アユの臀鰭における性的二型

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Sexual Dimorphism in the Anal Fin of Ayu *Plecoglossus altivelis*

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Sexual dimorphism in the anal fin of ayu *Plecoglossus altivelis* was studied by serial sampling of ayu. Changes in the shape of the anal fin were triggered by sexual maturation in both sexes; however, secondary sexual characteristics developed drastically in males while they did so inconspicuously in females. The anal fin base became larger in both sexes during sexual maturation, but grew much faster in males than in females, and consequently males have larger anal fin bases than females. Secondary changes in the anal fin height occur only in males, and the change is negative, and consequently females have larger anal fin height than males. The relationship between the shape of the anal fin and the sex hormone levels in diploid and triploid ayu suggested that the development of secondary sex characteristics in the anal fin of ayu is controlled by androgens.

Many sexual dimorphisms are caused by secondary changes in males.[1] Secondary sexual characteristics in males are often interpreted as promoting success in male-male competition or female choice, and hence increasing opportunities for mating.[2] Close to the spawning season, ayu *Plecoglossus altivelis* develops some secondary sexual characteristics involving body shape, pearl organs, body color, and fin size, in which the sexual dimorphism in the anal fin is particularly conspicuous.[3-5] The lengths of the dorsal, pelvic, and pectoral fins are larger in males than in females as in many other fish species showing sexual dimorphism in fins.[6] In the anal fin, the base length is larger in males than in females, while the height is larger in females than in males. However, the development of the sexual characteristics in the anal fin has not yet been clearly documented. In the present study, we examined changes in the shape of the anal fin by serial sampling of ayu and evaluated the influence of sex hormone levels on the shape of the anal fin.

Materials and Methods

Fish were fed with crumble pellet in outdoor ponds ($1\times5\times0.5$ m in depth) supplied with running water (120 *l*/min) from the Chihuma River from early May. Weights of body and gonad were weighed to the nearest 0.1 g. Standard length (SL), length of anal fin base (LAB), and height of the anal fin (HA) were measured to the nearest 0.1 mm. The sexuality of all fish was determined by visual examination of the gonads.

Changes in the shape of the anal fin were examined with two groups of fish which had been captured in Lake Biwa. Since morphological variables usually change not isometrically but allometrically relative to body size,[7] one group was fed sufficiently (SF group) to attain full growth in the body size and the other group was fed restrictively (RF group) so as not to increase in body size. Fish in SF group were fed 0.4–2.0% of body weight three times per day depending on the water temperature and were sampled every 10 days from June to October, 1988. Mean SL ($X\pm$SD, $N=10$) at the beginning of the experiment was 86.1 ± 7.7 mm in males and 84.0 ± 5.0 mm in females, and at the end of the experiment was 176.2 ± 9.5 mm in males and 172.7 ± 13.7 mm in females. Fish in the RF group were fed 0.2–0.6% of body weight three times per day depending on the water temperature and were sampled every ten days during the sexual maturation period from August to October, 1989. Mean SL ($N=5$) at the beginning of the experiment was 85.8 ± 3.3 mm in males and 84.0 ± 4.2 mm in females, and at the end of the experiment was 83.8 ± 4.0 mm in males and 82.4 ± 5.6 mm in females. No significant increasein SL was re-

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cognized during the experimental period in either sex (paired t-test, NS at 10% level). Although these fish showed no increase in SL, they spawned on artificial spawning grounds.

The influence of the sex hormone level on the shape of the anal fin was evaluated by comparisons between diploid ($2N$) and triploid ($3N$) fish. Triploid ayu is known to be sterile in both sexes.[8] They were produced by the Gifu Prefectual Fisheries Experimental Station and were reared with a sufficient amount of food. The fish were sampled on September 22, 1987, and the mean SL (N=30) attained 190.3±6.6 mm for $2N$ males, 189.6± 4.9 mm for $3N$ males, 188.5±5.1 mm for $2N$ females, and 189.7±6.7 mm for $3N$ females. No significant difference was recognized among these four mean values (NS at 10% level). Each of 5 fish was measured their serum steroid hormone levels by radioimmunoassay, according to Aida *et al.*[9] and Lou *et al.*[10] (2,4,6,7-3H) estradiof-17β and (1,2,6,7-3H) testosterone were used as labeled hormones.

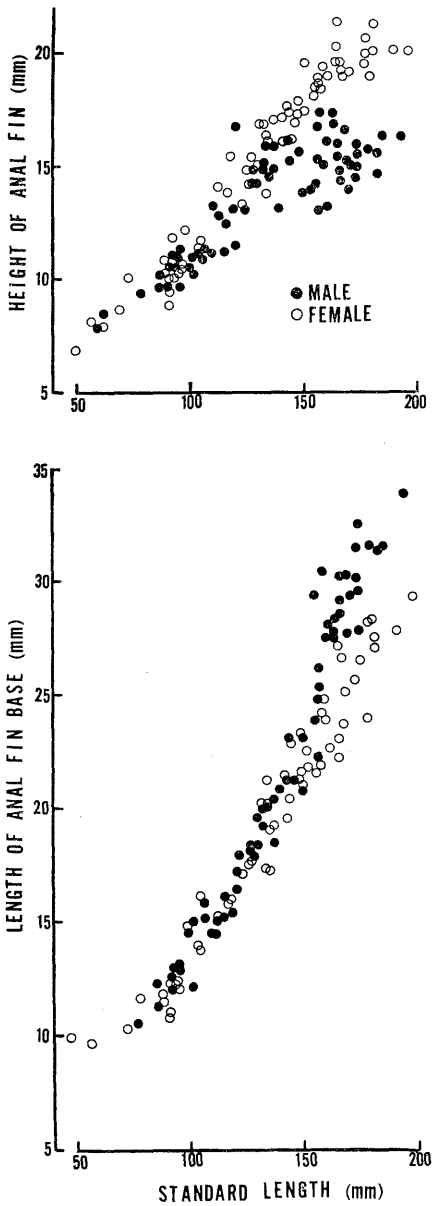

Fig. 1. Relationship of the length of the anal fin base and the height of the anal fin to the standard length in ayu reared in 1988 with a sufficient amount of food.

Results

LAB and HA of the individuals of SF group showed difference by sex with increases in SL (Fig. 1). The male LAB became larger than the female, while the female HA became larger than the male. In addition, the rays of the male anal fin were thickened, and pearl organs appeared on the fin rays. The gonadosomatic index (GSI) of both sexes showed a rapid increase from August (Fig. 2). The regression equations of LAB and HA to SL of the individuals of SF group are shown in Table 1. The slope in the regression of LAB to SL after August was larger than that before

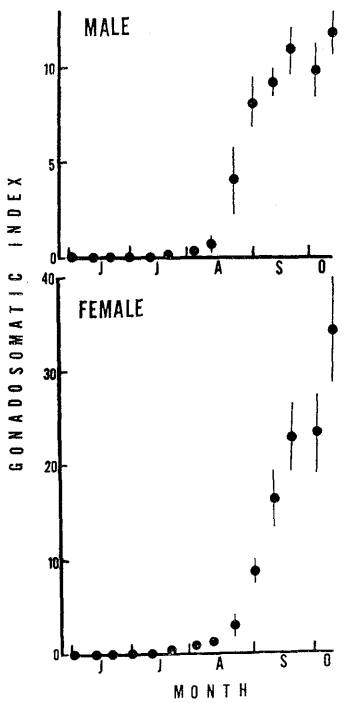

Fig. 2. Changes in the mean gonadosomatic index (X±SD, N=5) in ayu reared in 1988 with a sufficient amount of food.

Table 1. Regressions of the length of anal fin base (LAB) and the height of the anal fin (HA) to the standard length (SL) of SF group for each sex before and after August, 1988

		Length of anal fin base	Height of anal fin
Before August	Male	log LAB=0.647 log SL−0.139 (N=31, r=0.86, P<0.001)	log HA=0.675 logSL−0.298 (N=31, r=0.90, P<0.001)
	Female	log LAB=0.649 log SL−0.154 (N=28, r=0.83, P<0.001)	log HA=0.881 log SL−0.703 (N=28, r=0.89, P<0.001)
After August	Male	log LAB=1.667 log SL−2.251 (N=42, r=0.95, P<0.001)	log HA=0.175 log SL+0.792 (N=42, r=0.23, NS)
	Female	log LAB=1.101 log SL−1.054 (N=37, r=0.92, P<0.005)	log HA=0.675 log SL−0.216 (N=38, r=0.77, P<0.001)

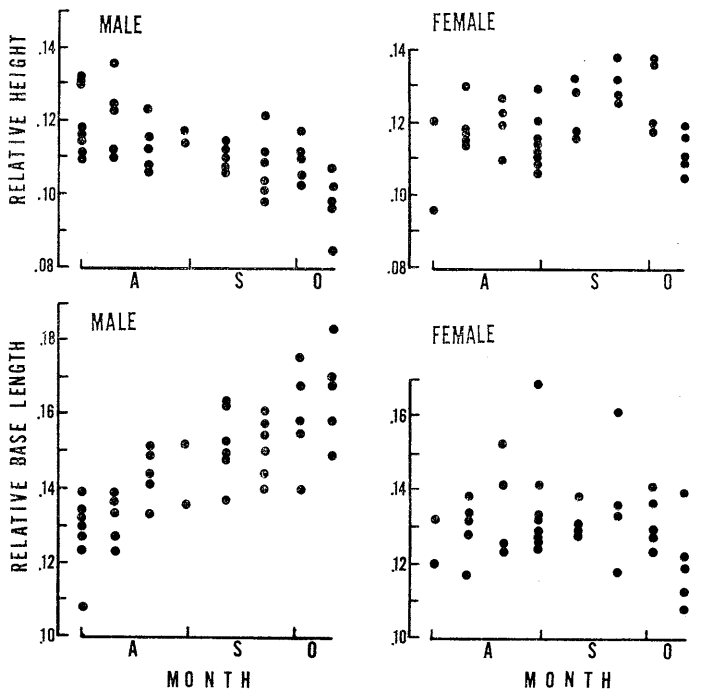

Fig. 3. Changes in the base length and the height of the anal fin relative to the standard length in ayu fed restrictively so as not to increase in standard length during the sexual maturation period in 1989.

August for both sexes (males, P<0.001; females, 0.05>P>0.01). These slopes showed no statistical differences between the sexes before August (NS at 10% level), but were larger in males than in females after August (P<0.001). In the regression of HA to SL, females showed no statistical difference in the slope between fish sampled before and after August (NS at 10% level). The males slope had a tendency to be smaller than the female before August (0.1>P>0.05). After August, statistical comparison of the male slope was judged unneccesary because the regression of HA to SL was non significant at the 10% level due to the large variation of HA in males.

In the RF group, in which no increase in SL was observed, the mean GSI (N=10) at the beginning of the experiment was 0.02±0.07 in males and 0.85±0.18 in females, and at the end of the experiment was 6.41±1.54 in males and 19.69±1.54 in females. During the sexual maturation period, changes in the relative anal fin size were observed in males, but not so clear in females (Fig. 3). In males, LAB/SL increasedw ith time (Kendall's τ=0.638, P<0.001), whereas HA/SL decreased with time (τ=−0.480, P<0.001). In females, however, LAB/SL and HA/SL did not change with time (τ=−0.057, NS at 10% level and τ=0.057, NS at 10% level, respectively).

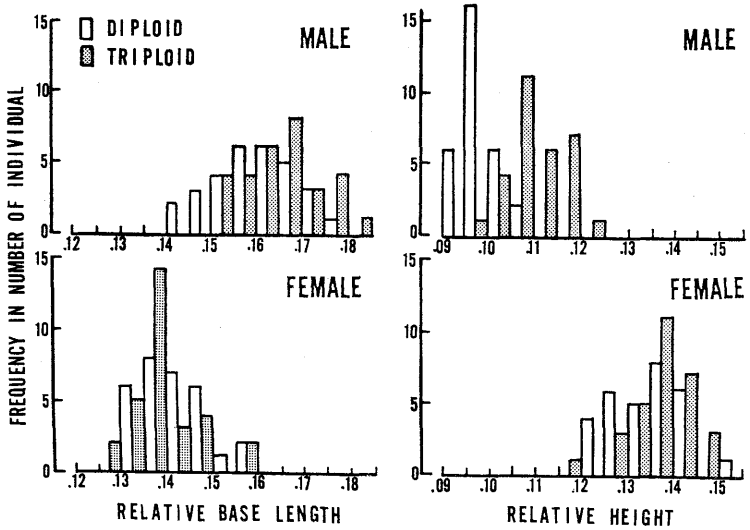

Fig. 4. Frequency distributions of the base length and the height of the analfin relative to the standard length in diploid and triploid ayu (each $N=30$) sampled on September 22, 1987.

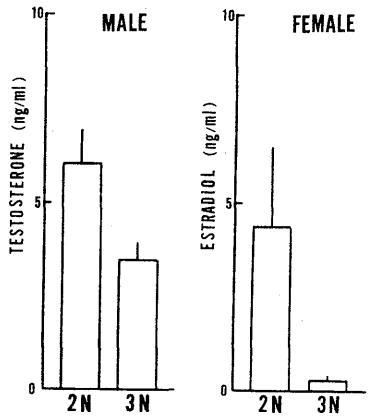

Fig. 5. The mean sex hormone levels ($X\pm$SD, $N=5$) in the serum in diploid and triploid ayu sampled on September 22, 1987.

Frequency distributions of LAB/SL and HA/SL were compared between $2N$ fish of the same age in the sexual maturation period of $2N$ fish (Fig. 4). In females, the mean values of LAB/SL and HA/SL showed no statistical differences between $2N$ and $3N$ fish (NS at 10% level). In males, however, the mean value of LAB/SL was smaller in $2N$ fish than in $3N$ fish ($P<0.01$) and that of HA/SL was much larger in $2N$ fish than in $3N$ fish ($P<0.001$). The mean GSI ($N=5$) was 8.52 ± 0.59 in $2N$ males, 5.53 ± 1.02 in $3N$ males, 6.73 ± 0.72 in $2N$ females, and 0.16 ± 0.08 in $3N$ females. Fish of $2N$ had higher sex hormone levels in serum than $3N$ fish of both sexes ($P<0.001$, respectively) (Fig. 5).

Discussion

The dorsal, pelvic, and pectoral fins of ayu are known to become larger in both sexes during the sexual maturation period but grow much faster in males than in females.[5] The secondary changes in the length of the anal fin base show the same pattern as the dorsal, pelvic, and pectoral fins, and consequently males have larger anal fin base than females near the spawning season. Secondary changes in the height of the anal fin occur only in males, and the change is negative, and consequently females have larger anal fin heights than males near the spawning season. Differences in the anal fin shape of ayu between diploid and triploid fish are discriminated only in males, although diploid fish near the spawning season show higher sex hormone levels in serum than triploid fish of both sexes. As in many other fish species,[11-13] the morphological change in the anal fin is considered to be controlled by androgens. It can be concluded that sexual dimorphism in the shape of the anal fin is attributed, in particular, to the consipicuous modification in males.

Secondary sexual characteristics in males are often considered to have evolved through sexual selection to promote success in male-male competition or female choice.[2] In Atlantic salmon *Salmo salar* male, body size and kype size are correlated with male dominance rank, and males signal their dominance rank by their relative kype size.[14] Dominant males having conspicuos secondary sexual characteristics are able to mate

more frequently. The anal fin size of ayu relative to the body size is almost equal among individuals regardless of body size,[5] although territoriality in the non-breeding season or migratory pattern in Lake Biwa make for considerable variation in body size within a population,[15-17] and spawning occurs mainly at night while densely crowded together.[18-21] The secondary sexual characteristics in the male anal fin of ayu may thus not function to signal dominance rank, as with Atlantic salmon. Secondarily changed fins of some other fishes are known to have practical functions. For example, male long finned smelt *Spirinchus lanceolatus* which belong to the same family as ayu and also show sexual dimorphism in the anal fin cover the genital pore of the female with the anal fin at spawning.[22] This behavior is assumed to enhance fertilization in rapid currents.[23] Spawning of ayu involves quivering the body and fins, and the eggs are thereby deposited in the gravel.[19] Since quivering is observed only in males,[24] the anal fin of males with shortened and thichened rays and larger base probably favors this action.

Acknowledgements

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