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Life History of Migigarei, *Dexistes rikuzenius* (Jordan et Starks), in Sendai Bay, with Special Reference to Sexual Dimorphism

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Summary

Migigarei are caught by the small trawlers in the 100–300 meters deep area and the catches are especially abundant in the area 135–150 meters deep. The asymptotic body length of Bertalanffy's growth equation is from 16.4 to 18.4 cm in the male and 22.3–25.3 cm in the female. The maximum age is 9 years in the male and 13 years in the female among all the fish sampled. The maximum GSI is about 2 per cent in the male and 30 per cent in the female. The spawning period is from late October to late January, with its peak in November to December. A female spawns several times in one spawning season. The regression of fecundity (F) on body length (BL) in cm is shown as $F=4.819BL^{3.618}$. The biological minimum size is 11.5 to 12.5 cm in the male and 13.5 to 15.0 cm in the female. Two years old individuals of both sexes that grow fast participate in spawning. The age when all the individuals spawn is 3 years in the male and 4 years in the female. *Ophiura* and polichaete are the major food of migigarei. In mature female annual change is observed in ovary-free body weight, liver weight, food intake, GSI and incidence of individuals with translucent zone at the periphery of otolith.

The marked feature in the life history of migigarei is the conspicuous sexual dimorphism. In the case of females, the average length at a given age, maximum length, longevity, age at first maturing and GSI have considerably higher values than those of males. Sexual differences are observed more or less in the littoral or demersal species, whereas in the fishes migrating in the surface or subsurface layers the difference in development or growth between sexes are small. The sexual differences are recognized as a strategy of littoral or demersal fishes to increase the egg number by means of allocating more resources to the female. Migigarei exhibit especially marked sexual differences among heterosomes. Migigarei feed on *Ophiura* of low caloric value and inhabit an especially adverse and poor environment. In these conditions it is supposed that the migigarei have selected a survival strategy to maximize the intersexual differences.

Migigarei, one of the heterosomes, has been known to inhabit only Japanese coast and be abundant along the northern Pacific coast of Japan. Previous to the present paper, three reports on the life history of the migigarei inhabiting the northern Pacific coast of Japan were published. Migigarei was reported to inhabit the coastal area from Tomakomai to Onahama and to be abundant off Hachinohe to Miyako (1, 2). The age and growth of migigarei off Hachinohe was reported by Ishito (3), but the life history of migigarei has been insufficiently investigated. The purpose of fish population studies is how to explain the fluctuation in number. Kawasaki (4), one of the authors, suggested the points at issue between the natural fluctuation theory and the man-made fluctuation theory and maintained that the fluctuation in population number should be understood as an adaptative strategy depending on the life history selected through the process of evolution and proposed two types of modes of fluctuation in number, applying the concept of r- and k- slection by MacArthur and Willson (5) to the marine teleosts. Moreover, he (6) proposed three extremes of population number fluctuations shown as the three-type triangle and stated that any marine teleost exists somewhere inside this triangle.

The life history means the concrete modes of life of a species or a subpopulation such as reproduction, growth, feeding habit and distribution. A species or a subpopulation is a reproductive unit in which reproduction is independent from other species or subpopulations, and the modes of the flucutation in population are different by species. Thus it is natural to think that the mechanism of the fluctuation in number is closely related to the life history, and the differences in the mode of the fluctuation in number are explained by the differences in the life history. The purpose of the life history study may be to know the function of each item of the life historical features and to know how the differences in the life history among species connect with the differences in the mode of fluctuation.

Migigarei, a species of heterosomes, is supposed to have the features of and functions as a heterosome in its life history. Practically it is impossible to know the features and functions of migigarei's life history unless they are compared with those of other species. The main purpose of this study is to find the life historical features and functions of migigarei by means of the comparative ecology.

Materials and Methods

The samples came from the commercial catches by small trawlers, collected once or twice a month from June 1977 to November 1978 at Haragama and Ishinomaki Fish Markets. Data were not available during July and August because of the closed season. About fifty to one hundred and fifty fish were sampled at a time and the following items, i.e., body length, body weight, gonad weight, liver weight and weight of digestive tract with its contents were measured. The contents of the digestive tract were examined for about twenty to thirty fish monthly. The body length of all fish taken by the small trawlers was measured three to five times a month. The otoliths at the blind side were used for age determination. The otoliths are flat and elliptic and their total radius and annual ring radii were measured toward the thin side along the major axis. The ovaries kept in formalin for 1-6 months were used for the study of the number and size of the oocytes. A piece of the blind side ovary sliced across the center was weighed and pushed with the fingers into separate oocytes. Four subsamples of the oocytes were taken with a 1 ml Stempel pipette and the number of oocytes in each subsample was counted to be averaged. The number of all oocytes in a blind side ovary were estimated by multiplying the mean oocyte number in a subsample by weight ratio of ovary to subsample. The oocyte diameter was measured in the fixed direction on a slide glass using a light microscope.

Results

Distribution

From Fig. 1 migigarei are supposed to inhabit the zone between 100 and 300 meters deep and are abundant 135 to 150 meters deep.

Growth

The incidence of individuals with a translucent zone at the periphery of the thin side of the blind side otoliths was examined all the year round. Over half of the fish had the opaque zone from May to September in male and from February to September in female, whereas over half of the fish had the translucent zone from October to April in male and from October to January in female. Thus a pair of translucent and opaque zones may be formed once a year in both sexes.

The relation between the body length (BL) in cm and the radius of otolith (R) in mm is linear in both sexes.

Male; $BL=7.692R-2.731$ $r=0.982$

range of body length in cm; 7.5 to 18.5

Female; $BL=7.194R-1.899$ $r=0.980$

range of body length in cm; 7.5 to 25.0

The distance from the focus to the inner margin of the translucent zones was measured as the annulus length. The negative intercepts of the above formulas mean that the lengthless fish has the otolith, (2.731/7.692) mm long in male and that of (1.899/7.194) mm long in female. This unreality suggests that only the length back-calculated over 7.5 cm is significant since we have no sample under 7.5 cm where the different relation between otolith and length must exist. Accordingly, the calculated length at the first annulus formation under 7.5 cm were excluded in calculating the Bertalanffy's growth parameters. The body length at the annulus formation (Method A) is shown in Table 1.

To obtain Bertalanffy's growth parameters, Walford's finite difference method was used for each year class by sex (Fig. 2). Each regression was determined by the method of least squares from the plots execpt two, L_0, L_1 and L_1, L_2 to exlude L_1 below 7.5 cm. In Fig. 2, the departure of L_0, L_1 plot from the line was observed

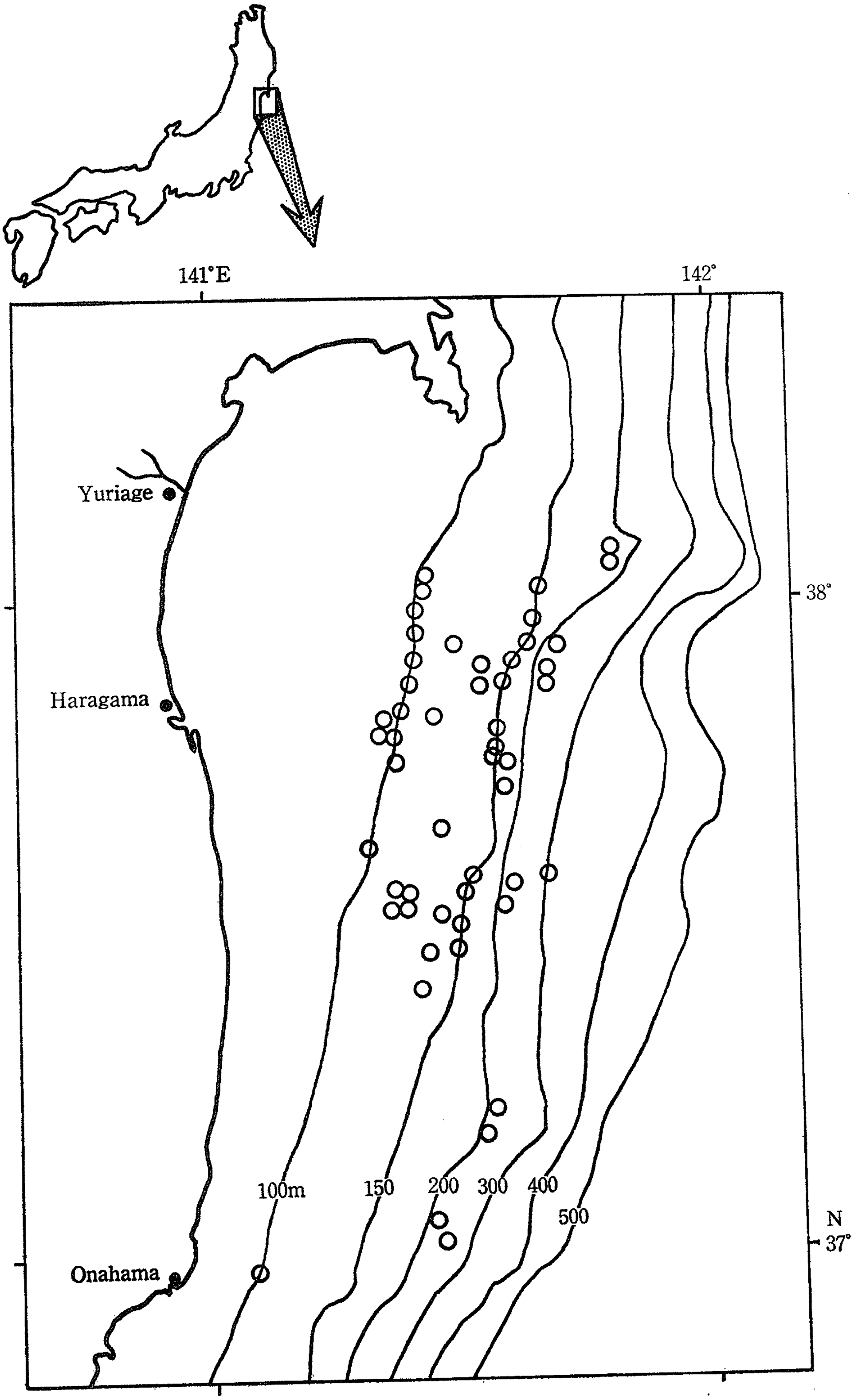

Fig. 1. Showing the localities where the catch records of *Dexistes rikuzenius* were obtained.

Table 1. *Body Length When the Annual Ring Is Formed. L_1 Means the Length at the First Ring Formation, etc.*

♂

Year class	Age	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8		
1975	2	6.1	12.1								
1974	3	5.0	10.9	13.9							
1973	4	4.8	9.9	13.0	14.6						
1972	5	4.3	9.3	12.5	14.4	15.6					
1971	6	5.0	9.8	12.2	13.8	15.1	15.9				
1970	7	4.5	8.7	11.9	13.6	14.9	15.9	16.8			
1969	8	4.6	9.5	12.2	13.6	15.0	15.9	16.8	17.3		

♀

Year class	Age	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
1975	2	7.5	14.1								
1974	3	6.5	13.0	16.5							
1973	4	5.1	11.1	15.0	17.6						
1972	5	4.8	10.4	14.2	16.8	18.6					
1971	6	6.4	11.5	15.0	17.1	18.7	20.0				
1970	7	5.0	10.2	14.2	16.2	18.0	19.6	20.6			
1969	8	4.7	10.1	14.2	16.7	18.3	19.8	21.1	22.2		
1967	10	4.6	10.0	14.0	16.4	18.5	20.2	21.4	22.4	23.3	23.8

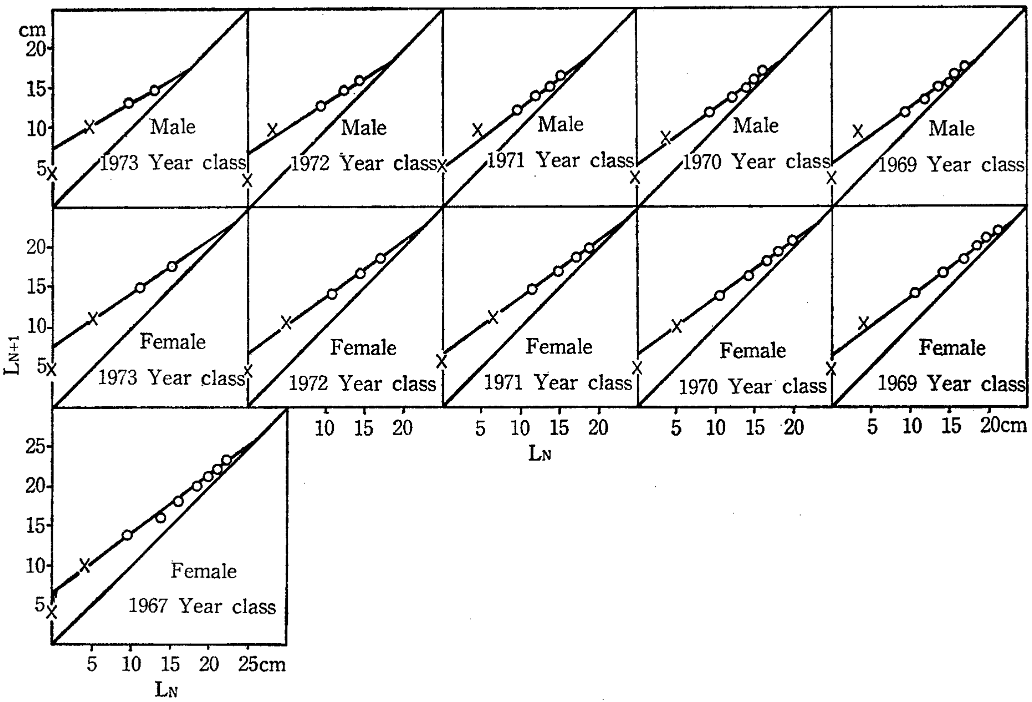

Fig. 2. Walford plots for each year class and each sex group.

TABLE 2. *Comparisons among the Values of Body Length Calculated by the Three Different Methods.*

Male		L_3 of the 1974 year class	L_4 of the 1973 year class	L_5 of the 1972 year class
Method A		13.9	14.6	15.6
Method B			15.2	16.0
Method C	Oct. 28	14.1	14.7	15.6
	Nov. 4	14.2	14.7	15.4
	Nov. 25	14.1	14.6	15.5

Female		L_3 of the 1974 year class	L_4 of the 1973 year class	L_5 of the 1972 year class
Method A		16.5	17.6	18.6
Method B		17.4*	18.4	19.1
Method C	Oct. 28	16.2	17.9	18.3
	Nov. 4	15.9	18.2	18.5
	Nov. 25	15.9	18.2	18.5

* In case of female of the 1974 year class, the body length at the first ring formation is 6.5 cm close to 7.5 cm over which the relation between body length and otolith radius is clearly observed. Thus the L_3 of the 1974 year class is calculated by means of method B.

except for the male of the 1971 year class. This departure has often been explained as the result of the time lag between spawning and annual ring formation. This time lag suggests that the first ring may be formed within less than one year after birth, explaining the departure of L_0, L_1 plot from the line. Thus the intersection between the ordinate and the line are able to be regarded as the length at one full year after birth (Method B). In the case of migigarei, the translucent zone of the otolith is formed from September to November, i.e., in the spawning season. So, a time lag between spawning and annual ring formation does not exist. The results of the length calculation by three different methods are shown in Table 2, resulting in the significant difference between that by method B and that by method C*. This means that each annual ring is formed every full year.

In Table 3, the Bertalanffy's growth parameters are shown. Asymptotic length was calculated for male of 16.4 to 18.4 cm and for female of 22.3 to 25.3 cm. In Fig. 3, the growth curves for the 1970 year class are shown.

Relation Between Body Length and Sex Ratio

In Fig. 4, we can see that whereas the sex ratio of migigarei below 12.5 cm in body length was around 0.5, most fish between 12.5 and 16.5 cm were males,

*; Average body length of each year class in spawning period, calculated from the length measurements at Haragama Fish Market using sex ratio-length and age-length keys.

TABLE 3. *Bertalanffy's Growth Parameters by Year Classes and by Sexes.*

$$L_t = L_\infty(1-e^{-K(t-t_0)})$$

Male

Year class	Age	L_∞	K	t_0
1973	4	16.4	0.648	0.578
1972	5	17.4	0.508	0.519
1971	6	18.1	0.331	−0.376
1970	7	18.0	0.393	0.385
1969	8	18.4	0.327	−0.287

Female

Year class	Age	L_∞	K	t_0
1973	4	22.3	0.435	0.424
1972	5	22.4	0.378	0.333
1971	6	22.8	0.348	−0.008
1970	7	22.7	0.347	0.285
1969	8	24.2	0.315	0.347
1967	10	25.3	0.281	0.232

followed by the increase in female up to 18.5 cm, over which no male was found. The maximum length was 18.5 and 27.1 cm in male and female, respectively.

Body Length Composition for Each Year Class

The length measurements on Oct. 28, 1977 and Apr. 27, 1978 were separated into sexes and year classes, using the sex ratio-length and age-length keys as seen in Table 4, showing that three to four year classes are overlapping in females. The fact that most fish between 12.5 and 16.5 cm in length were males is due to the difference in growth pattern between sexes. Since the length range of 12.5 to 16.5 cm is close to the asymptotic length for males, its growth rate was lessened around this length and several year classes gathered to this range in male and the males were more abundant than females which had rapidly passed this body length range.

Reproduction

Seasonal Change in GSI and Spawning Period

Seasonal change in GSI (GSI=100×Gonad Weight/Whole Body Weight) of males over 13 cm in body length and females between 17 and 22 cm is shown in Figs. 5 and 6. From the seasonal change in GSI of female and difference in the external appearance of gonads, the spawning period is estimated to be from late October to late January with its peak in November to December. In male, GSI begins to rise in March to reach the maximum in May, keeping this state until September. In female, GSI begins to rise in May to reach the maximum in October. The maximum GSI is about 2 per cent and 30 per cent in male and female, respectively.

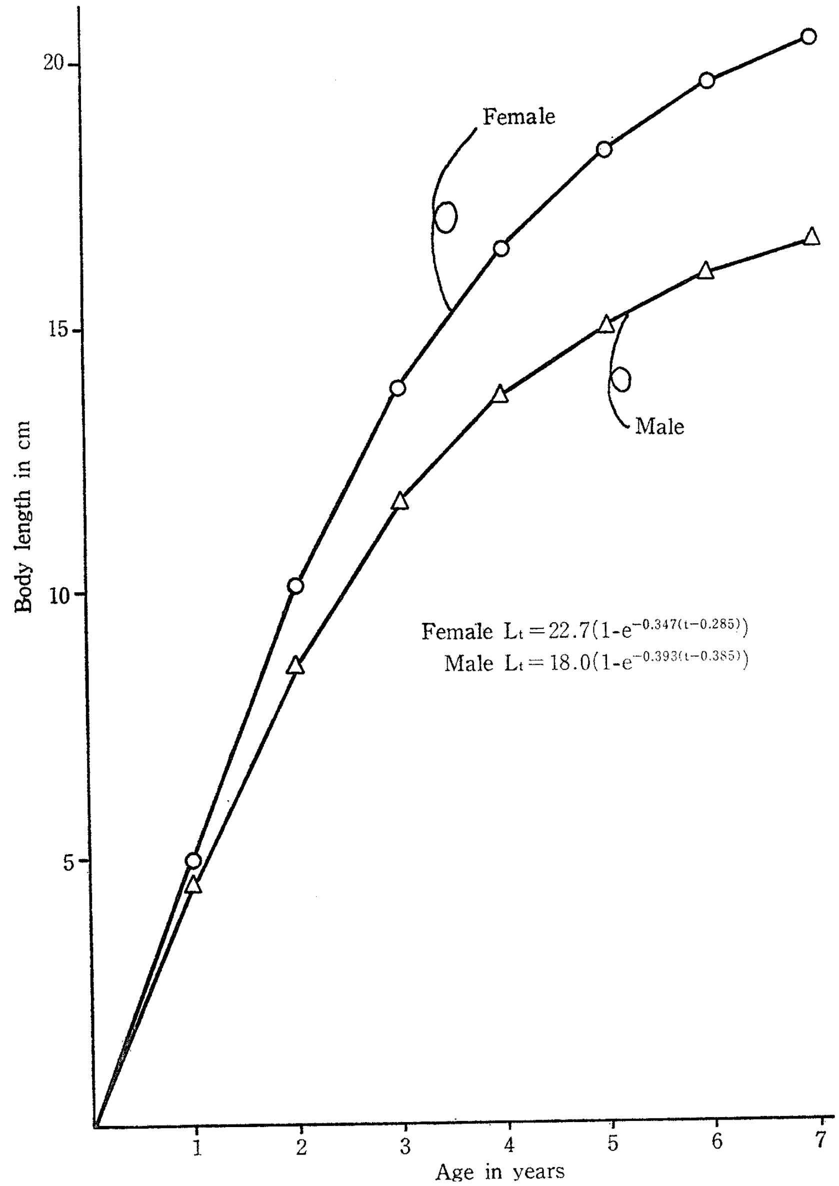

FIG. 3. Growth curves of the 1970 year class by sexes.

Mode of Spawning

Four ovary types are discriminated in the spawning season. Type A; ovary wall is stretched and traslucent oocytes are not observed. Type A′; ovary wall is stretched and translucent oocytes are observed. Type B; ovary wall is loose and translucent oocytes are observed. Type C; visible oocytes are not observed. To designate the spawning type, the oocyte diameter distributions were examined for four types of ovaries which differed from each other in external appearance. Firstly, the differences in oocyte diameter distribution were examined within an ovary as well as between the ovaries of both sides, not resulting in the detection of any differences. A piece of ovary was removed from the center of the blind side

TABLE 4. *Body Length Frequencies by Year Classes and by Sexes.*

Year class	Age	Sex	8.0–	8.5–	9.0–	9.5–	10.0–	10.5–	11.0–	11.5–	12.0–	12.5–	13.0–	13.5–	14.0–	14.5–	15.0–	15.5–	16.0–	16.5–	17.0–	17.5–	18.0–	18.5–	19.0–	19.5–	20.0–	20.5–21
			Body length in cm																									
1975	1	♂											3	1	1													
1974	2	♂											2	7	3	5	2											
1973	3	♂										1	5	9	14	20	9	11	4	3								
1972	4	♂														2	2	5	2	3								
1971	5	♂														1	1	2		3	2							
1970	6	♂															2	3	6	3								
1969	7	♂															2				2							
OCT. 28, 1977																												
1975	1	♀																										
1974	2	♀														1	1	3	1	2		1						
1973	3	♀																	3	10	17	15	8	6	11		5	
1972	4	♀																		2		1	4	2	2	2		
1971	5	♀																						1				
1970	6	♀																						1		4		1
1969	7	♀																								1		
1976	1	♂	2	1	6	13	31	30	12	3																		
1975	2	♂								1	3	5	15	11	7	2												
1974	3	♂												9	13	13	12											
1973	4	♂													11	18	16	14	13	2								
1972	5	♂														2	7	7		4								
1971	6	♂															2											
1970	7	♂																5			4							
APR. 27, 1978																												
1976	1	♀	4	1	4	12	21	19	13	7	3	1																
1975	2	♀													3	2		4				2						
1973	3	♀															3		7	15	21	13	7	6	3			
1972	4	♀																	2	5	2	16	23	28	27	14	9	1
1971	5	♀																								4		
1970	6	♀																										
1969	7	♀																										

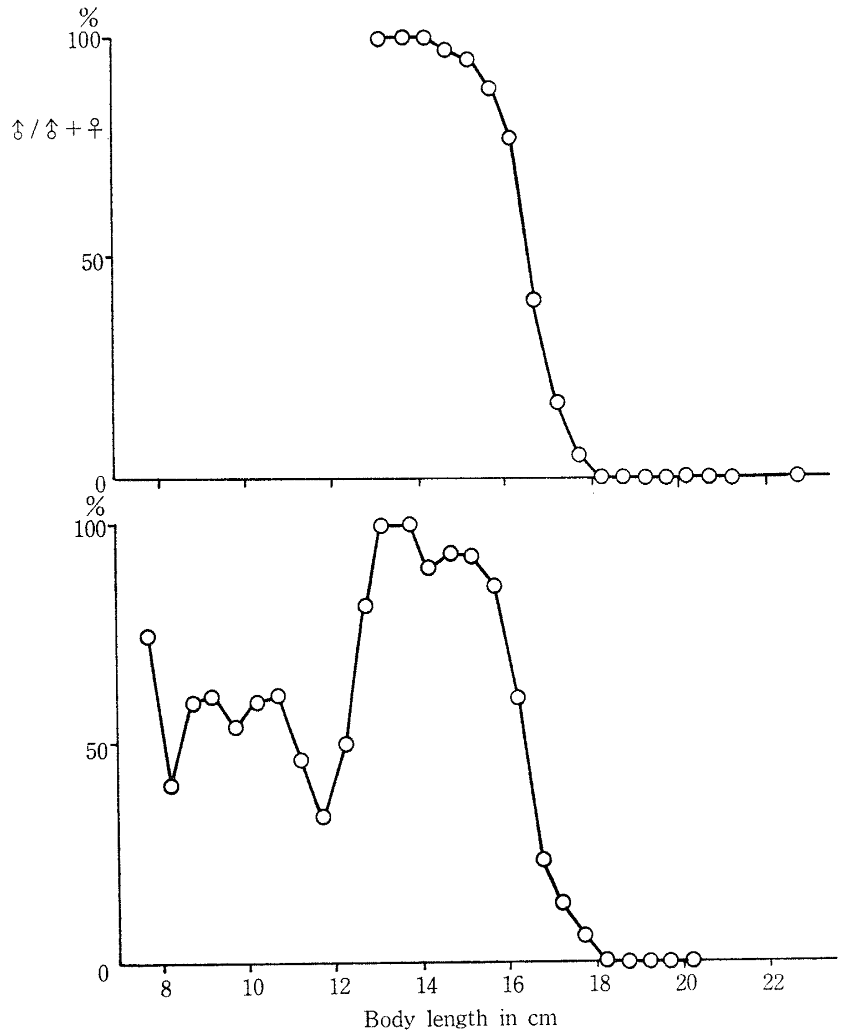

FIG. 4. Changes in sex ratio by length.
Top; Sample taken on Oct. 10, 1977. Bottom; Sample taken on Apr. 27, 1978.

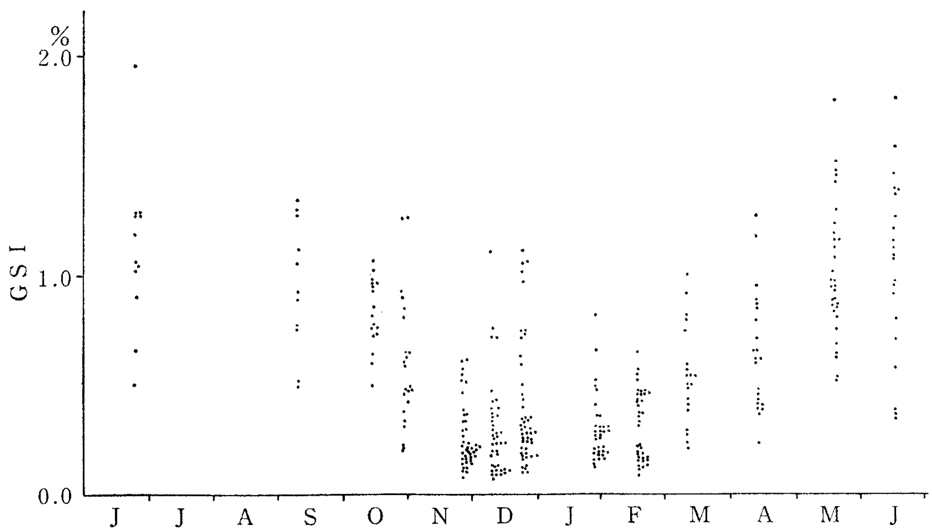

FIG. 5. Seasonal change in GSI of the males over 13 cm.

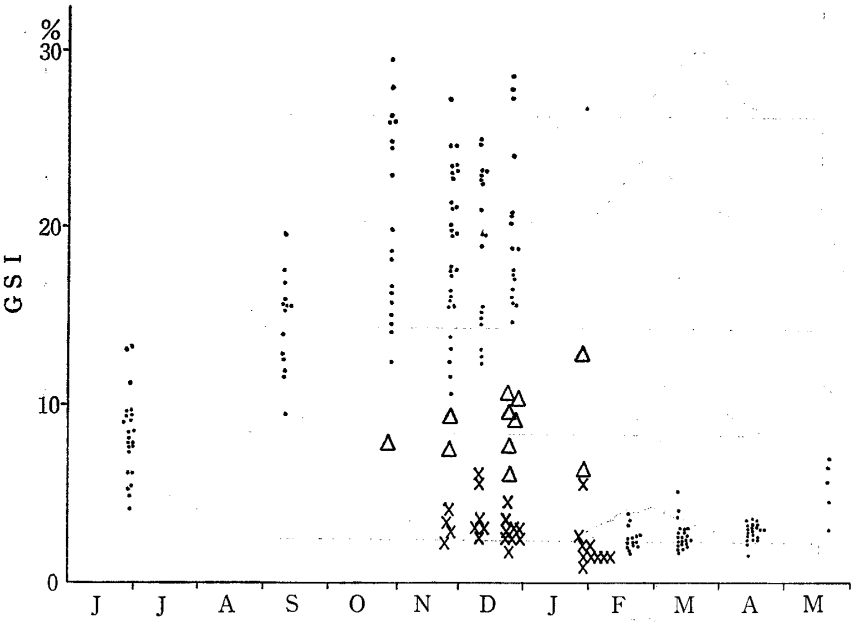

FIG. 6. Seasonal change in GSI of the females of 17–22 cm.
●; Ovary wall is stretched. △; Ovary wall is loose and translucent oocytes are observed.
×; Visible oocytes are not observed.

to obtain oocyte diameter distributions. As shown in Fig. 7, the oocytes in type A are distributed in a narrow range and their modes are from 0.65 to 0.75 mm. Most oocytes in type A′ ovary are distributed in a narrow range, having their mode at 0.65 mm, and a few translucent oocytes are distributed between 1.1 and 1.2 mm. Oocytes in type B ovary are distributed in a wider range than those above and this trend is more conspicuous in the type C ovary. The aggregation of translucent oocytes along the ovarian cavity was observed both in the blind side and the eyed side ovaries of 23.1 cm fish caught on Oct. 28, 1977 (Fig. 8), which was one of the only two ovaries at this maturity stage, suggesting that a female spawns several times in one spawning season. Namely, when the oocytes have grown to 0.65 or 0.75 mm in diameter (Fig. 8, A), a small part of the oocytes grow homogeneously in an ovary to the translucent oocytes, 1.1 or 1.2 mm in diameter (Fig. 8, A′), which ovulates in the oviduct (Fig. 9) to be spawned, and the same processes may be repeated several times.

The maturity stage of ovaries on both sides are identical as a rule, showing no difference in the maturation process.

The fish in the spawning season were caught off Ukedo to Haragama, 100–150 meters deep.

The regression of the fecundity (F) on the body length (BL) is $F=4.819BL^{3.619}$ and $r=0.920$ in the length range of 15.2 to 23.6 cm (Fig. 9).

Biological Minimum Size

In Fig. 10 the relation between GSI of female and body length is shown.

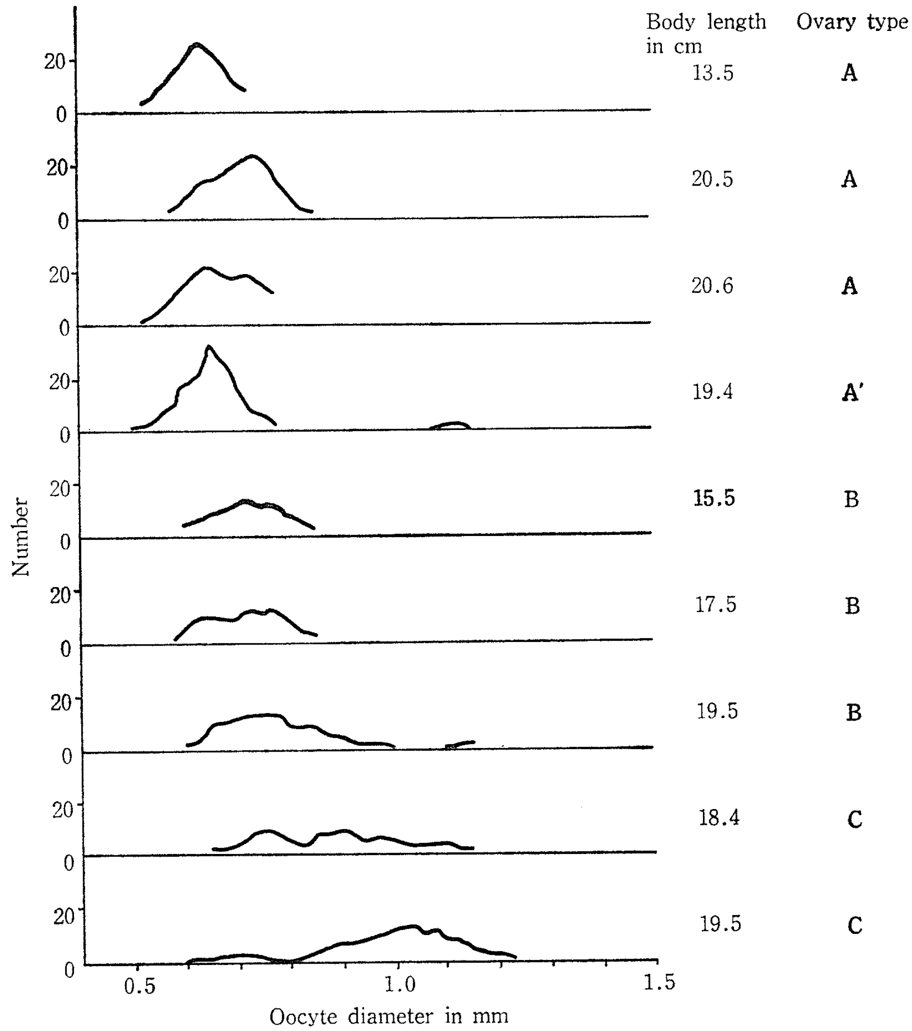

FIG. 7. Oocyte diameter distributions in progressing order.

Between 13.5 and 15.0 cm two groups of GSI are observed, i.e., one is from 7 to 15 and another from 0.5 to 1.0. Since the spent ovary was found for a 14.1 cm fish, the former group is supposed to take part in spawning, showing that the biological minimum size of the female is from 13.5 to 15.0 cm. The biological minimum size of male may be 11.5 to 12.5 cm using the criterion that the white testis is in full maturity.

Age at First Spawning and Longevity

Two-year olds beyond the biological minimum size were observed both in male and female in the spawning period in 1977 and 1978. A two years old female was observed having ovaries to have spawned at least once. Thus, fast-growing two-year olds may participate in spawning in both sexes. Judging from the relation between the biological minimum size and age, all the males and females may spawn at three and four years, respectively. The oldest fish taken were 9 years old in male and 13 years in female.

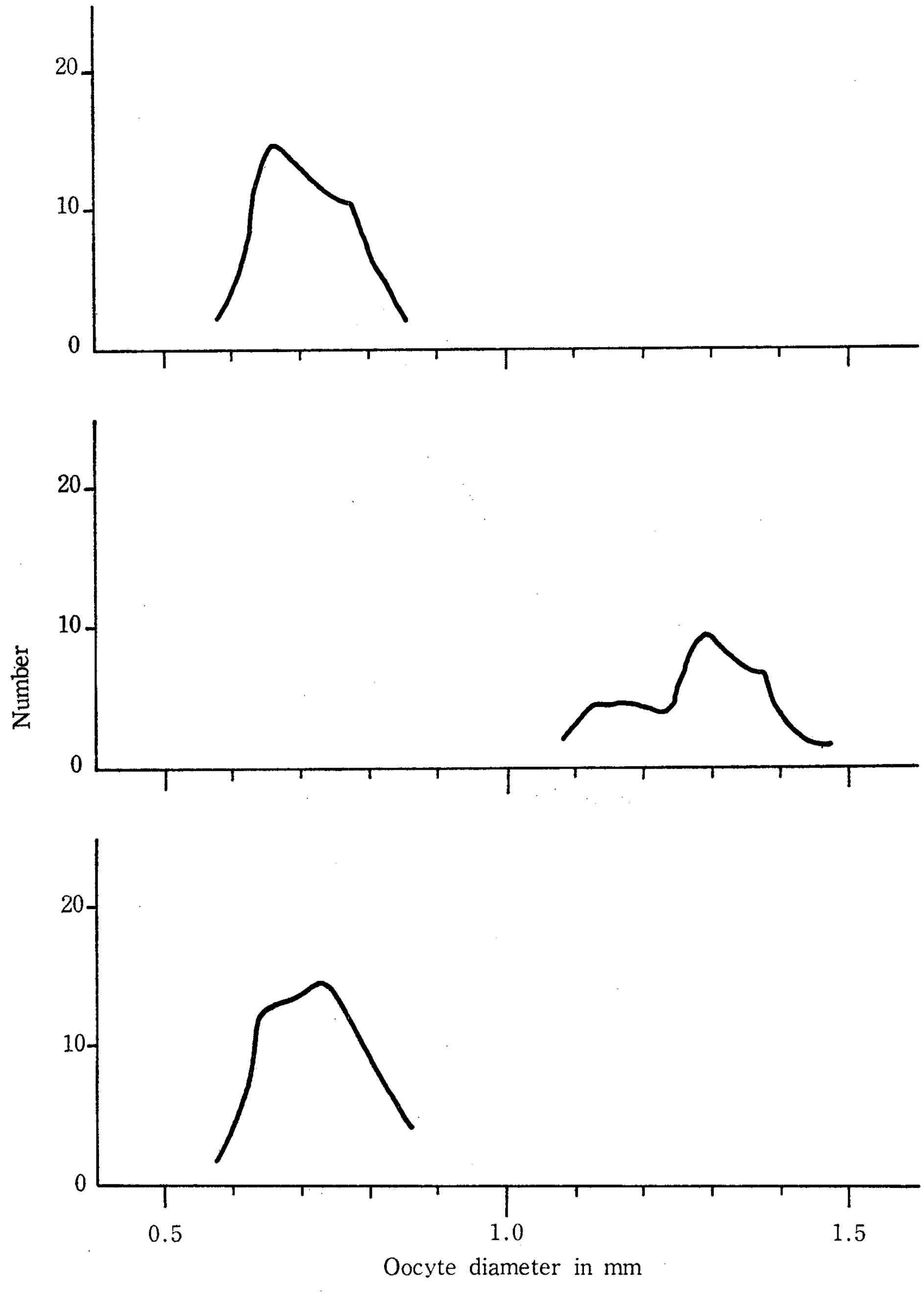

FIG. 8. Oocyte diameter distribution of a ripe female, 23 cm long.
Top; Oocytes taken from the dorsal side of the central part.
Middle; Oocytes taken from the center of the central part.
Bottom; Oocytes taken from the ventral side of the central part.

Feeding Habit

The contents of the stomach and the anterior one third of the intestine of the males of 12–18 cm and the females of 14–24 cm in body length were examined. As seen in Fig. 11 polychaetes and *Ophiura* are the major food for both sexes, followed by the occasional occurrence of small clams, showing that migigarei mainly feeds on the infauna and epifauna (7, 8).

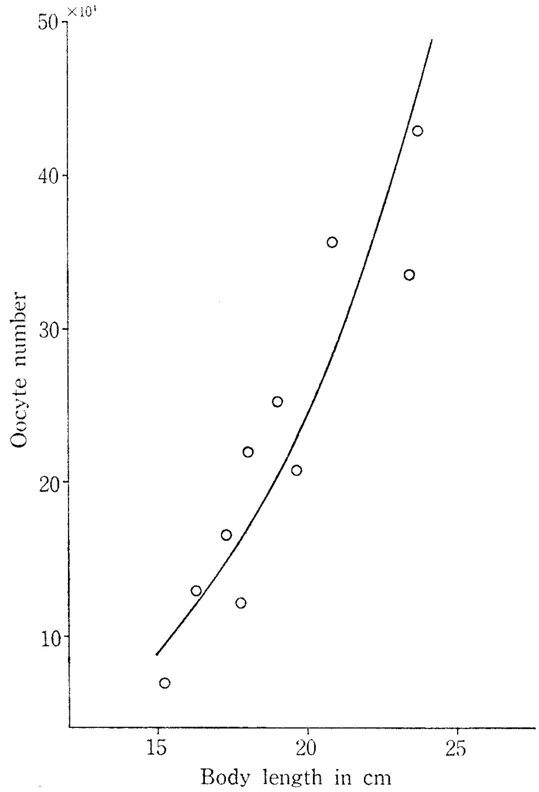

Fig. 9. **Regression of fecundity on body length.**

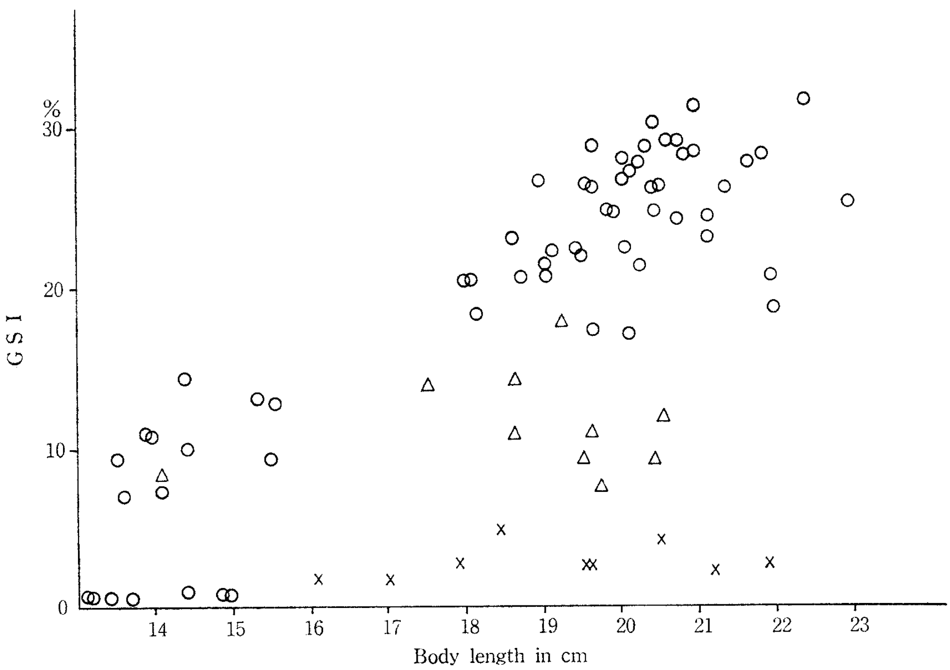

Fig. 10. **Relation between GSI and body length for female in the spawning season in 1978. ○; Ovary wall is stretched. △; Ovary wall is loose and translucent oocytes are observed. ×; Visible oocytes are not observed.**

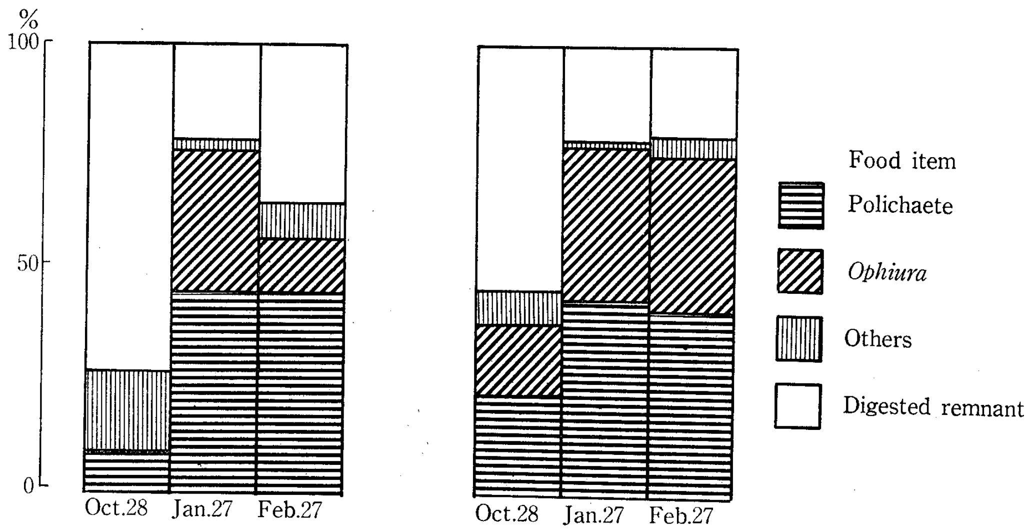

FIG. 11. Proportions of food items in weight from the stomach and the anterior one third of the intestine. Left; Male, Right; Female.

Seasonal Change in Food Intake and Liver Weight

Seasonal change in average liver weight and food intake for 1 cm interval in body length is shown in Fig. 12. Food intake is defined here as the weight of digestive tract with its contents. In the spawning season, both the food intake and the liver weight are minimal and food intake after spawning is much greater than that before spawning for females, whereas the change in these values is small for males.

Seasonal Change in the Body Weight for the Given Body Length

Weight without gonad and digestive tract for the fixed length considerably changes seasonally in female as compared with that in male as seen in Fig. 13, showing the yearly cycle with its peak and bottom in April-June and November-December, feeding and spawning seasons, respectively, for female.

Annual Cycle of Life in Female

In Fig. 14, the seasonal change in ovary-free weight of the fish, 21 cm long, weight of digestive tract with its contents, i.e., food intake of the fish 20 to 21 cm long, weight of liver, GSI of the fish, 17 to 22 cm long and the incidence of the fish with translucent zone at their otoliths' periphery, are shown. Since the width of the translucent zones is much narrower than that of the opaque zones, it seems natural to think that the period of the opaque zone formation is the growing period and the rate is slow in the spawning period when the body weight, liver weight and food intake are the lowest as well. Since the somatic weight recovers in April and GSI does not change from February to April, the food intake in this period seems to be allocated to the somatic tissues, i.e., muscle and liver.

In the maturing period of gonad in teleost, by the action of female sex hormone,

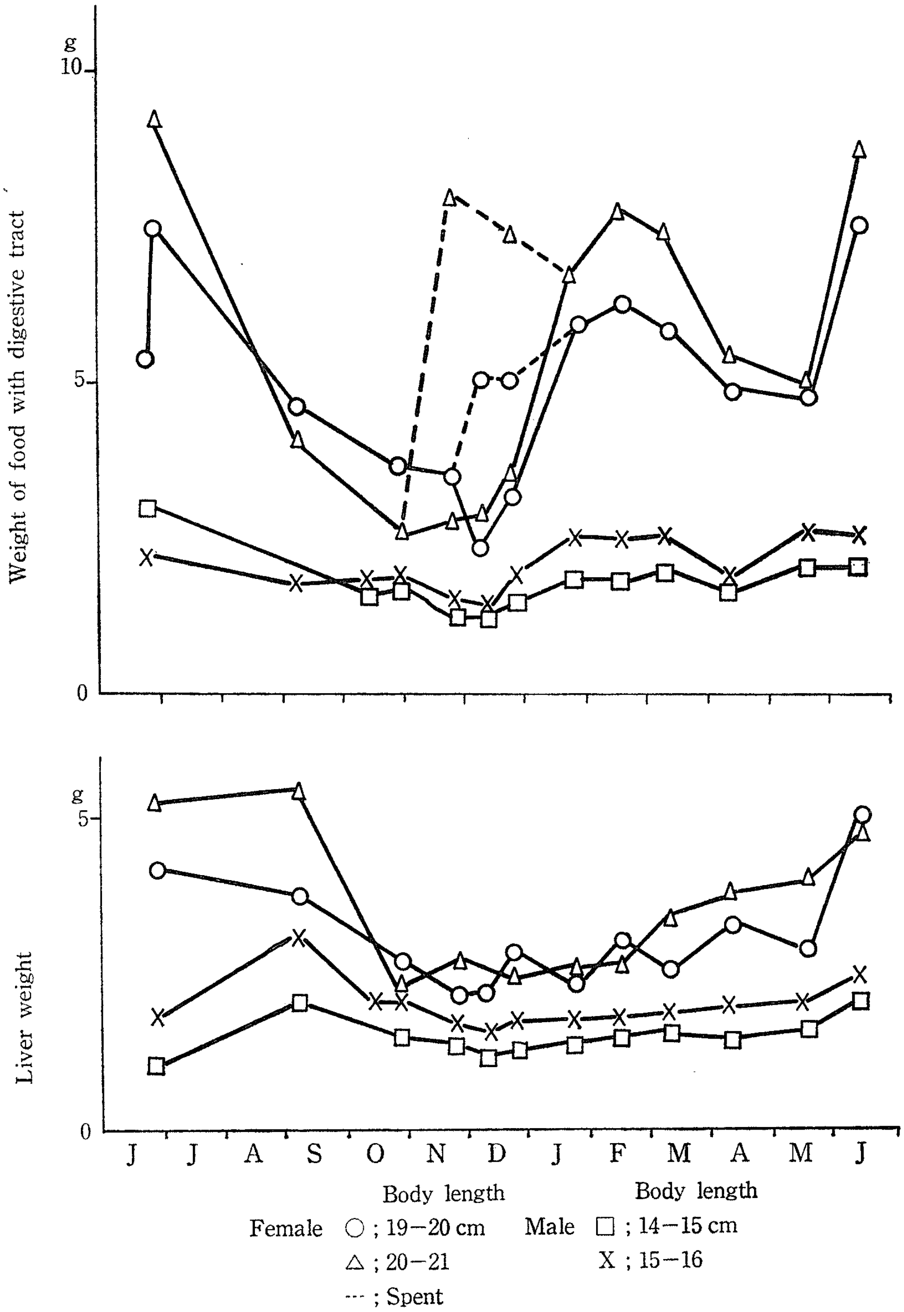

FIG. 12. Seasonal change in mean weight of food with digestive tract and liver, by 1 cm length intervals.

sexual differences of liver are observed, i.e., in female proteins to be transferred to yolky proteins later have been produced actively in the liver, which becomes bigger than that of the male (9). In the liver cells of female chum salmon, kept starved for long, the yolky proteins are synthesized from substances which have been reserved in its body when the female is migrating for its native river (10).

From the reports above, the rising process of GSI seems to correspond to the period of large liver from May to September, and the reduction process of ovary-

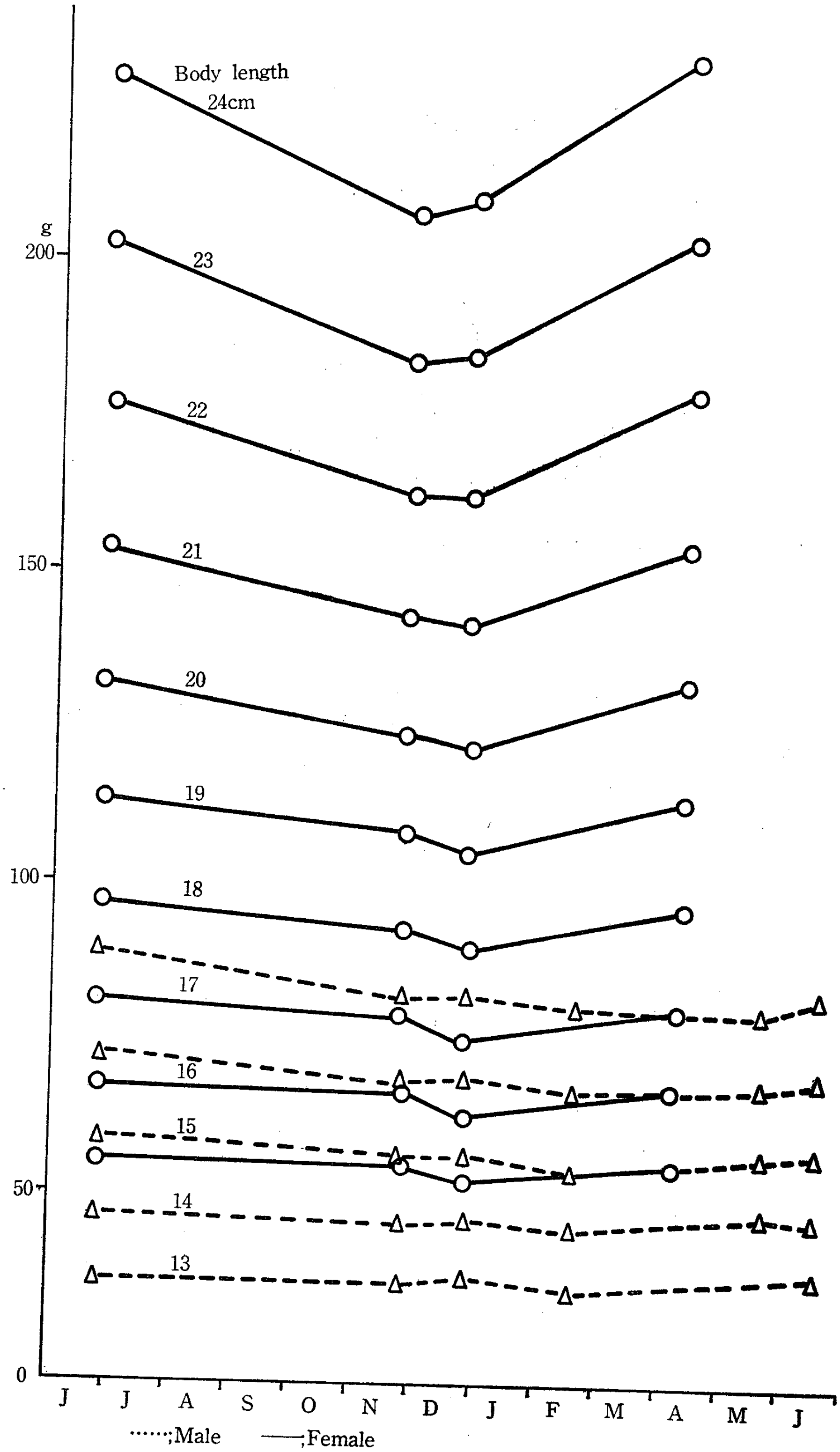

FIG. 13. Seasonal change in body weight without gonad and digestive tract, by separate length intervals.

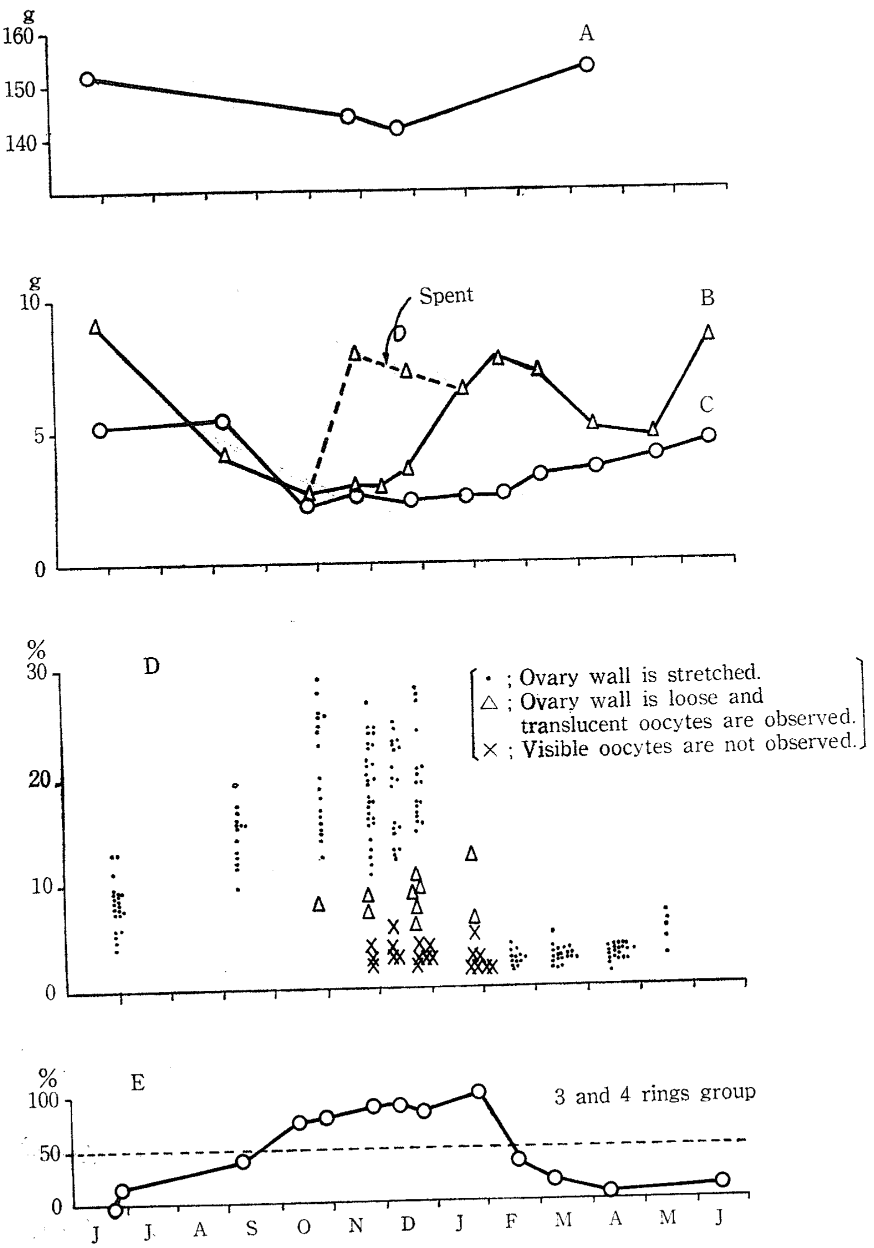

FIG. 14. Seasonal changes in ovary-free weight of the fish, 21 cm long (A), weight of food intake of the fish 20 to 21 cm long (B), weight of liver (C), GSI (D), and the incidence of the fish with translucent zone at their otoliths' periphery (E).

free body weight near the spawning period seems to be explained by the conversion of substances which have been reserved in its body into yolky proteins.

From September to October, the liver weight falls to the lowest, whereas the GSI continues to rise to reach a maximum, showing the other relation between liver and gonad (11).

Discussion

As has been clarified from the foregoing sections, the marked feature in the life history of migigarei is the conspicuous sexual dimorphism. In the case of females, the average length of the fish of the same age, maximum body length, longevity, age at first maturity and GSI have considerably higher values than those of the males. We are going to examine the adaptive significance of the striking characteristics in the migigarei's life history.

Generally, in the fishes migrating in the surface or subsurface layers such as clupeids or scombroids, differences in development or growth between sexes are scarcely found. On the contrary, the sexual differences are observed more or less in the littoral or demersal species. The conclusive differences between the pelagic fishes and the littoral and/or demersal ones lie in that the former utilize the environment widely and three-dimensionally whereas the latter live in the narrow and restricted environment. In the pelagic species, since the members of the same cohort form a school as a rule, the selection favors the homogeneity among fish in the swimming ability and the age of maturation. Moreover, a substantial quantity of the reproductive matter of the male is needed as the chance of encountering between eggs and spermatozoa is very small.

In littoral or demersal species, the two sexes do not necessarily behave in the same way as their ranges are limited. Since the eggs are able to be fertilized efficiently as seen in the sexual behavior of the babagarei, *Microstomus achne*, in which the male embraces the female's ventral portion (12), the selection favors the small quantity of the sexual matter of the male. On the other hand, the direct interspecific relations for food, etc, among these species would be very keen compared with those among the pelagic fishes, and they have to produce many offsprings to win the struggle for existence. The optimum strategy for the preservation of the brood in the conditions like this is to increase the egg number by means of allocating more resources to female.

The migigarei exhibits the especially marked sexual differences among the heterosomes. For instance, in the bastard halibut, *Paralichthys olivaceus*, the difference in the body length by sex occurs in the fish older than three years. Subsequently the male becomes larger than the female gradually resulting in only small difference and the substantial difference in life span is not seen between sexes (13). In comparing the forage of these two flatfishes, the bastard halibut is a typical piscivore feeding on the sandeel and anchovy, whereas the major food of the migigarei is *Ophiura* added by polychaetes. The caloric value expressed in calories per gram in wet weight is 1,270 for anchovy (14), whereas it is 349–368 for *Ophiura* and 511–829 for polychaete according to the authors' data.

The migigarei feed on the foodstuffs of low calorific value and inhabit the especially adverse and poor environment, presumably resulting in the very severe interspecific relations with the competitors. In these conditions the migigarei have selected the survival strategy to maximize the intersexual differences. The akagarei, *Hippoglossoides dubius*, in the Japan Sea is another heterosome exhibiting conspicuous sexual differences, though not so large as the migigarei, and they also feed on *Ophiura* (15).

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