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Sexual Dimorphism in the Goby *Tridentiger kuroiwae brevispinis*

Katsuo Mashiko and Sôichi Yamane

Biological Laboratory, Faculty of Education, Ibaraki University, 2-1-1 Bunkyo, Mito 310, Japan

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Sexual dimorphism has been reported and discussed with respect to reproductive behavior in various groups of fishes, such as Gobiidae (Miyazaki, 1940; Egami, 1960), Cottidae (Downhower et al., 1983; Goto, 1984), Cyprinidae (Mizuguchi and Hiyama, 1969), and Gasterosteidae (Mori, 1984).

Egami (1960) compared sexual dimorphism and related biological aspects among 13 species of Japanese gobiids, and classified the fishes into four sexual types. His compared species included "*Tridentiger obscurus*" collected from freshwater around Tokyo, central Japan. Subsequently, "*T. obscurus*" occurring in Japan was divided into two subspecies, *T. o. obscurus* and *T. o. brevispinis*, based on the length of the third spine in the first dorsal fin, number of gill rakers and habitat, among other factors (Katsuyama et al., 1972). More recently, *T. o. brevispinis* has been treated as a subspecies of *T. kuroiwae* (*T. k. brevispinis*) (Kawanabe and Mizuno, 1989) or as a distinct species, *T. brevispinis* (Iwata, 1989). In this paper *T. k. brevispinis* is used for the taxon which was cited as *T. o. brevispinis* by Katsuyama et al. (1972).

This paper compares nine external body characters of male and female *T. k. brevispinis* collected from Lake Kitaura, central Japan. In addition, behavioral functions of each character are briefly discussed, based on preliminary observations.

Material and Methods

A total of 225 specimens (141 males and 84 females) of *Tridentiger kuroiwae brevispinis* (including mature and immature fish) were collected by rod and line and fixed shore nets on 15 occasions at about 2-week intervals from May to November (except October) 1990 in Lake Kitaura (36°00′N, 140°35′E). To analyze sexual dimorphism, the following nine body parts were measured to the nearest 0.1 mm with a vernier caliper: body length (BL: standard length), head width at cheeks (HW), head length (HL), mouth width (MW), length of 3rd spine in 1st dorsal fin (D_3L), length of central pectoral fin ray (PcL), length of pelvic fin ray (PlL), length of posteriormost anal fin ray (AL) and length of central caudal fin ray (CL). Body and gonadal weights (wet weight) were measured to 1 mg with an electronic balance to calculate the gonadosomatic index (GSI = gonadal weight/body weight × 100).

In this study, four categories of samples classified by sex and maturity, which was determined from the GSI values as suggested by Kaneko and Hanyu (1985) for *T. obscurus*, were used: *MM* (mature males; GSI ≧ 0.6), *IM* (immature males; GSI ≦ 0.4), *MF* (mature females; GSI ≧ 4.0) and *IF* (immature females; GSI ≦ 2.0). Specimens with GSI values intermediate between those denoting maturity and immaturity were excluded from the analyses. In addition to the morphometric character analyses, some reproductive behavior was observed in an aquarium on the campus of the Itako Hydrobiological Station, Ibaraki University. A computer program, the Statistical Analysis System (SAS) at the Data Processing Center of Ibaraki University was used for statistical analyses.

Results

Morphological observations.—The average body length of mature males ($n = 75$) was significantly larger than that of mature females ($n = 50$) (mean, 54.2 vs. 42.4 mm BL; *t*-test, $p < 0.01$, Table 1).

Average lengths (relative to body length [BL]) of the remaining eight characters, HW, HL, MW, D_3L, PcL, PlL, AL and CL were compared among *MM*, *IM*, *MF* and *IF* (Table 1). The relative lengths of HW, MW, D_3L and AL differed statistically between *MM* and *MF* (Wilcoxon's rank-sum test, $p < 0.01$), whereas only MW and D_3L differed between *MM* and *IM* and none between *MF* and *IF*. The relative length of D_3L of *MM* (0.20) was much larger than in *IM* (0.16), *MF* (0.14) and *IF* (0.14). MW and HW of both male categories were larger than in females.

To compare the relative growth of the above four characters, which differed statistically between *MM* and *MF*, single regression analyses were performed (Fig. 1). The relative HW differed only slightly between the categories (Fig. 1A). For MW, values of *MM* and *MF* were separately distributed, indicating that *MM* had larger mouths than *MF*, although the allometry was weak (Fig. 1B). It was known that *MM* had a relatively longer D_3L than *MF*, and this character in the males showed strong allometry (Fig. 1C). The relative lengths of AL had a similar pattern to MW, indicating that *MM* had longer anal fin rays than *MF* (Fig. 1D). In conclusion, (1) for the four characters, values of *MM* were always larger than those of *MF*, irrespective of body size, and (2) regression lines for HW, MW and AL had similar gradients, while that for D_3L was apparently steeper, indicating the occurrence of strong allometry.

To estimate the overall relationship between the four sample categories in terms of external morphology, a canonical discriminant analysis (CDA: Rao, 1973) was performed, using six variables (BL, HW, MW, D_3L, PcL and AL), which were selected by a stepwise discriminant analysis with a forward selection.

The first and second canonical variables (CAN1 and CAN2 respectively) were given by the following equations and plotted on Figure 2: $CAN1 = -1.23(BL-47.2) - 4.74(HW-13.0) + 10.50(MW-8.3) + 5.91(D_3L-8.1) - 3.45(PcL-9.6) + 2.16(AL-5.9)$, and $CAN2 = -3.88(BL-47.2) + 11.51(HW-13.0) + 3.66(MW-8.3) - 5.40(D_3L-8.1) + 0.09(PcL-9.6) + 6.96(AL-5.9)$. CAN 1 explained 88% of the total variation and CAN2 11%, hence 99% of the variation was explained if both were combined. Since the female groups (*MF* and *IF*) nearly overlapped each other, three groups (*MM*, *IM*, and *MF+IF*) were identifiable on the scatter-diagram. The female groups and *MM* only partially overlapped, and *IM* was located between them. The squared Mahalanobis distance, an index of distance between the class means, computed by CDA based on the pooled within-class covariance matrix, was 9.1 between *MM* and *MF*. The distance increased considerably with maturation in the males (*MM−IM*: 5.0), but remained virtually constant in the females (*MF−IF*: 0.3).

Preliminary observations of reproductive behavior.—During the breeding season from May to August in Lake Kasumigaura (Lakes Kitaura and Nishiura combined)(Kaneko and Hanyu, 1985), *T. k. brevispinis* males, like *T. obscurus* (Kishi, 1979, 1981), established their nests variously under or on vertical rock surfaces, on concrete walls, or in empty cans on the bottom.

The reproductive behavior of a mature male was observed in an aquarium during the period from May 12 to August 21, 1991. Whilst waiting for visits by gravid females, the male removed sand grains and pebbles from the nest site with his mouth and tail, and brushed up the substrate in readiness for eggs, with the pectoral and anal fins. After becoming aware of a gravid female, the male began courtship by momentarily darkening his body color and extending the first dorsal fin, from which D_3 (3rd spine) projected remarkably in many cases. By contrast, the body color of the gravid female brightened. Facing her from the nest site, the male oscillated his opercular region (repeated rapid opening and closing), swimming to the female to emphasize the action. During this phase, the male's first and

Table 1. Comparisons of body length (BL) and lengths of eight external body characters relative to BL (mean ±S.E.) among four sample categories of *Tridentiger kuroiwae brevispinis*. (Individuals with GSI values intermediate between those of mature and immature fish were excluded from the calculation)

Characters[a]	Males		Females	
	Mature (n=75)	Immature (n=66)	Mature (n=50)	Immature (n=34)
BL (mm)	54.2±11.4	46.5±9.9	42.4±10.1	39.7±7.4
Relative length to BL				
HW*	0.28±0.02	0.28±0.02	0.26±0.02	0.26±0.02
HL	0.31±0.02	0.32±0.03	0.31±0.02	0.31±0.02
MW*	0.19±0.02	0.18±0.02	0.16±0.02	0.16±0.02
D_3L*	0.20±0.04	0.16±0.02	0.14±0.02	0.14±0.01
PcL	0.20±0.02	0.21±0.02	0.21±0.02	0.21±0.02
PlL	0.16±0.02	0.16±0.02	0.16±0.02	0.16±0.02
AL*	0.13±0.02	0.13±0.01	0.12±0.01	0.12±0.01
CL	0.22±0.02	0.22±0.02	0.21±0.02	0.22±0.03

[a] Abbreviations given in text; *significant differences between mature males and mature females (Wilcoxon's rank-sum test, $p<0.01$).

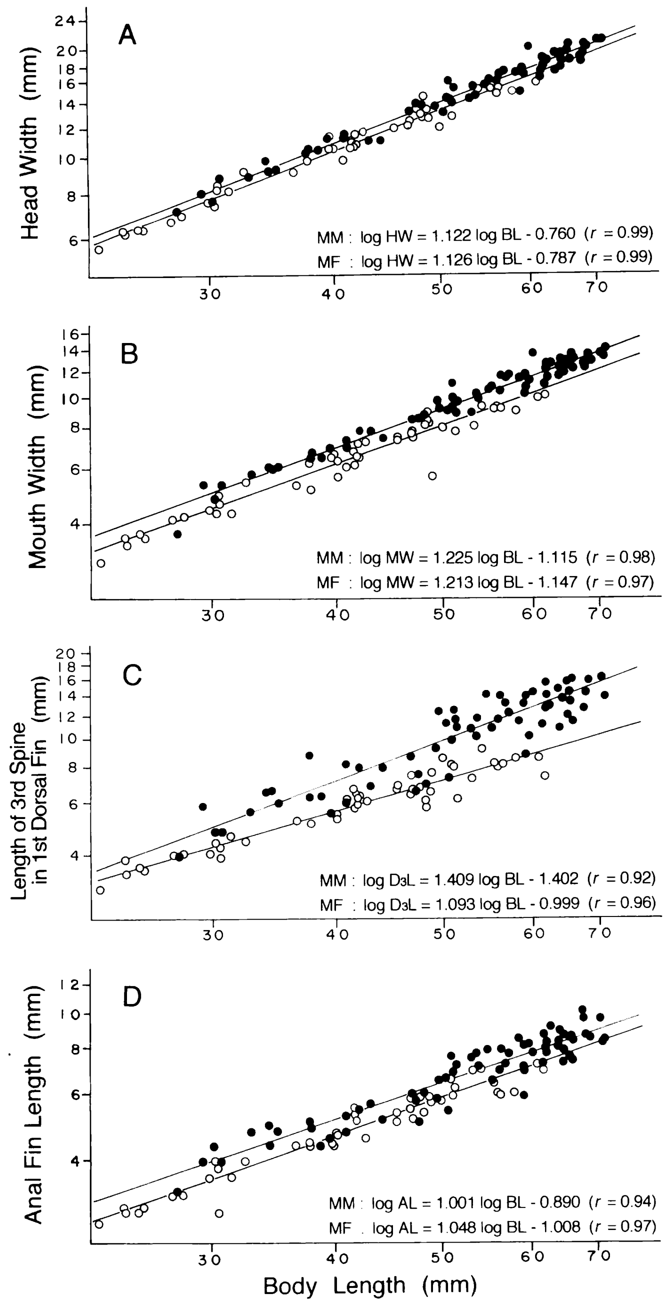

Fig. 1. Relationships of four characters, head width (A), mouth width (B), length of 3rd spine in 1st dorsal fin (C) and length of posteriormost anal fin ray (D), which differed significantly with body length between mature males (●) and mature females (○). Both axes are represented by logarithmic scales.

second dorsal fins and anal fin remained erect in many cases. Particular emphasis was given to behavior emphasizing the sides of the body, called "lateral display" in *Tridentiger obscurus* (Kishi, 1979). If the courtship was successful, the female spawned a mass of eggs in a single layer on the ceiling of the nest. Subsequently, the male inseminated the eggs, drove the female away and began to care for the eggs, very

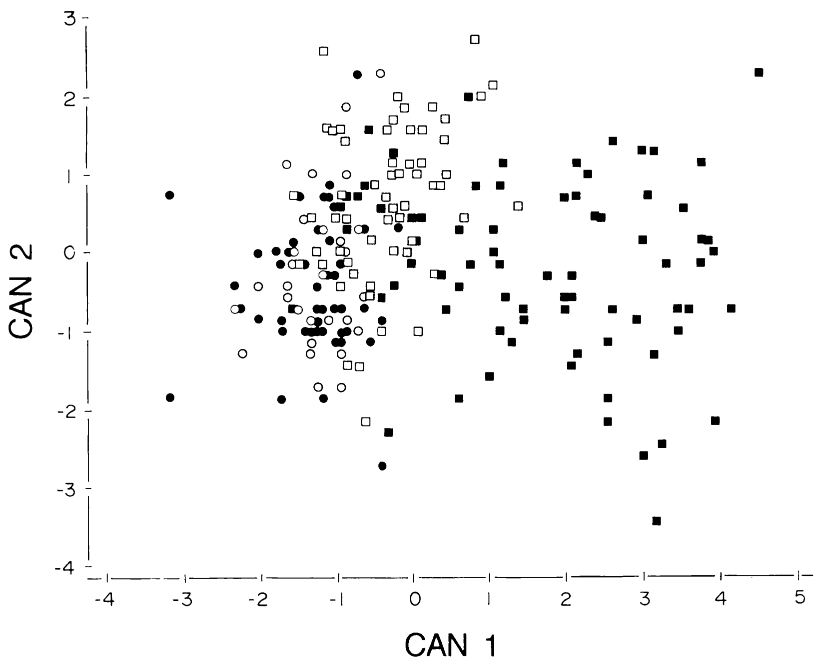

Fig. 2. Discrimination of four sample categories (mature males [■]; immature males [□]; mature females [●]; immature females [○]), based on canonical discriminant analysis using six characters, which were selected by a stepwise discriminant analysis with a forward selection. CAN 1 and 2 indicate the first and second canonical variables, respectively.

often brushing them with his anal and pectoral fins. The male also kept the nest clean by removing sand grains and pebbles, until the eggs hatched. If conspecific individuals tried to intrude into the nest area, the male actively drove them away by dashing toward the latter with lateral display and extended opercular region. If such displays were insufficient to expel the intruders, the defensive acts escalated, biting taking place.

Discussion

The present study showed that the body size is larger in males than in females of *Tridentiger kuroi-*

Table 2. Means and canonical coefficients used for discrimination of four sample categories of *Tridentiger kuroiwae brevispinis*

			Characters*					
			BL	HW	MW	D_3L	PcL	AL
Mean±S.E. (mm)								
Mature male		(n=75)	54.2±11.4	15.4±3.7	10.3±2.6	11.2±3.5	10.9±2.3	7.0±1.6
Immature male		(n=66)	46.5±10.0	13.1±3.1	8.3±2.1	7.5±1.9	9.5±1.7	5.8±1.2
Mature female		(n=50)	42.4±10.0	11.2±3.0	6.8±2.0	6.1±1.6	8.8±2.0	5.0±1.3
Immature female		(n=34)	39.7± 7.5	10.4±2.4	6.3±1.5	5.6±1.1	8.3±1.4	4.9±1.0
Total		(n=225)	47.2±11.5	13.0±3.7	8.3±2.7	8.1±3.4	9.6±2.2	5.9±1.6
CAN1	Standardized		−1.42	−1.75	2.81	1.98	−0.75	0.34
	Raw		−1.23	−4.74	10.50	5.91	−3.45	2.16
CAN2	Standardized		−4.47	4.26	0.98	−1.81	0.02	1.10
	Raw		−3.88	11.51	3.66	−5.40	0.09	6.96

* Abbreviations given in text.

wae brevispinis, this being consistent with reports on a congeneric species, *T. obscurus* (Nakamura, 1942; Egami, 1960; Kishi, 1979), and many other gobiids (Egami, 1960). It contradicts, however, reports on some other gobiids, such as *Chaenogobius laevis* (Kishi, 1981), *C. urotaenia* (cited as *C. annularis* by Egami, 1960) and *Leucopsarion petersi* (Egami, 1960), in which females are larger than males, and *C. isaza*, in which the body length does not differ between the sexes (Takahashi, 1974).

The result of the CDA, especially the squared Mahalanobis distance, showed that maturation-linked, morphological differences occur only in males and that even at a premature stage, some intersexual differences occurred. Among the eight morphological characters examined (other than BL), sexual dimorphism was recognized in HW, MW, D_3L and AL, relative lengths being greater in males than in females. Of these characters, the long D_3 in males, representing the largest intersexual difference, was apparently realized by elongation during maturation (Table 1). Hormonal processes are seemingly involved in such rapid growth, as suggested by an experiment with a steroid hormone in "*T. obscurus*" (Egami, 1960). According to Katsuyama et al. (1972), the relative length of D_3 was 16.3–52.0% in *T. obscurus* and 13.5–23.5% in *T. k. brevispinis*, which is consistent with the present findings. On the other hand, MW, HW and AL showed sexual differences prior to maturation, suggesting that the growth of these parts is subject to other mechanisms. At present the factor responsible for the rapid, strongly allometric growth of the D_3 in males during a short period of maturation is unknown.

The sexually dimorphic feature has possibly arisen through intrasexual and/or intersexual selection, and, in particular, from the polygamic mating system (Wilson, 1975). Goto (1984) discussed sexual dimorphism in *Cottus hangiongensis* in respect to that species' mating system and sexual selection. The preliminary observations here, which were consistent with observations by Kishi (1979, 1981), suggested that four dimorphic characters, HW, MW, D_3L and AL, play important roles in the reproductive behavior in *T. k. brevispinis.*

During the present observations, the mouth was often used by males for (1) fighting, if displays with the first dorsal fin erect were unsuccessful, and (2) removing sand grains and pebbles from the nest. The larger mouth of the male seems to impart greater ability for nest and/or egg mass defense against intruders, or agression against other nest-owning males. The observed male maintained D_3 erect, while attracting a partner to his nest and when threatening and expelling intruders. The longer D_3 may indicate the male's maturity and greater egg-caring capabilities to approaching females, as well as higher fighting capabilities to rival males and predators. The large head may be similarly effective. The long anal fin rays may be effective, not only in preventing the deposited eggs from being infested with fungi, but also in the lateral display in combination with the longer third dorsal fin ray (S. Takahashi, pers. comm.).

If these well-developed characters increase not only the male's reproductive chances but also the survival rate of eggs, the males with such characters may result in high reproductive output through both intersexual and intrasexual selections. Females that pair with such males may also receive higher reproductive benefits. To evaluate the comprehensive functions of these characters, however, quantitative as well as qualitative studies are needed.

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ヌマチチブの性的二型

増子勝男・山根爽一

茨城県北浦で 1990 年に採集したヌマチチブ *Tridentiger kuroiwae brevispinis* 225 個体の性的二型を分析した．成熟雄の平均体長は成熟雌よりも大きく (54.2 vs. 42.4 mm)，また，成熟雄の頭幅と口幅，第一背鰭第三棘長，尻鰭軟条長の体長に対する相対長は成熟雌よりも有意に大きかった．特に，第一背鰭第三棘の相対長の性差は，成熟雄と雌の間で最大で (0.20 vs. 0.14)，これは，雄の第一背鰭第三棘が成熟にともない強い相対成長を示したため生じたものであった．室内水槽でのヌマチチブの繁殖行動の予備的観察から，これらの形質は雄の繁殖上，求愛や雄同士の闘争において重要な役割を果たしていることが予想され，結果として，雌雄の繁殖成功率に影響を与える可能性が示唆された．

(〒310 水戸市文京 2 丁目 1-1　茨城大学教育学部生物学研究室)