RELATIONSHIP BETWEEN EXTERNAL AND INTERNAL MORPHOLOGICAL CHANGES AND FEEDING HABITS IN THE FRY STAGE OF JAPANESE CATFISH *SILURUS ASOTUS*

Osamu Yada*
System Development Center, Hitachi Air Conditioning Systems Co., Ltd.,
508-8, Toyofuta, Kashiwa, Chiba 277-0872 Japan
*Tel: 011-81-471-32-8191; Fax:011-81-471-31-5309; e-mail: o-yada@hitachiacs.co.jp
and
Atsushi Furukawa
Colloquium on Aqua Breeding Technique, 4-26-927, Wakabadai,
Asahi, Yokohama, Kanagawa 241-0801 Japan

ABSTRACT

The prevention of sibling cannibalism during the early stages of development is a very important consideration for the successful seed production of the Japanese catfish *Silurus asotus*. Although several methods have been tested for this purpose, none thus far has reliably reduced cannibalism-induced mortality to acceptable levels. To clarify the phenomenon of sibling cannibalism, a study was carried out on the relationship between external and internal morphological changes and feeding habits during the fry stage of Japanese catfish. The results show that the growth of body height and mouth width were temporarily arrested when the fry attained a total body length of 40 mm and at the time of disappearance of the mandibular barbels, respectively. Furthermore, the relationships between the length of the stomach and intestine *versus* the total body length (TL) were best described by sigmoid curves.

INTRODUCTION

The Japanese catfish *Silurus asotus* is well known as a carnivorous fish and is widely distributed in Japan (Miyadi et al. 1976). In seed production of this species, biting and cannibalistic behavior were recognized about 40 d after hatching, inducing high mortality. Although several methods have been tested for the prevention of sibling cannibalism, for example, localization by shelter (Fukuda 1974; Umezawa et al. 1994a) and dispersion by aeration (Fukuda 1974), none have reliably reduced cannibalism-induced mortality to acceptable levels. According to a very recent study, the observed cannibalism is related to the feeding (quality and quantity) and the density of the larvae (Umezawa et al. 1994b; Kuruma and Nomura 1997; Tejima et al. 1996, 1997). It has also been reported that mortalities due to cannibalism can be effectively reduced if larvae are raised quickly at an optimum temperature to shorten the developmental periods of when cannibalism occurs. However, despite these technical developments, little is known about the relationship between the morphology and feeding habits during the early growth stages of Japanese catfish.

In general, it is well known that the Japanese catfish fry have an interesting external morphological change involving the disappearance of a pair of mandibular barbels. Regarding this point, Atoda (1935) reported that the fry of the Japanese catfish possessed two pairs of mandibular barbels. One was permanent and the other was temporary. Sato and Katagiri (1966) reported that the temporary mandibular barbels showed signs of degeneration at 35 mm TL when Japanese catfish were reared in the laboratory. These fell off spontaneously in fishes ranging in size of 60-70 mm TL, and ultimately disappeared (Atoda 1935).

Regarding internal morphological changes, Suyehiro (1942) and Ishida and Sato (1960) reported the development of the digestive system in detail. However, their body sizes were not clarified and the individuals investigated were more than 200 mm TL. There is little information on the relationship between the morphology and

feeding habits during the fry stages of the Japanese catfish.

In this study, we describe the relationship between the external and internal morphological changes and feeding habits during the fry stage of Japanese catfish reared in the laboratory in an attempt to clarify the phenomenon of sibling cannibalism.

MATERIALS AND METHODS

Capture of Mature Fish

During the spawning season of June 1998, mature Japanese catfish were captured with a small set-net "Fukube ami" from an irrigation creek in the tributary of the Omonogawa River, Akita, Japan. The captured fish were transferred to the laboratory and kept in a stock pond until collection of eggs and sperm. Mature fish were selected by body size, palpation, and the shape of the caudal fin. It was easy to distinguish the sex of the fish using these criteria.

Collection of Eggs and Sperm

The collection of eggs and sperm was done according to the methods described by Kuge et al. (1989), Kanazawa and Tasaki (1989), and Nomura (1996). To induce final maturation selected individuals were given an intraperitoneal injection with human chorionic gonadotropin (HCG) at a dosage of 10,000 IU/kg BW for females and 5,000 IU/kg BW for males, respectively. Oocytes underwent final maturation and ovulation between 16 h and 20 h after injection. Determination of male maturation was very difficult, and the quantity of collected sperm was very poor. Therefore, the testes were removed and homogenized with 0.6% Ringer solution, and a sperm suspension was prepared for use in artificially fertilizing the eggs.

Fertilization and Incubation

Artificial fertilization was conducted using the dry-method technique and the percent fertilization was high, ranging from 80 to 99%. Fertilized eggs were incubated at 20 C on hatching trays with a continuous water exchange. The eggs hatched out after 96 h of incubation and the percent hatch ranged from 80 to 93%.

Rearing of Larvae

A brood of Japanese catfish larvae was reared at 20 C in a 100-L polycarbonate tank equipped with a sponge filter. Feed was given three times daily at 0900, 1300, and 1700 and was supplied at about 40% of the body weight with *Daphnia* sp. for the first 14 d after hatching. Switching from the live feed to a formulated feed used for marine fish larvae (crude protein content: 52%, Nippon Nosan Kogyo K.K.) took place gradually from 8 to15 d after hatching. The formulated feed was given daily in three equal rations at 0900, 1300, and 1700, and providing the formulated feed to satiation of the larvae began from16 to 60 d after hatching. The Japanese catfish fry was later weaned on to a commercial carp feed (crude protein content: 39%, Nippon Formula Feed Mgf Co., Ltd.) and resulted in good growth (Fig. 1.).

Sampling and Measurements

The experimental fish were sampled periodically and fixed in 10% formalin for external and internal morphological investigations. The body weight (wet weight) for the preserved specimens was measured 6 mo after fixation. The following body parts were also measured: total body length (TL), body height (BH), mouth width (MW), and the number of barbels were recorded.

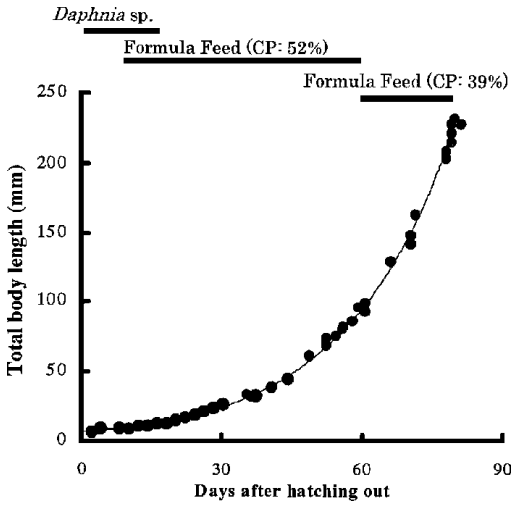

Figure 1. Increase in total body length of Japanese catfish *Silurus asotus* reared at 20 C. Feeding schedule is illustrated at the top of the figures.

Regarding the internal morphology, the coiling of the digestive tract was observed by first removing it from the body cavity and sketching it from the ventral side. The digestive tract was divided into the stomach and intestine parts. Distinguishing between the esophagus and stomach was difficult and the thinnest portion of the tract between the esophagus and the stomach was used as the division point for measurements of the length of the stomach parts (SPL; S-1, S-2, S-3, Fig. 2.). The intestine part length (IPL) was carefully measured using calipers as described by Suyehiro (1942).

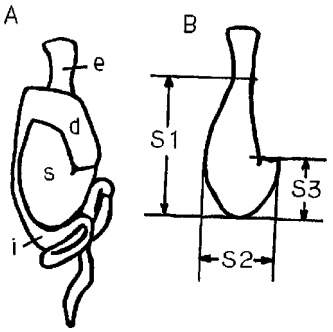

Figure 2. Digestive tract in Japanese catfish *S. asotus*. A, ventral view of digestive tract; B, measuring points of stomach parts (ventral view). e, esophagus; s, stomach; d, duodenum; i, intestine.

RESULTS

External Morphological Changes

The relationship between the body height and mouth width versus total body length are shown in Fig. 3. Although the BH and MW increased in proportion to the increase in TL, their continued development was temporarily arrested when the fry attained a size of 40 mm TL. At this size (age) the disappearance of the mandibular barbels also occurred. Moreover, the catfish larvae acquired the adult body shape when at 40 mm TL, and possessed three pairs of barbels. Cannibalistic behavior was observed when fry ranged in size from 20 mm to 80 mm TL.

Internal Morphological Changes

A diagram of the stomach and intestine of the Japanese catfish are shown in Fig. 2. Suyehiro (1942) previously reported the I-shape of the stomach. However, from specimens

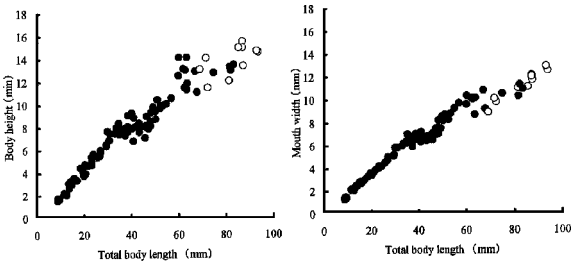

Figure 3. Relationship between body height and mouth width versus total body length in Japanese catfish *S. asotus*. Closed symbols, 3 pairs of barbels; Open symbols, 2 pairs of barbels.

examined during the current examination reveal a structure more like a V-shape. Ohara (1987) also reported that the stomach was generally short, and was closely related to a V-shape. The stomach and intestine were easily discerned by a valve and from their outward appearance. Although measuring the stomach length was attempted, accurate measurements could not be made due to the expansion and contraction of the stomach.

Illustrations of the digestive tract in Japanese catfish are shown in Fig. 4. The morphological changes in the intestines are indicated according to the method described by Kafuku (1952). They were as follows: body length of 22 mm (A), the intestine continues from the pyloric region and is very thick, crossing the esophagus to the lower right part of the fish's body in an arc. It then bends back again to the pyloric region of the stomach and reaches the anus.

At a body length of 44 mm (B), the intestine moves upwards, turns to the left, and bends back at the crossing point of the esophagus. After that, it moves downward along the stomach

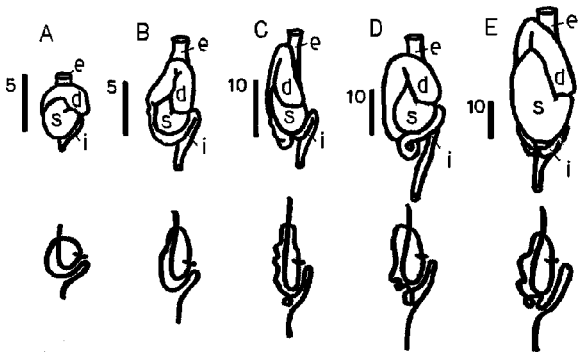

Figure 4. Illustrations of the digestive tract in Japanese catfish *S. asotus* at different stages during growth. A, 22 mm TL; B, 44 mm TL; C, 108 mm TL; D, 169 mm TL; E, 195 mm TL.

surface and upward while again drawing an arc before reaching the anus.

At a body length of 108 mm (C), the intestine was twice as small going toward the body cavity back from the stomach surface. It bends back once or twice at the lower end of the stomach and once at the pyloric region before reaching the anus. Although the coiling patterns of the intestine were similar to each other, they became more complex after the disappearance of the temporary mandibular barbels (Fig. 4. (C), (D), (E)).

Relationship Between SPL and TL

The relationship between the stomach parts length (SPL) and total body length (TL) is shown in Fig. 5 and is best described as a sigmoid curve. After the disappearance of the temporary mandibular barbels, the growth of the stomach parts were temporarily arrested at a body length ranging from 70 to150 mm. The change in stomach part (S1) was greater in comparison with the other parts (S2, S3).

Relationship Between IPL and TL

The relationship between the intestine parts length (IPL) and total body length (TL) is shown in Fig. 6, can also be best described as a sigmoid curve. The growth of the intestine was temporarily arrested at a body length ranging from 100 to150 mm. The changes in the intestine occurred later than those observed in the stomach.

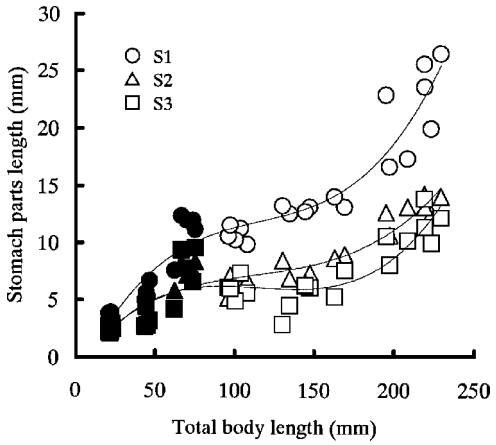

Figure 5. The relationship between stomach parts length and total body length in Japanese catfish *S. asotus*. Three parts of stomach (S1, S2, S3) are shown in Fig. 2. Closed symbols, 3 pairs of barbels; Open symbols, 2 pairs of barbels.

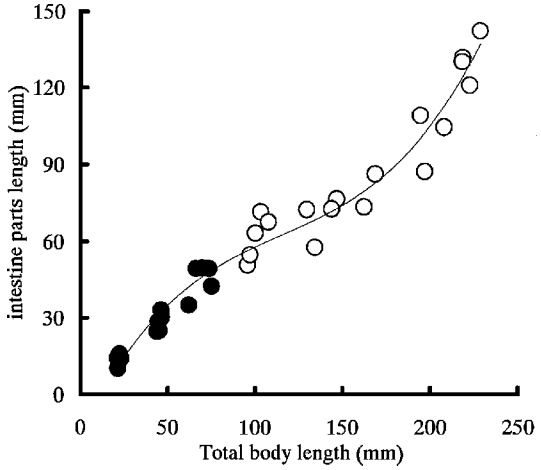

Figure 6. The relationship between the intestine parts length and total body length in Japanese catfish *S. asotus*. Closed symbols, 3 pairs of barbels; Open symbols, 2 pairs of barbels.

Although the temporary mandibular barbels were just recognizable at a body length of 70 mm, they almost disappeared at the body length of 100 mm.

DISCUSSION

The Japanese catfish *Silurus asotus* is well known as a carnivorous fish during its early developmental stages. During the culture process, the larvae actively shook their bodies continuously both to the right and left. When their barbels touched the body or caudal fin of another individual, a biting behavior was observed. From the recorded culture data, the mortality was high between 6 and 20 d after hatching. The percent survival at 30 d after hatching was 0.5% (initial, 12,045; final, 56; dead, 7,095; unknown, 4,894). Mutual biting was perceived as the main cause of mortalities and the "unknowns" were attributed to cannibalism. Judging from the observations made during the rearing process, the mouths that were suitable to hunt and swallow smaller fish were very large during the larval stage. Moreover, the temporary arrestment of BH and MW occurred at the same time as the when the adult form was attained and the mandibular barbels disappeared.

Regarding the relationship between body size and cannibalism, Hirakawa et. al. (1997) reported that cannibalism was occurring when larvae ranged between 10 and 15 mm to 70 mm TL, and not at the first feeding stage. Moreover,

Umezawa et. al. (1994a) observed a cloudiness from the tail to hind body portions of the bodies of some individuals to the exposure of caudal vertebra as early as 10 d after hatching.

According to reports from the Saitama Prefectural Fisheries Station (1992), cannibalism did not occur in fish more than 7.8 g in weight. To confirm this report, a rearing experiment was conducted in 1999 using fry that were more than 8.0 g in body weight. Percent survival after 3 mo in culture was 84% which is consistent with what was reported previously.

The disappearance (degeneration and disappearance) of the temporary mandibular barbels was the most noticeable external morphological change that was observed. The catfish apparently used the barbels to search for food, and when touching another individual instinctively tries to swallow the other individual from the head. It is also known that the barbels function as taste buds reacting to mechanical and chemical stimulation (Bardach et al. 1967). The function(s) of the temporary mandibular barbels are of great interest and an obvious area of future investigations.

Cannibalism in the Japanese catfish may also be related to external and internal morphological changes during the early stages of growth. The mouth and stomach were very large and although there is no valve between the esophagus and stomach, the sphincter does not restrict the possibility for larger catfish fry to swallow smaller catfish fry easily. Cannibalistic activity increased in fry above 20 mm TL and decreased after they ranged in size from 70 to 100 mm TL. This response was also coincident with the disappearance of the temporary mandibular barbels. In contrast, the internal morphological changes were expressed later than the external changes (Fig. 3).

In general, it is well known that the ratio of intestine length and total body length (relative length of gut, RLG) approximates a value of one or less (Takeuchi 1991). In the current investigation, the RLG in catfish fry was from 0.6 when individuals were 100 mm TL, 0.25 when 100-150 mm TL, and then 0.6 again when ranging from 150 to 200 mm TL (Fig. 6).

These results indicate that the relationship between external and internal morphological changes and feeding habits in Japanese catfish fry may be closely related and the feeding habits were different between fry and early larval stages in this species. It is still not clear as to the significance of the temporary curtailment in growth of body height, mouth width, or length of stomach parts and intestine parts during development. An examination into Japanese catfish fry bred at high temperatures and fed the same diet is currently underway to shed some light on this observation. Furthermore, research on the barbels, digestive enzymes, reproductive endocrine systems, and genetic factors are being investigated in order to clarify the phenomenon of cannibalism in the Japanese catfish *Silurus asotus*.

ACKNOWLEDGMENT

The authors thank Mr. Shingo Tanabe and Mr. Michihiro Ishida of Masuda Town Office, Akita prefecture, for their excellent technical support in performing the experiments.

LITERATURE CITED

Atoda, K. 1935. The larva of the catfish: Parasilurus asotus L. Sci. Rep. Tohoku Imp. Univ., Fourth Series (Biology). 10(1): 29-32.

Bardach, J.E., J. H. Todd and R. Crickmer. 1967. Orientation by taste in fish of the genus *Ictalurus*. Science. 155: 1276-1278.

Fukuda, M. 1974. Seed production of Japanese catfish, *Silurus asotus* (volume V). Rep. Saitama PrefecturalFisheries Station. 33: 1-4.

Hirakawa, N., T. Takeuchi, K. Sakai, T. Watanabe. 1997. Feeding trial of larval Japanese catfish using live food or formulated micro-diets. Jour. Tokyo Univ. Fisheries. 83(1·2): 43-52.

Ishida, M. and M. Sato. 1960. The anatomical and histological observation of the alimentary tract of a catfish *Parasilurus asotus* (L). Sci. Rep. Fac. Lit. Sci., Hirosaki Univ. 7(2): 57-63.

Kafuku, T. 1952. Races of wild gold-fish with special reference to the digestive tract. Bull. Freshwater Fish. Lab. 1(1): 41-56.

Kanazawa, H. and S. Tasaki. 1989. Studies on the artificial stripping of natural grown catfish *Silurus asotus*. Rep. Saitama Prefectural Fisheries Station. 48: 57-62.

Kuge, T., E. Matsuoka, K. Konishi and S. Kobayashi. 1989. Fundamental research on propagation and culture of Japanese catfish, *Silurus asotus*. Gunma Journal of Agricultural Research E Fisheries. 5: 36-43.

Kuruma, A. and H. Nomura. 1997. Stocking density and feed at the early stage of feeding to Japanese catfish, *Silurus asotus*. Rep. Saitama Prefectural Fisheries Station. 55: 1-5.

Miyadi D., H. Kawanabe and N. Mizuno. 1976. Colored Illustrations of the Freshwater Fishes of Japan. New edition completely revised. Hoikusha, Osaka, Japan, 462 p.

Nomura, H. 1996. Culture technology of the Japanese catfish. Top. Youshoku. 33(6): 70-74.

Ohara, K. 1987. Japanese catfish. Atlas of fish anatomy (A. Ochiai, ed.). Midori-syobou, Tokyo. Japan. p. 111-116.

Saitama Prefectural Fisheries Station. 1992. Business Rep. Saitama Prefectural Fisheries Station in 1992. p. 36.

Sato, M. and Y. Katagiri. 1966. Regeneration of the mandibular barbels of the fry of the catfish, *Parasilurus asotus*, and comparison of histological structure of the mandibular barbels of three catfishes inhibiting Lake Biwa. Jap. Jour. Ichthyology. 13(4/6): 169-175.

Suyehiro, Y. 1942. A study on the digestive system and feeding habits of fish. Jap. J. Zool. 10(1): 1-303.

Takeuchi, T. 1991. Digestion and Nutrition. Fish physiology, pp. 67-101. *In:* Y. Itazawa and I. Hanyu, (eds.), Koseisha -Koseikaku, Tokyo, Japan.

Tejima, C., H. Arai and A. Sato. 1996. Cannibalism prevention test for catfish. Rep. Gunma Fisheries Experiment Station. 1: 60-63.

Tejima, C., N. Shimizu, H. Tanaka, Y. Matsui and A. Sato. 1997. Cannibalism prevention test for catfish (II) . Rep. Gunma Fisheries Experiment Station. 3: 45-48.

Umezawa, K., S. Suzuki and F. Tanaka. 1994a. The influence of the shelter upon a survival rate of Japanese catfish fry *Silurus asotus*. Rep. Saitama Prefectural Fisheries Station. 52: 93-96.

Umezawa, K., S. Suzuki and F. Tanaka. 1994b. The influence of stocking density upon a survival rate of Japanese catfish fry *Silurus asotus*. Rep. Saitama Prefectural Fisheries Station. 52: 89-92.