Japanese Journal of Ichthyology
Vol. 18, No. 3 December 1, 1971

魚 類 学 雑 誌
18巻3号 1971年12月1日

Hermaphroditism and Sex Reversal in Fishes of the Platycephalidae—II. *Kumococius detrusus* and *Inegocia japonica**

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(Received December 22, 1970)

Abstract The occurrence of sex reversal was investigated in two species of the Platycephalidae, *Kumococius detrusus* and *Inegocia japonica*. In the former, all the individuals, and in the latter, at least 50 percent of the fish (perhaps all individuals) reverse their sex protandrously in function in their life span. In *K. detrusus*, as the sex reversal from the functional male to the functional female occures, the gonad of the fish is transformed to the ovary from an ovotestis in which only the testicular part is functional, whereas in *I. japonica*, the development goes to ovary from testis through the hermaphroditic stage. Accordingly in the former case the ovotestis may be recognized easily even by the naked eye, whereas in the latter it is difficult to discern the hermaphroditic gonad from the testis except by histological observation. Considering the differences among such patterns as *Kumococius*-type, *Onigocia*-type and *Inegocia*-type, the evolutional process of the sex reversal phenomena was conjectured. If it is assumed that protandrous sex reversal or sex change from functional male to functional female is advantageous to reproduction, the *Inegocia*-type could be more adaptive where the gonadal form corresponds suitably to the change in sexual function. Therefore, the pattern of sex reversal would have evolved from *Kumococius*-type to *Inegocia*-type in which simultaneous hermaphroditic tendency disappears.

Either sex reversal or hermaphroditism is known among the fishes of several orders, and especially detailed studies have been progressed in the fishes of the Serranidae, Sparidae and Labridae belonging to the Perciformes. As for normal hermaphroditism three types have been distinguished, that is, simultaneous, protogynous and protandrous ones (Reinboth, 1971). Simultaneous and protogynous types are found in the Serranidae. The Sparidae possesses protogynous and protandrous types, and at present the Labridae is known to have only protogynous type. What sort of relationships there are among three types has become a subject of the day. Presence of the protandrous hermaphroditism has already been known also in the platycephalidae belonging to the Cottiforms from the studies of *Cociella crocodila* (Tilesius) (Aoyama et al., 1963) and *Onigocia macrolepis* (Bleeker) (Fujii, 1970). In this study, the sexuality of some platycephalid fishes has been investigated on the developing process of protandrous hermaphroditism. The results have revealed that *Kumococius detrusus* (Jordan and Seale) and *Inegocia japonica* (Tilesius) change their sexual function from male to female during their life span and a clue for understanding the phenomena was found by considering the pattern differences of gonad change accompanied by the reversal of sexual function.

Samples and method

Four lots of samples comprising 356 fish of *K. detrusus* and five lots of samples comprising 268 fish of *I. japonica* were obtained from 1965 to 1968 at the market of Fisheries Cooperative Society in Kochi Pref. Like in the previous study (Fujii, 1970), the relationships between the sex ratio and standard length were

* Contribution from the Tohoku Regional Fisheries Research Laboratory, No. 272.

examined as a means of confirming sex reversal, after having found as hermaphroditism of the fish. Sex of the fishes was judged mainly with the naked eye. As for *I. japonica* all of the testis-like gonads were observed histologically, since it is difficult to discriminate the hermaphroditic gonad from testis. For histological observation of the gonads, paraffin sections (7 μ) were made and stained with haematoxylin and eosin.

Result

I. *Kumococius detrusus*

Preliminary observations showed that most of smaller specimens possessed ovotestis, and that ovaries were present in larger ones. It seems therefore that in regard to sexual function normal protandrous sex reversal takes place as in *C. crocodila* and *O. macrolepis*.

Cross sections of the ovotestis showed its construction to consist of an ovarian part ying in the proximal area, and a U-shaped testicuarl part covering the former laterally (Fig. 1). The form of the ovarian part does not differ from that of the ovaries seen in general fishes with a cavity into which lamellae bearing numerous oocytes project. The testicular part consists of many spermatic lobules. Although no special septum exists between the testicular and ovarian parts, both parts are demarcated distinctly. Cysts of oocytes are, however, occasionally observed embedded in testicular tissue.

Young fish (about 80 mm long) have gonads in various degrees of undifferentiated hermaphroditic state. This, on the whole, suggests the way in which ovotestis is formed. In some individuals the ovarian tissues are not so differentiated and separated from testicular tissue (Fig. 1, A). Others are apparently ovotestis since they have both the cavity and differentiated testicular tissue (Fig. 1, B and C). The ovotestis must be built up directly without passing through the "testis" phase, since both testicular tissue and ovarian parts are formed at the same time

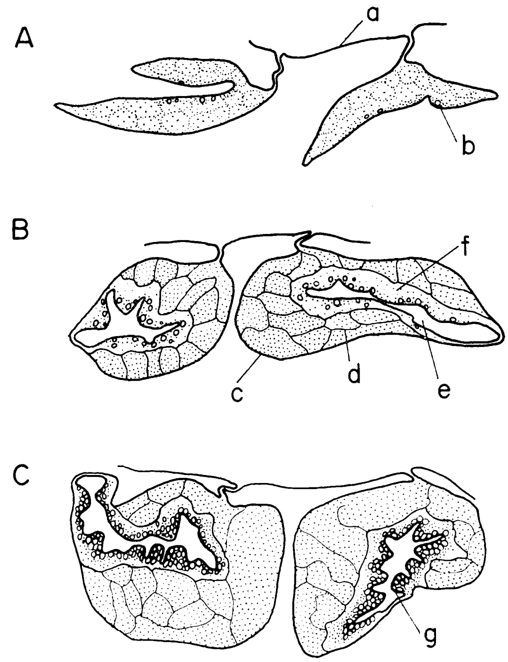

Fig. 1. Diagrammatic representation of the differentiating process of gonad to ovotestis (from A to C) in young of *Kumococius detrusus*. a, peritoneum; b, oocyte; c, testicular part; d, seminiferous lobule; e, ovarian cavity; f, ovarian part; g, ovarian lamellae.

although testicular tissue becomes mature earlier in the gonad of adult fish.

In the ovotestis of fish collected near the spawning season (in about October), it is observed that spermatozoa formation in the testicular tissue becomes highly active and consequently spermatic lobules and vas deferens are filled with mature spermatozoa, while in the ovarian part, oocytes stay uniformly at the perinucleolus stage. Though most of the ovotestis show the state mentioned above, some fish near the sex reversal point rarely have oocytes reaching the yolk vesicle stage. But in such cases, degenerating oocytes coexist with them. From these observations it is seen that in normal ovotestis only the testicular part matures while the ovarian part remains at an early maturation stage.

The ovotestis have both vas deferens and oviducts. The vas deferens is unpaired and one and a half times as long as the gonad. The oviduct is attached to the ventral side of the vas deferens. The duct seems to develop slightly later, corresponding to the function of the ovotestis and is not open to the body surface in the hermaphroditic state. At the open end to the surface the vas deferens is encircled together with the urinary duct by the common constrictor. While the oviduct opens in front of the vas deferens and outside of the constrictor.

It is assumed that the ovotestis will turn into an ovary some time later when fish comes to a certain age, by the fact that only the testicular part is functional in the ovotestis and vestigial testicular tissue is often seen microscopically remaining in the gonads of female fish. Sex reversal can be indicated more obviously from the relationship between standerd length and the sex ratio, illustrated as a regressive curve (Fig. 2). The ratio changes from 0 to 100% at the size about 140 to 180 mm in the standard length. The fact means that all individuals of this species

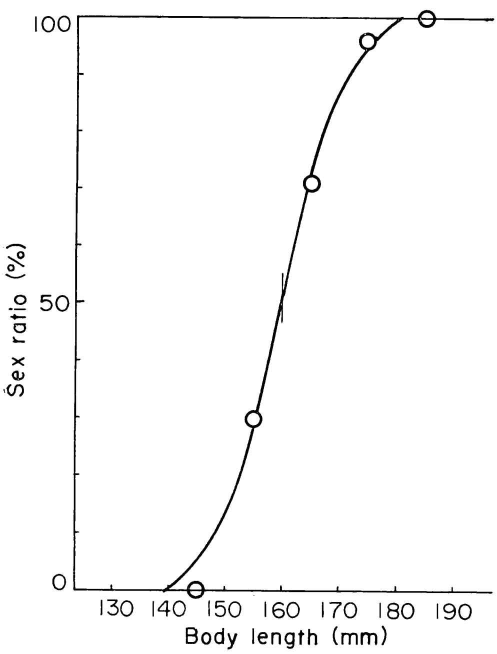

Fig. 2. Relationship between size of fish and the sex ratio (females/total ×100) in sample IV. See also Tables 2 and 3.

change their sex from hermaphrodite (functional male) to female during their life span.

II. *Inegocia japonica*

In the present species three kinds of gonads are found, namely testis, ovary and transitional hermaphroditic one. The appearance of the testis and ovary is the same as that seen in general fishes which does not undergo sex reversal. The hermaphroditic gonad is originally a testis in which oocytes have appeared. Changing process of gonad from testis to ovary is conjectured from different degree of the hermaphroditic state (Fig. 4). At the beginning of the process oocytes are arranged as if they are formed near the dorsal surface of the testis, and are invading gradually into testicular tissue (see Fig. 5, 2). Gross-sectional transformation to form ovarian cavity occurs more or less in the most of hermaphroditic gonad (Fig. 5, 3).

The ratio of the hermaphroditic gonads to the testis-like ones (as which both testis and hermaphroditic one were inclusively named since they cannot be distinguished in outside appearance) in each sample is appended in Table 4 in which it can be also roughly estimated at what time the sex reversals are apt to arise in year cycle. The ratios of sample lot II and lot IV are in contrast. Considering that sample lot II of low ratio was obtained a few months before spawning season, that is, in summer, it is assumed that sex reversal barely occurs prior to the spawning season. On the other hand, the ratio is notably high in sample lot IV collected in September (after spawning season). It may be said, therefore, that sex reversal does not take place during a few months prior to the spawning season, but constantly does in the rest of months, especially in the period after the spawning season.

The relationship between standard length and sex ratio in each size class (shown in Table 5) substantiates the results of the histological observation of the gonads. Although the fish samples dealt in this study were small in number, it is concluded that there

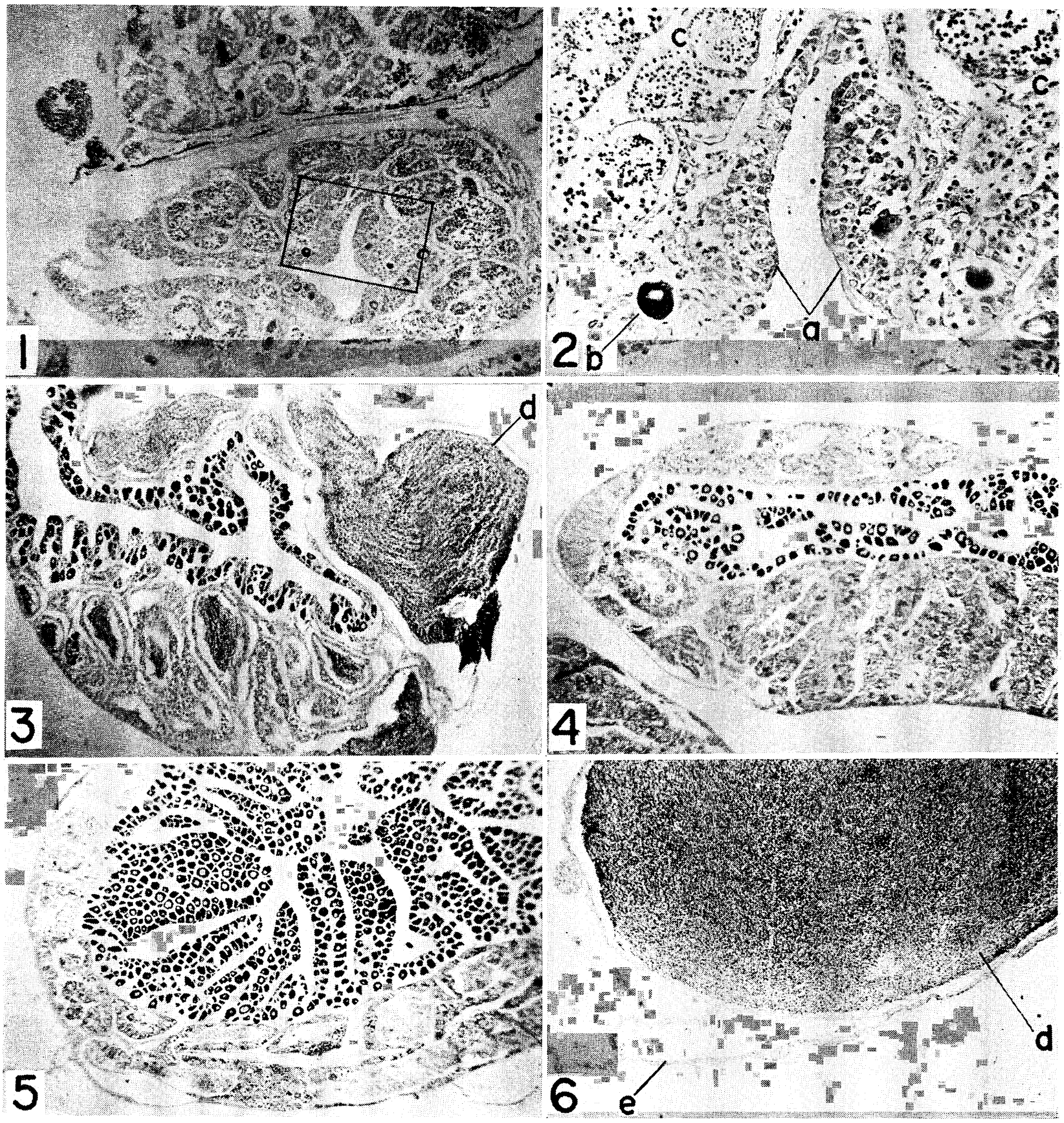

Fig. 3. Histomicrophotos to show the cross section of the gonad in *Kumococius detrusus*.
1) Hermaphroditic gonad differentiated in low degree. It is possible to discern both testicular and ovarian parts (98 mm in standard length). ×66.
2) Partial magnification of the above. ×265.
3) Well differentiated hermaphroditic gonad (98 mm). ×56.
4) Ovotestis of adult fish (132 mm). ×26.
5) Same as (4) (143 mm). ×16.
6) Vas deferens containing full spermatozoa and provided with oviduct ventrally (116 mm). ×56. a, ovarian part; b, oocyte; c, testicular part; d, spermatozoa; e, ovarian duct.

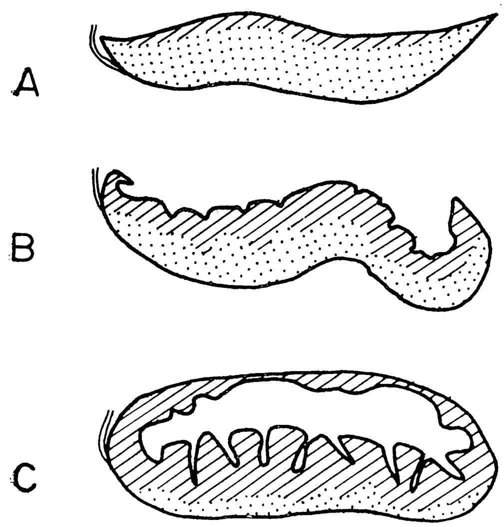

Fig. 4. Diagrammatic representation of gonad transformation accompanied by sex reversal from testis with oocytes appearing near the dorsal surface (A), to the transitional hermaphroditic gonad changing the shape to form ovarian cavity (B), and to ovary with remaining testicular tissue (C). Testicular tissue is shown by dots and ovarian tissue by oblique lines. See also Fig. 5.

are no females when the standard length is smaller than about 100 mm and the subsequent growth leads to a sex ratio of 50% or more. This proves that at least 50% (there is the possibility of 100%) of the specimens are undergone protandrous sex reversal in their life span.

Discussion

This study has revealed that all the individuals of *K. detrusus* and at least half of *I. japonica* perform protandrous sex reversal on the reproductive function throughout their life, and although both are protandrous in respect to reversal of reproductive function, the changing patterns of gonadal shape accompanied by change of sexual function are different from each other. The gonad of *K. detrusus* first differentiates into ovotestis with mature testicular tissue. When the male phase comes to an end, the testicular tissue degenerates and disappears from the ovotestis, and the gonad changes into an ovary. In *I. japonica*, the gonad differentiates originally into testis and then changes into ovary. Consequently in this species the hermaphroditic gonad appears in the process of sex reversal as a transitional form. Thus, transformation of the gonad can be formulated as ⚥→♀ (conveniently named as A-type) in the former, and ♂→(⚥)→♀ (named as B-type) in the latter. With regard to A type, a modified pattern, such as the sex reversal in *O. macrolepis*, reported by Fujii (1970), is distinguished as a subpattern (named as A′-type). In A′ type the ovarian part of the ovotestis does not assume as complete shape unlike that of *K. detrusus*, that is, it has no cavity. This type has both aspects common to A-type and to B-type, because on the one

Table 1. Three types of sex reversal in the Platycephalidae.

Type	Changing pattern of the gonad	Species
A	⚥ ———→♀	*Kumococius detrusus* (Jordan and Seale) *Suggrundus meerdervoorti* (Bleeker)* *Rogadius asper* (Cuvier)* *Cociella crocodila* (Tilesius)
A′**	⚥ ———→♀	*Onigocia macrolepis* (Bleeker) *Onigocia spinosa* (Temminck and Schlegel)*
B	♂→(⚥)→♀	*Inegocia japonica* (Tilesisus)

* It has been confirmed by the present writer that many individuals of these species have an ovotestis of A-type in preliminary investigations and also probability of sex reversal in both *S. meerdervoorti* and *R. asper* has been refered to by Aoyama et al. (1963).

** Refer to the text as regards the difference of A′-type from A-type.

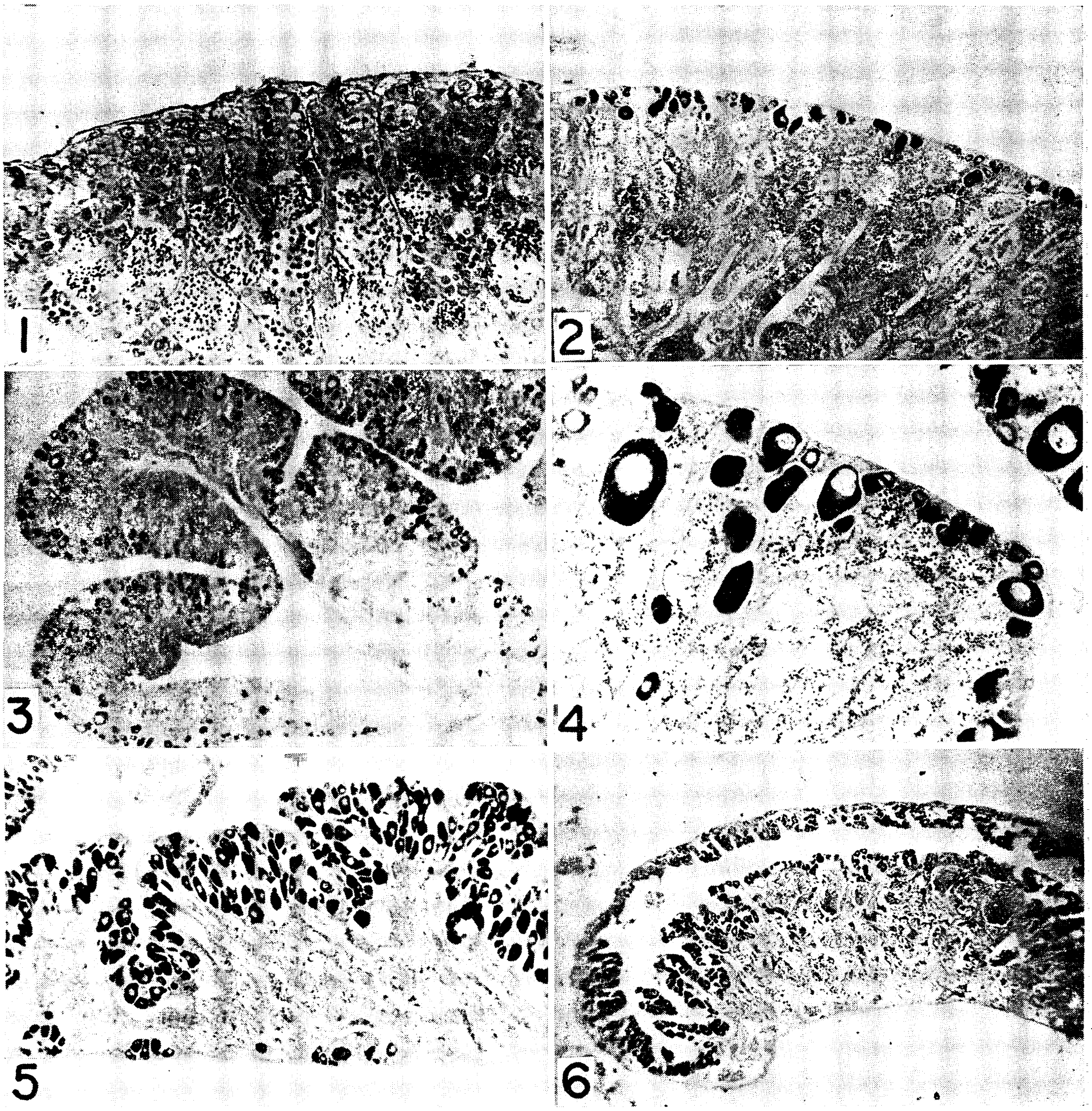

Fig. 5. Histomicrophotos to show the cross section of the gonad in *Inegocia japonica.*

1) Testis in which bunches of gonocytes are seen located along the dorsal surface (145 mm in standard length). ×198.
2) Oocytes appearing in the dorsal side of the testis (147 mm). ×55.
3) Transitional hermaphoroditic gonad showing the increase of oocytes and transformation of the contour (152 mm). ×23.
4) Partial magnification of the above. ×92.
5) Transitional hermaphroditic gonad in which the oocytes have increased and consequently have become integrated as ovarian tissue (143 mm). ×24.
6) Hermaphroditic gonad in which ovarian cavity has been formed (165 mm) ×23.

hand hermaphroditic state is maintained during functional male phase, on the other hand ovarian cavity formation is delayed until the beginning of female phase.

Other platycephalid species have also been shown to undergo protandrous sex reversal. They are classified and arranged according to the types in Table 1. When these main two types of sex reversal were set up and compared, it appears that A-type expresses a more intensive hermaphroditic nature than B-type in the sense that the both masculine and feminine elements exist simultaneously, considering that the ovotestis in A-type is held for a fairly long period in the life span. The reversal of function from male to female is thought to have certain significance in the maintenance and the prosperity of the species. This being true, A-type where the gonad contains feminine elments when in the male phase seems to have a disadvantage in comparison with the B-type where the gonad changes from testis to ovary in correlation with the reversal of sexual function. A-type seems less adaptive, and more primitive than B-type, so that the process may evolve from A-type to B-type. A′-type, represented by *O. macrolepis*, is situated between A-type and B-type since the incomplete ovarian part of the ovotestis is thought to imply an inclination for the feminine element to disappear from the hermaphroditic gonad when in the male phase. B-type is considered as the most advanced form of that of the inclination. The differences among these three types are thought to be caused by the gradual delay of ovarian tissue formation on the ontogenetic process in hermaphroditism such as A-type in which both testicular and ovarian parts are originally formed simultaneously.

A question then arises as to the meaning of the simultaneous existence of both sexual elements in A-type. The answer seems to lie in the probability that previous to A-type there existed a type in which the ovotestis was held throughout life span, namely, that is simultaneous hermaphroditism. This inference appears to have some support considering that there now exist some simultaneous hermaphroditic species (Smith, 1959; Clark, 1959) in the serranids, though they are not closely related to the platycephalids phylogenetically.

Table 2. Samples used in this study (*Kumococius detrusus*).

Sample lot	Date	Number of fish	(⚥*,	♀)	Standard length	Number observed histologically
I	May 5, '65	26	26	0	72–106 mm	20
II	Sept. 20, '66	47	43	4	100–168	15
III	Oct. 22, '65	22	21	1	98–160	16
IV	Dec. 10, '66	261	181	80	111–230	25
	Total	356				76

* Functional male.

Table 3. Size frequency and female sex ratio (%) in Sample IV (*Kumococius detrusus*).

Size class	111–130	131–140	141–150	151–160	161–170	171–180	181–190	191–200	201–230	Total
Number of material	14	80	63	23	24	26	20	5	6	261
Number of hermaphrodite	14	80	63	16	7	1	0	0	0	181
Number of female	0	0	0	7	17	25	20	5	6	80
Sex ratio of female	0	0	0	30.4	70.8	96.2	100	100	100	

Table 4. Samples examined and rate of hermaphorodite in each sample (*Inegocia japonica*).

Sample lot	Date	Number of fish	(♂, ⚥, ♀)	⚥/(♂+⚥)	Standard length
I	Apr. 5, '66	75	33 17 25	0.33	77–184 mm
II	May 5, '66	74*	60 1 11	0.02	85–171
III	June 6, '68	99	84** 15	——	72–171
IV	Sept. 20, '66	13	3 8 2	0.73	135–171
V	Oct. 22, '65	7	5 1 1	0.17	113–164

* Two fish where the gonad has degenerated were contained in this sample.
** Total of males and hermaphorodites.

Table 5. Size frequency and sex ratio (%) of female in three samples (*Inegocia japonica*).

	Size class	71 –100	101 –110	111 –120	121 –130	131 –140	141 –150	151 –160	161 –170	171 –190	Total
Sample I	Number of material	9	15	10	4	10	8	4	7	8	75
	Female	0	1	1	0	3	5	2	5	8	25
	Sex ratio	0	6.7	10.0	—	30.0	62.5	—	71.4	100	
Sample II	Number of material	9	13	25	8	7	3	5	3	1	74
	Female	0	1	1	*	3	1	2	2	1	11
	Sex ratio	0	7.7	4.0	—	42.9	—	40.0	—	—	
Sample III	Number of material	8	16	34	18	11	6	3	2	1	99
	Female	0	0	1	2	4	2	3	2	1	15
	Sex ratio	0	0	2.9	11.1	36.4	33.3	—	—	—	

* Standard length of two fish with degenerated gonad belong to this size class.

Acknowledgments

The writer wishes to express his deep appreciation to the late Prof. Kiyomatsu Matsubara and Prof. Tamotsu Iwai of Department of Fisheries, Kyoto University for making this study possible and also to Dr. Shigekatsu Sato, Dr. Hisashi Kanno, Tohoku Regional Fisheries Research Laboratory and Dr. James W. McBeth, Scripps Institution of Oceanography, University of California, for criticism of the manuscript.

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コチ科魚類における雌雄同体性と性転換現象—II. クモゴチおよびトカゲゴチの雄性先熟雌雄同体性

藤井 武人

コチ科魚類の二種，クモゴチ *Kumococius dertrusus* およびトカゲゴチ *Inegocia japonica* について性転換現象の有無を調査した結果，前者では全個体が，後者では少なくとも 50% (おそらく前者と同様に全個体が性転換するものと予測される) が機能の上では雄性先熟の性転換を行なっていることがわかった．雄性から雌性への性機能の転換にともなって，生殖巣は，前者では両性生殖巣

から卵巣に，後者では精巣から卵巣へと移行する．したがって前者では肉眼によって両性生殖巣を容易に見つけることができるのに対して，後者では両性生殖巣は移行的なかたちで現われるので肉眼では精巣と識別するのはむずかしい．

このような両者の性転換様式の差異に着目して雌雄同体性の進化過程を考察し，次のように結論した．性の転換が雄性先熟であることに種の繁殖上のいみがあると考えると，性機能の変化に生殖巣がうまく対応しているトカゲゴチ型の方が雄相にある時に雌性の要素をもっているクモゴチ型よりも適応的であるといえる．したがって性転換の様式はクモゴチ型からトカゲゴチ型に進んだものであり，その過程は一個体の魚から雌雄両要素が分離する過程，すなわち雌雄同体的傾向の消失をいみするものである．またクモゴチ型が示すように，その両性生殖巣の形態的特徴と両性生殖巣の維持される期間が相当長いことから判断して，その先駆型として同時成熟の雌雄同体性がかつて存在したにちがいない．

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