggs mature in batches, a polymodal distribution is formed in the frequency diagram of egg size. To estimate the developing speed of eggs, the frequency distributions of the position of peaks which appeared in the egg size distribution were calculated using data of all samples and shown in Fig. 5. It seems that the growing speed of egg size is slow at the position where a height is formed but fast at a valley. There were apparently some peaks and valleys; the first peak was located at less 0.3 mm but we could not identified its definite position because of lower measurement limit at 0.15–0.2 mm. The second one was at 0.6–0.65 mm and the third small one at about 1.0 mm. As for the valleys the first valley located at 0.45–0.5 mm, the second 0.8–0.85 mm. There was no significant difference between years in this aspect.

Profiles of Egg Size Distribution

To understand the maturation of mackerel ovaries in detail, it is necessary to examine the frequency distributions of egg diameter. Analyzing the polymodal frequency distribution, profiles of ovarian egg size distribution were determined for each sample. Of the total ovaries 95% had from one to six peaks.[9] In the frequency distribution of ovarian eggs at the most advanced stage of ovaries, there appeared a discontinuous space (DS) in which no eggs existed. The DS divided the distribution into the developing egg group and the hydrated egg group. The seasonal variations in composition of the number of peaks in frequency distribution were also reported by Asano and Tanaka.[9]

The egg size distribution profile types were classified into ten representative profiles which are shown graphically in Fig. 6. The arrows in the most advanced egg group in types VI and IX represent the heights of the egg group are variable. Also, the dotted line in type X shows the alternative from which frequently appeared in ovaries containing hydrated eggs. Egg size distributions in each sample were sorted into some of these types and the profile type compositions of each sample are shown in Table 3. The change of profile composition in whole wintering and spawning period could be observed in the 1979 year samples. The profiles I, II and III (immature ovaries), predominated on January 25 and February 1. The ovaries of type IV gradually increased and the type I–III disappeared on March 2. After that the type V and the more advanced profiles became to predominate. The type VIII and IX first appeared on March 16 in 1977, March 7 in 1978 and March 2 in 1979. The first appearances of the type X (ripe ovary with hydrated eggs) were on March 16 in 1977, May 2 in 1978 and March 7 in 1979.

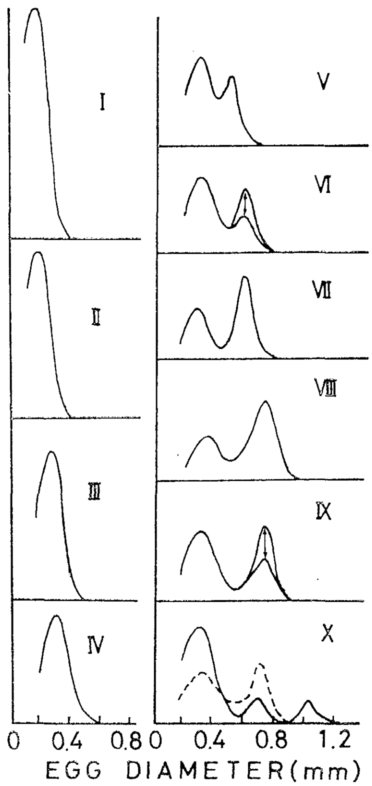

Fig. 6. Typical profiles in the egg size distributions. The arrows in the most advanced egg group in types VI and IX show the variation of heights. Also the dotted line in the X shows the alternative form which frequently appeared in ovaries containing hydrated eggs.

Spawning Period

The spawning period of common mackerels was estimated by the degree of ovarian development in the following manner. In the external maturity observations, if we assume that the spawning starts around the day when the proportion of the stage AB′ and the more advanced stages exceed 50% of all ovaries, the spawning began around March 9 in 1977, March 3 in 1978 and February 2 in 1979. If the appearance of hydrated eggs is taken in account as the practical spawning sign, it stated around March 2 in 1977, March 16 in 1978 and March 2 in 1979.

The analysis of egg size distribution profiles showed that the periods when the proportion of three or more peak type ovaries exceeded 50% of all in each sample were on April 18 in

Table 3. Composition of profiles of the egg diameter distribution in each sample

Sampling Date	Distribution Type								Total
	I-III	IV	V	VI	VII	VIII	IX	X	
1977									
Mar. 1	4	9	5	10	2				30
9	11	12	8	2	4				37
16		2	6	14	7	1	1	4	35
22	1	1	4	8	8	1	6		29
Apr. 4				10	9	4	1		24
12		1		8	8	13	1		31
18				8	9	7	10	6	40
28	1	3	4	15	5	9	6	3	46
May 10		1		8	13	15	2	2	41
18		1		13	27	1			42
Jun. 2				1	20			4	25
1978									
Mar. 7		3	11	3	4	2	1		24
16			2	7	6	11	1		27
25		2		11	13				26
Apr. 10			1	13	13				27
17		1	1	20	4				26
25				4	15				19
May 2				7	10			3	20
5		4	4	5			1	6	20
11		2	5	25	2				34
19		2	3	9				14	28
24		3	4	16	3			2	28
Jun. 7		1	2	11	3			2	19
1979									
Jan. 25	15	1							16
Feb. 1	15	6	1						22
6	11	21	6						38
14	6	16	11	2					35
22	3	6	12	11	2				34
Mar. 2		4	5	22	3	1			35
7			1	10	3		2	12	28
14				10	20				30
28				19	2	1	4	4	30
Apr. 20		1	3	15	6		1	5	31
26		1		10	2		1	5	19
May 7			3	35	3	1	5	3	50
16		1	3	20			2	2	28
Jun. 1			5	6	1			9	21

1977, March 16 in 1978 and March 2 in 1979. However, applying the date when the proportion of the IV type and the more advanced profiles rise above 50%, the spawning began on March 16 in 1977, March 16 in 1978 and March 2 in 1979.

Size at Maturity

To estimate the minimum sizes at the first maturity of common mackerel, the mean KG and its standard deviation were calculated for each fork length class (1 cm) below 36 cm and were shown in Tables 4–1 and 4–2.

In the samples of year 1977, most fish were more than 30 cm in fork length, but after March 16, individual fish of the 31 cm class had the high mean KG; 8.54±0.62 in April 4 and 6.11 ±0.72 in May 10. In the samples of the year 1978, by March 7 the mean KG exceeded 5.0 and a fish of the 28 cm class recorded 5.32. Also, a fish of the 29 cm class was 6.61. Individuals of 30 cm class continued to show high

Table 4-1. Mean KG for the different size groups of mackerel (1977-1978)*

Sampling date	Length Class (Fork Length in cm)							
	28-29	29-30	30-31	31-32	32-33	33-34	34-35	35-36
1977								
Mar. 1		0.95±1.06	2.80±1.37	3.53±1.08	3.53±1.31	2.77±0.89	3.02±0.87	3.03±1.82
9				5.49	3.61±2.04	4.75±2.30	2.26±0.82	2.60±0.96
16					8.12	5.45±0.41	7.43±2.90	4.77±1.69
22					3.52±0.16	7.02±1.12	3.66±0.85	5.88±2.19
Apr. 4				8.54±0.62	9.14±6.15		5.48±0.74	5.04±1.61
12					7.60±4.24	8.70±2.20	7.70±1.30	9.50±2.80
18				3.72	5.17±1.11	6.37±2.28	6.37±3.70	8.17±6.85
28					3.66±1.62	3.69±1.62	2.96±1.20	4.02±1.29
May 10				6.11±0.72	5.18±1.85	5.37±4.22	7.98±3.86	4.12±0.88
18						5.88	4.29±0.72	3.62±1.09
June 2							3.22±0.93	4.30±1.89
7								6.53±3.26
1978								
Mar. 7			7.70±0.87	9.81±2.40	4.26±1.55	4.02	5.15±1.43	7.57
16			4.88±1.63	4.91	6.12	4.74±2.05		6.02±2.00
25	5.23		7.28±2.60	6.42±0.96	6.28±1.85	7.38±1.47	5.51±1.47	5.13
Apr. 10						7.50		6.77±0.51
17								4.20±0.36
25				8.45			6.65±1.69	9.42
May 2						7.70±0.83	14.79	10.68
5						16.92±7.26	2.93±0.36	6.80±3.09
11				9.88	4.84±1.82	4.49±1.86	6.02±2.80	4.84±1.21
19		6.61			4.22±0.60		7.76±1.26	7.82±1.93
24					4.60		3.60±0.19	4.04±0.76
June 7				4.63			7.09	

* Figure without standard deviation means that only one individual belongs to the class.

Table 4-2. Mean KG for the different size groups of mackerel (1978-1979)*

Sampling date	Length Class (Fork Length in cm)							
	28-29	29-30	30-31	31-32	32-33	33-34	34-35	35-36
1978								
Nov. 16	0.67±0.09		0.61	0.77	0.75±0.06	0.57		
20					0.95±0.15		1.00	0.77
23	0.58±0.04	0.77±0.10	0.54	0.56±0.04				
1979								
Jan. 12				0.95±0.33	1.40	1.12±0.22		
25					1.59	1.36	1.72±0.29	1.29
26				1.41±0.27	0.99±0.08	1.80±0.76	1.92	2.03±0.71
29				1.69±0.53	1.76±0.56	1.82±0.14		1.67±0.63
Feb. 1		2.69	1.64±0.86	1.16±0.37	1.32±0.19	1.46±0.43	1.04±1.00	1.81±0.31
6		1.25	1.25±0.80	1.72±1.03	2.01±0.76	1.87±0.49		2.50±0.80
8			0.71	1.05±0.43				
14				4.03		4.13±1.07	2.92±1.19	3.14±1.03
22	8.50	2.87	3.77±2.16	6.62±3.84	4.38±2.21	4.14±0.70	4.41±3.14	2.82±0.94
Mar. 2		3.57	1.85	5.17±2.35	3.80±1.39	5.08±1.39	4.68±1.81	6.86±2.31
7				9.24		6.71±1.76	6.23±2.12	7.02±3.12
14						7.19±1.13	7.31±1.60	7.76±2.91
28		4.30	6.62±4.14	4.97±1.00	11.20±6.70	5.41±1.78	5.59±2.23	7.66±1.82
Apr. 19	2.90±0.64	4.76	1.29±0.02		4.11		9.66	5.19±3.78
20			5.24±2.02	5.74±0.92	7.07±3.71	4.30±1.47	4.72±1.59	7.32±1.63
26				6.43	4.80±1.83	13.81±5.68	8.42±2.75	4.38±0.59
May 7				5.04	3.79±0.88	5.61±1.98	4.13±1.13	4.85±1.88
16					3.79	3.92	4.45±1.49	4.21±0.62
21								8.14±5.18
June 1				5.85±2.11	3.59±0.62	5.96±3.22	3.28	5.54±1.50

* Figure without standard deviation means that only one individual belongs to the class.

values; 7.70±0.78 in March 7, 4.88±1.63 in March 16 and 7.28±2.60 in March 25. In the samples of the year 1979, the total mean KG exceeded 5.0 in February 22. At the same day, a fish of the 28 cm class recorded a high value 8.50, but it hovered around 2.90±0.64 on April 19. The value of fish of the 30 cm class were 3.77±2.16 in March 28 and 1.29±0.02 in April 20 and the 31 cm class recorded high values as much as the larger fish group.

From the results described above, we can conclude that most mackerels larger than 30 cm in fork length have the potential to mature and spawn in the spawning season. From the observation of egg size distribution many individual fish of the 28–30 cm class had yolked eggs (about 0.6 mm in diameter). This suggests that the greater part of these fish contribute to the spawning.

Discussion

In the course of seasonal change of external appearance composition, after the dominant point of B type ovaries, each ovary may pass through the C stage at least once. If this process proceeds quite rapidly, the fact that the ratio of the C stage ovaries were very low is explicable.

In the latter half of the spawning period the AB′ stage ovaries again increased markedly. The cause of this phenomenon was not clear because the AB′ stage ovary was sometimes difficult to distinguish from the E stage ovaries which did not show a reddish color. It is probable that some part of the E type ovaries must be sorted in error into the AB′ stage group and vice versa. If the common mackerel spawns more than once within a spawning season, we can estimate that the process E→AB′ and AB′→B→C→E or E→B and B→C→E occurs repeatedly. It is necessary to clarify the mechanism of the increase of the AB and AB′ type ovaries in the late spawning season and the relationship between the E and AB′ stage ovaries by other methods.

The process of the ovarian maturation of mackerel can be estimated roughly through the seasonal variation of the mean gonad weight or the mean KG. However the changes of these values are not simple and fluctuate greatly during the spawning season. This shows that the maturation and spawning process of mackerel is complicated.

By the result of egg developing speed analysis we can estimate the egg development as follows. A batch moves rapidly from the immature stage of less than 0.3 mm to the developing stage at about 0.6 mm accumulating yolk in each egg and stops there. Then the batch prepares for spawning increasing the number. The spawning occurs after the preparation is completed. Eggs hydrate at about 0.9 mm in diameter and are shed at 1.0–1.2 mm. The shallow trough at about 0.8–0.9 mm indicates the possibility that the sequence from the ripe eggs to their release via hydration occurs very quickly. Also, the height around 0.6 mm means that during the spawning season, yolked eggs usually exist there in preparation for final maturation and they are always ready to be shed as hydrated eggs when the environmental and physiological conditions are satisfied. This process characterizes the ovarian maturation of common mackerel.

As a criterion of the beginning of spawning the Tokai Regional Fisheries Research Laboratory and the related prefectural fisheries experimental stations have officially adopted the day when the mean KG exceeds 5. Following this criterion, the first spawning occurred on March 9 in 1977, March 7 in 1978 and March 2 in 1979 respectively. On the other hand, in the stratified KG composition if the day when ovaries of KG≧5 exceed 50% is adopted as a criterion, the spawning started on March 16 in 1977, March 7 in 1978 and March 2 in 1979.

Comparing the results mentioned above, there was little variation, but we could conclude that the spawning of common mackerels began around early or mid March for these three years in this spawning area. Generally the fishing of spring mackerel ceases at the time when the aggregation of spawning population gets relatively weak and begins to migrate to the north from the sea around the Izu islands. However, the mean value of KG were still in the high level and hydrated ovaries were also found in samples of June, so that the end of the spawning period was not clear.

By the examination of ovarian eggs it became clear that an ovary shows the polymodal phase in the frequency distribution of egg diameter; two or three peak types are dominant. The coexistence of different maturation stages pro-

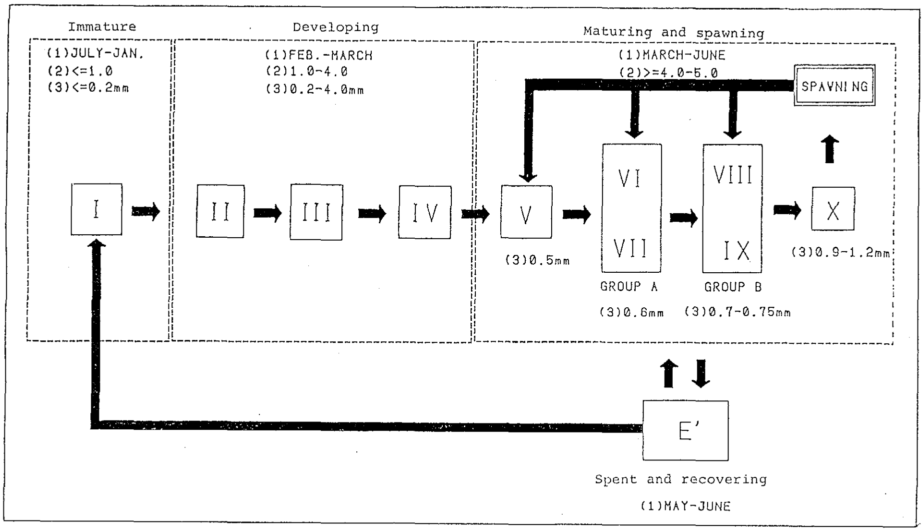

Fig. 7. Diagrammatic representation of the maturity development process in the Japanese common mackerel. (1) period of occurrence, (2) range of mean KG, (3) position of the most advanced peak appeared in the frequency distribution of egg diameter.

vides proof of multispawning. The overlapping of the KG range of mature ovaries with yolked eggs and riped ovaries with hydrated eggs give an another proof. Tateishi *et al.*[2] histologically proved the multispawning characteristics and there are similar works to support this.[1,3,21] It must be certain that mackerel spawns eggs more than once within a season. Within an ovary the development of eggs occurs as batches and a batch of eggs is released repeatedly after the egg size exceeds a given size (0.9–1.2 mm).

Following the view mentioned above, the maturation and spawning process can be summarized and shown schematically in Fig. 7. The development of ovaries is divided into four main stages which will be given below.

Immature Stage

In this stage, even a ovary of adult fish is very small and immature. The mean KG value is still less than 1.0. The profile of the frequency distribution of egg diameters is clasified into the I type and ovarian eggs are not visible by the naked eye. Most eggs are less than 0.2 mm. Those ovaries appear in feeding and wintering periods. In the case of the Pacific subpopulation of common mackerel, ovaries of this stage are found in fish caught from the east of Hokkaido and the Sanriku area (July through November)[22] and in the Boso and the Izu islands areas (November through January).[5]

Developing Stage

Ovaries begin to mature and prepare for spawning. The delopment of an ovary refers to the growth in size (e.g. weight, KG), the increment of egg diameter and the increase of the number of yolked eggs. The external observation shows that this stage is characterized with various types of ovaries, containing eggs from immature to fairly yolk accumulated. The main profile of egg diameter distribution changes; type II→III→IV. Also the mean KG increases step by step. The mean KG ranges from 1.0 to 4.0 and the most advanced peak of egg group locates at the range from 0.2 mm to 0.4 mm. Ovaries of this stage appears in the wintering and spawning seasons; from February to March in the sea around the Izu islands.

Maturing and Spawning Stage

This stage has the highest variety of ovary condition. The following processes occur repeatedly.

(1) Completeness of eggs in quality and quantity as a mature ovary.

(2) Hydration and spawning of eggs.

(3) Recovery and replenishment of yolked eggs.

(4) Respawning.

Externally, we can observe that ovaries of this stage contain from moderately yolked eggs to the full yolked ones. The mean KG ranges widely from 4.0–5.0 up to 20.0 or more. The distribution profiles of egg diameter are type V, VI, VII, VIII, IX and X. As the type VI and VII are similar in the position of the most advanced peak, as well as the type VIII and IX, the former is rearranged in the Group A and the latter the Group B respectively. The profile changes; type V→Group A (type VI and VII)→group B (type VIII and IX)→X. Conjecturing from the shape of the profile, it is probable that in the Group A the type VI may change into the type VII, the type IX into the type VIII in the Group B. Also both the type VI and VII may be converted into the type IX or VIII progressively. After an ovary reaches the type X stage and attains spawning, it may return to the type V, the Group A or the Group B and there prepare for the next spawning. Although this route in repeating the spawning cycle is not clear here, the conversion among profiles or groups with dynamic feature of the number of yolked eggs must be studied in detail.

The mean KG are widely overlapping among profiles. The position of the most advanced peak locates at around 0.5 mm in the type V, 0.6 mm in the Group A, 0.7–0.75 mm in the Group B and 0.9–1.2 mm in the type X. Ovaries of this stage appear only in the spawning season; March through June in the sea of Tokai Region. The process of multispawning or the transition between the profile types requires further study.

Spent and Recovering Stage

Spent ovaries were not shown in the profiles, because they could not identified by the figures of egg diameter distribution. Therefore, in Fig. 7 we add the end stage which mainly comprises of spent ovaries. This stage appears in May through June and overlaps seasonally with the maturing and spawning stage. As spent ovaries are quite similar to the type V, VI and VII ovaries for the distribution profile of egg diameter, it can be imagined that in practice, a portion of the spent ovaries recovers and spawns again. Generally spent ovaries do not contribute to the spawning in the same spawning season, but in this study we used a definition of spent ovaries as ovaries which contain both completely exhausted ovaries and still recovering ones.

As for the multispawning process, it is necessary to study the ovaries histologically in detail. When the mechanism of ovarian maturation and spawning are made clear by histological studies, the EPM (Egg Production Method)[23] could be applied to this species, and the stock abundance estimation of the Japanese common mackerel would be accomplished.

Itoh[24] reported that a mackerel sampled from the Sea of Japan subpopulation which was 27.5 cm had a ripe ovary. Enami[15] described that mackerels of the Tsushima Current mature at about 25.5 cm. For the Pacific subpopulation Usami[25] studied the relationship between the fork length and the KG and estimated that reproduction starts at two years of age or more: two year old fish range approximately from 28 to 33 cm. With a similar method, Watanabe[17] determined the minimum female size at the first maturity to be 29 cm long. In this study, the smallest fish for which ovary was measured was of the 28 cm class. The majority of mackerels which were fished by the gears mentioned above in the spring spawning period were 30 cm or larger. Therefore the ratio of immature fish to all fish used in this study does not seem to be so high.

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References

1) Y. Takemura: *Bull. Tokai Reg. Fish. Res. Lab.*, **15**, 29–37 (1957).
2) S. Tateishi, Y. Koh, and K. Mizue: Suisangaku Shusei, Tokyo Univ. Press, Tokyo, 1957, pp. 797–802.
3) S. Tateishi: Rep. Tsushima Curr. Expr. Res., **4**, Fish. Agency, Tokyo, 1958, pp. 50–52.
4) S. Enami: Rep. Tsushima Curr. Expr. Res., **4**, Fish. Agency, Tokyo, 1958, pp. 39–50.
5) S. Usami: *Bull. Tokai Reg. Fish. Res. Lab.*, **47**, 85–100 (1966).

6) T. Sawada and M. Makita: *Bull. Shizuoka Pref. Exp. Stat.*, **5**, 31–36 (1972).
7) S. Usami: *Bull. Japan. Soc. Fish. Oceanogr.*, **6**, 112–122 (1965).
8) K. Asano and S. Tanaka: *Bull. Fac. Fish., Mie Univ.*, **11**, 135–140 (1984).
9) K. Asano and S. Tanaka: *Bull. Fac. Fish., Mie Univ.*, **12**, 14–27 (1985).
10) G. A. Steven: *J. Mar. Biol. Assoc. U.K.*, **30**, 549–568 (1952).
11) E. H. Knaggs and R. H. Parrish: *Calif. Fish Game*, **59**(2), 114–120 (1973).
12) W. W. Morse: *Fish. Bull., U.S.*, **78**, 103–108 (1980).
13) I. Kubo and T. Yoshihara: Suisan Shigengaku, Kyoritsu Syuppan, Tokyo, 1969, pp. 135–139.
14) G. P. Farran: *J. Cons perm. int. Explor. Mer*, **13**, 91–100 (1938).
15) I. Amemiya and O. Tamura: *Suisan Gakkai Ho*, **9**, 65–80 (1944).
16) R. Ishida and M. Kitakata: *Bull. Tokai Reg. Fish. Res. Lab.*, **107**, 61–105 (1982).
17) T. Watanabe: *Bull. Tokai Reg. Fish. Res. Lab.*, **62**, 1–283 (1970).
18) H. Yasuhara, M. Makita, Y. Nakamura, F. Muranaka, H. Suzuki, and F. Itoh: Kantoh Kinkai no Masaba, Pref. Exp. Stations (Tokyo, Kanagawa, Chiba and Shizuoka), 1977, pp. 31–33.
19) Y. Nakamura, R. Watase, M. Makita, H. Suzuki, M. Koizumi, and H. Yasuhara: Kantoh Kinkai no Masaba, Pref. Exp. Stations (Tokyo, Kanagawa, Chiba and Shizuoka), 1978, pp. 31–42.
20) H. Suzuki, M. Koizumi, H. Yasuhara, Y. Nakamura, and F. Tsukui: Kantoh Kinkai no Masaba, Pref. Exp. Stations (Tokyo, Kanagawa, Chiba anp Shizuoka), 1979, pp. 30–45.
21) R. Leong: *Fish. Bull., U.S.*, **75**(1), 205–211 (1977).
22) Y. Sato, K. Iizuka, and K. Kotaki: *Bull. Tohoku Reg. Fish. Res. Lab.*, **28**, 1–50 (1968).
23) R. Lasker: in "An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy, *Engraulis mordax*" (ed. by R. Lasker), NOAA Tech. Rep. NMFS, 36, U.S. Department of Commerce, Springfield, Virginia, USA, 1985, pp. 1–3.
24) T. Itoh: Paper Presented to the 1st Symposium on the Tsushima Curr. Expr. Res., Fish. Agency, Tokyo, 1954, pp. 146–156.
25) S. Usami: Suisan Kenkyu Sosho, Jap. Fish. Res. Cons. Assoc., **18**, Tokyo, 1968, pp. 1–114.

Nippon Suisan Gakkaishi : Formerly *Bull. Japan. Soc. Sci. Fish.*