OTSUCHI MARINE SCIENCE 28: 45–51 (2003)

Growth rates, relative growth and a potential aging method using vertebral centra in *Silurus biwaensis* (Siluriformes: Siluridae)

Noriyuki Takai[1) 2)] *, Takashi Kitagawa[1) 3)], Midori Kobayakawa[4)], Yasushi Mitsunaga[1) 5)], Masayoshi Maehata[6)] and Wataru Sakamoto[1)]

[1)] *Faculty of Agriculture, Kyoto University, Kyoto 606–8502, Japan*
[2)] *Present address: Shimoda Marine Biological Station, College of Bioresource Sciences, Nihon University, Shimoda 415–0014, Japan*
[3)] *Present address: Ocean Research Institute, University of Tokyo, Tokyo 164–8639, Japan*
[4)] *Faculty of Science, Kyushu University, Fukuoka 812–8581, Japan*
[5)] *Present address: Faculty of Agriculture, Kinki University, Nara 631–8505, Japan*
[6)] *Lake Biwa Museum, Kusatsu 525–0001, Japan*
* *E-mail: takai@brs.nihon-u.ac.jp*

Received: 24 September 2002
Accepted: 7 January 2003

Relative growth and relationship between age and growth in *Silurus biwaensis* were examined on the basis of the body size data of the catfish collected from Lake Biwa and the reared catfish which were hatched from artificially inseminated eggs. Although it had been reported that the proportion of head length to body length increased with growth in *S. biwaensis*, such a relationship was not found for 218 catfish that were examined in this study. On the other hand, the proportion of head length to head width significantly decreased with SL in females. This result indicated that the narrow head shape peculiar to *S. biwaensis* becomes slightly squarer in bigger females. The three catfish reared from the hatching grew to 196–410 mm SL for 2.7 years (73–152 mm/yr). This growth rate was in contrast with that of a tagged adult male, which grew only 50 mm from 460 mm SL to 510 mm SL in the lake for two years (25 mm/yr). These results suggested that the growth of the adults might extremely slow down after the fast growth at the immature stage. This study also reported that the number of transparent zones in vertebral centra of *S. biwaensis* increased with growth. The vertebral centrum may possibly be utilized as an age indicator for this species and the other kinds of Silurid.

Key words: *Silurus biwaensis*, growth, age, proportion, vertebral centra

INTRODUCTION

The catfishes of the genus *Silurus* are broadly distributed throughout Eurasia from Europe to Japan, inhabiting not only freshwater ecosystems but also brackish waters such as estuaries and the Caspian Sea (Kobayakawa 1989). They often grow into the biggest fish in the local ecosystems; the maximum body size reaches three meters in *Silurus glanis* (Harka 1984). Such prominent growth makes it possible for these catfishes to position the top of the local ecosystems (Tomoda 1962, Xie and Sun 1993).

Silurus biwaensis, which is endemic to Lake Biwa and Yodo River watershed, Japan, is the biggest fish in the areal ecosystems. This species mates and spawns along rocky or stony shores flooded in the rainy season, from June to August, and its reproductive behavior can be observed along the shorelines at night (Tomoda 1978, Maehata et al. 1990). The eggs are adhesive and the larvae hatch 48 hours after fertilization and are already benthic, having no planktonic period (Tomoda 1978, Kobayakawa 1985). Occasionally fishermen capture the juveniles of about 50–100 mm TL in autumn and the young of about 150–200 mm TL in early summer (Tomoda 1978).

Although such fragmentary and ambiguous information about their growth has been accumulated, relationship between age and growth are not yet clear. Thus in the present study, the growth characteristics of *S. biwaensis* were inferred on the basis of the body size data of the catfish collected from the lake and the reared catfish which were hatched from artificially inseminated eggs. Particularly, we examined changes in body proportion with growth in *S. biwaensis*. Tomoda (1962) reported that the proportion of head length to body length increased with growth in this species, in contrast to that this proportion decreased with growth in the other two Japanese Silurids, *Silurus asotus* and *Silurus lithophilus*. We focused on this specific characteristics of the head growth in *S. biwaensis*, considering the ontogenetic change of head width as well as head length.

Furtheremore, we dealt with the method of determining the age of *S. biwaensis*, in order to present the basis for the growth study of this species and the other *Silurus* catfishes. The previous studies regarding the growth have only shown that rays of pectoral fins are useful for the growth study of the *Silurus* (Harka 1984, Orlova 1987, Harka and Bíró 1990). However, the erosion of the earliest formed material with age makes it difficult to determine the growth rate of the catfish with this character precisely. Therefore, this study examined the usefulness of the vertebral centrum of *S. biwaensis* as a potential age indicator, since this character is not exposed to the ambient water and thus can avoid the erosion of the earliest formed material.

MATERIALS AND METHODS

Lake Biwa consists of two distinct areas; the broad and deep "North Basin" averaging 43 m in depth and the small and shallow "South Basin" averaging 4 m in depth (Fig. 1). Fishermen often capture *S. biwaensis* around the spawning areas in the northern North Basin and the southernmost

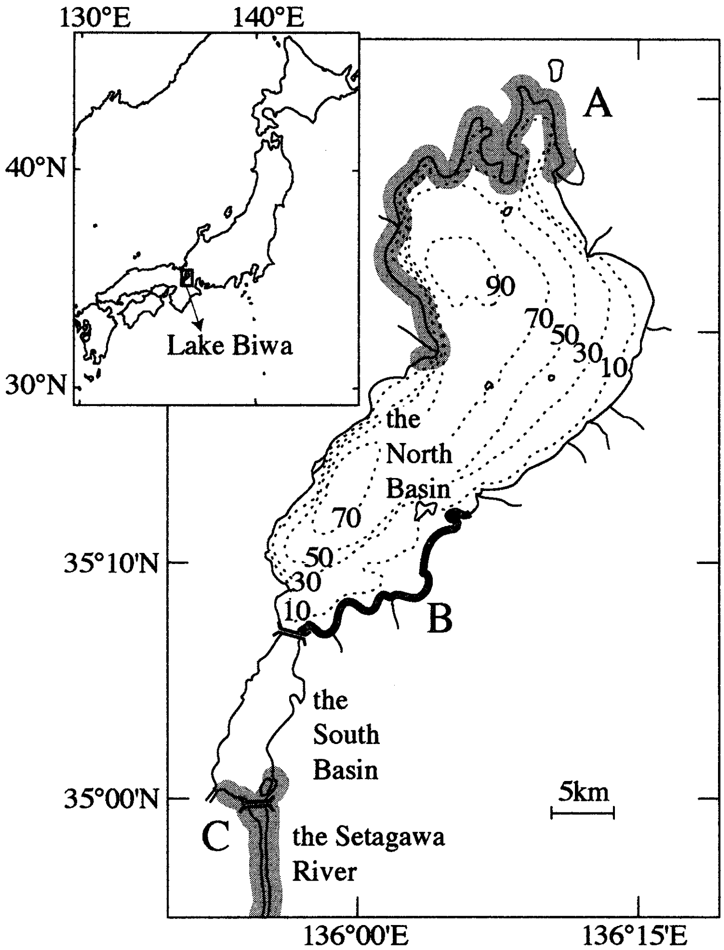

Fig. 1. Sampling locations in Lake Biwa. The samples were captured along the shorelines A, B, and C. The spawning grounds of *S. biwaensis* are distributed along the shaded shorelines, A and C. Although the spawning grounds have not been found along the shoreline B, the adults are occasionally captured by fishermen there every year. The broken lines indicate the isobath in meters.

Table 1. The numbers of *Silurus biwaensis* examined for each analysis and the total of *S. biwaensis* collected from Lake Biwa. The numbers of *S. biwaensis* collected from 1977 to 1980 are shown in the parentheses.

Analyses*	Males	Females	Sex not identified	All
Body size distributions (SL)	56 (13)	184 (8)	0	240 (21)
Relationship between SL and BW	43 (0)	152 (0)	0	195 (0)
Relative growth (head size)	43 (0)	175 (0)	0	218 (0)
Relationship between N_{TZ} and SL	53 (13)	134 (8)	0**	187 (21)
Relationship between SL and Ra	53 (13)	134 (8)	0**	187 (21)
The total of samples collected from Lake Biwa	56 (13)	184 (8)	1 (1)	241 (22)

* SL, standard length; BW, body weight; N_{TZ}, the total number of the transparent zones in vertebral centra; Ra, the radius of vertebral centra.

** These relationships of the immature fish whose sex was not identified were shown in Figs. 5 and 7.

South Basin every year, but they occasionally capture some in the southeastern area of the North Basin, where no spawning grounds have been found (Tomoda 1978, Maehata et al. 1990). A total of 219 catfish (176 females and 43 males) were captured by set–nets, gill–nets and throwing nets along the shorelines A, B, and C from May 1992 to July 1995 and a total of 22 catfish (eight females, 13 males, and one sample whose sex was not identified) were captured from June 1977 to July 1980 (Fig. 1). Most of our sampling depended on casual by–catches in the lake by fishermen and consequently the captured season and the developmental stage of the catfish collected in this study were almost restricted to adults around the spawning season from spring to summer. As shown in Table 1, the numbers of the catfish examined for this study were different among the analyses, due to the lack of data for part of the samples.

Measurements of the samples included standard length (SL), head length (HL), head width (HW), and body weight (BW; wet weight) for the catfish. The10th to 15th vertebral centrum was extracted by dissection and was allowed to dry on a hot plate for a week. It was observed under a binocular microscope at 10 to 20 times magnification.

Four fish (named V, W, X, and Y), which were hatched from artificially inseminated eggs, were reared in a pond or an aquarium. For the fish V, gonadotropin (10 I.U. per gram in body weight) was injected into an adult female to promote the maturity. The ova were squeezed out 18 hours after the injection of gonadotropin and inseminated by homogenized testis. For the fish W–Y, we captured adults by a throwing net during their mating in the spawning grounds and extracted the ova and the testis for the insemination there. Fish V was reared in a 1.2-kl pond for a year from hatching in late June in 1977. Fish W was reared in a 60-l aquarium from early July in 1995 to late February in 1998 (2.7 year). Fish X was reared in a 180-l aquarium from early July in 1995 to late March in 1999 (3.7 year). Fish Y was reared in a 60-l aquarium for the same period as was fish X. Fish V was fed on *Tubifex* sp. and cyprinid fishes, fish W and X on *Hala* sp. and artificial pellets, fish Y on *Hala* sp. and cyprinid fishes. Fish W, X, and Y were constantly under the rearing experiment and their vertebral centrum could not be observed.

In late June in 1992, a male, which was captured in the southernmost South Basin, was tagged on a spine of its pectoral fin and was released in the same area. This fish was recaptured in the same area in late June, 1994. We also observed the vertebral centrum of this fish.

RESULTS AND DISCUSSION

Body length of *Silurus biwaensis* collected from Lake Biwa: The body length of *Silurus biwaensis* collected from Lake Biwa was mainly distributed from 500 to 700 mm SL for males and from 600 to 900 mm SL for females (Fig. 2). The females were significantly larger than males (males, n=56, 610±95 mm; females, n=184, 755±133; Mann Whitney's U–test, $p<0.0001$). The maximum values of the standard length were 800 mm in males and 1070 mm in females. Although this difference might suggest that the selectivity of fishing gears for the catfish was different between the sexes, it is more likely that it was simply a reflection of the sexual dimorphism in natural ecosystems. In fact, in the spawning grounds, the adult females have been observed to range from 500 to 1100 mm in TL, apparently bigger than the adult males ranging from 400 to 800 mm in TL (Tomoda 1962, Maehata et al. 1990).

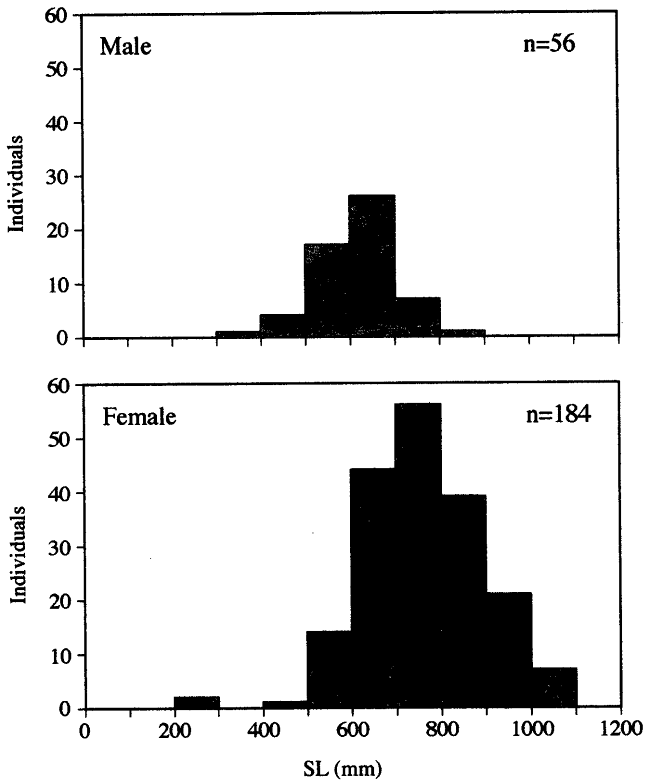

Fig. 2. The distributions of standard length (SL) in *S. biwaensis*.

Relative growth: The relationship between standard length (m) and body weight (kg) was exponential in both males and females (Fig. 3). The allometric equations can be expressed as follows:

Female: $BW=12.37\,SL^{3.484}$ (n=152, R=0.97)
Male: $BW=11.77\,SL^{3.312}$ (n=43, R=0.94)

There was no striking difference between the sexes in these relationships. These parameters are consistent with general parametric values reported for various kinds of fish (Kubo and Yoshihara 1969).

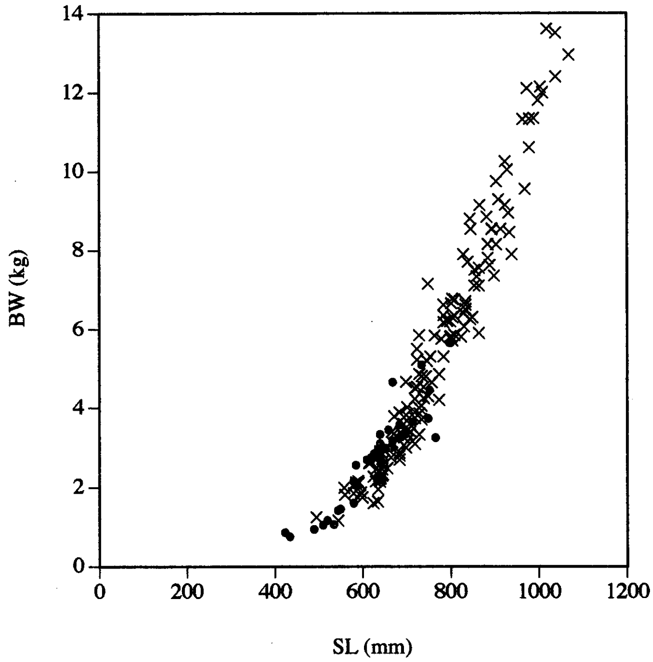

Fig. 3. The relationship between standard length (SL) and body weight (BW) in males (●) and females (×) of *S. biwanensis*.

Both length and width of head significantly increased with standard length in *S. biwaensis* (Fig. 4a, 4b). The Pearson correlation coefficients were 0.92 ($p<0.0001$) in males and 0.95 ($p<0.0001$) in females for the head length and 0.91 ($p<0.0001$) in males and 0.93 ($p<0.0001$) in females for the head width (Table 2). Significant positive correlations were also found for the relationship between the length and the width of the head (males, r=0.85, $p<0.0001$; females, r=0.94, $p<0.0001$; Table 2, Fig. 4c). Recently, Takai and Sakamoto (1999) suggested the ontogenetic dietary shifts and the consequent shift to a higher trophic position in *S. biwaensis* on the basis of a positive correlation of body size with nitrogen stable isotope ratio ($\delta^{15}N$). The growth of the head shown in this study makes it possible for the catfish to feed on larger preys and would

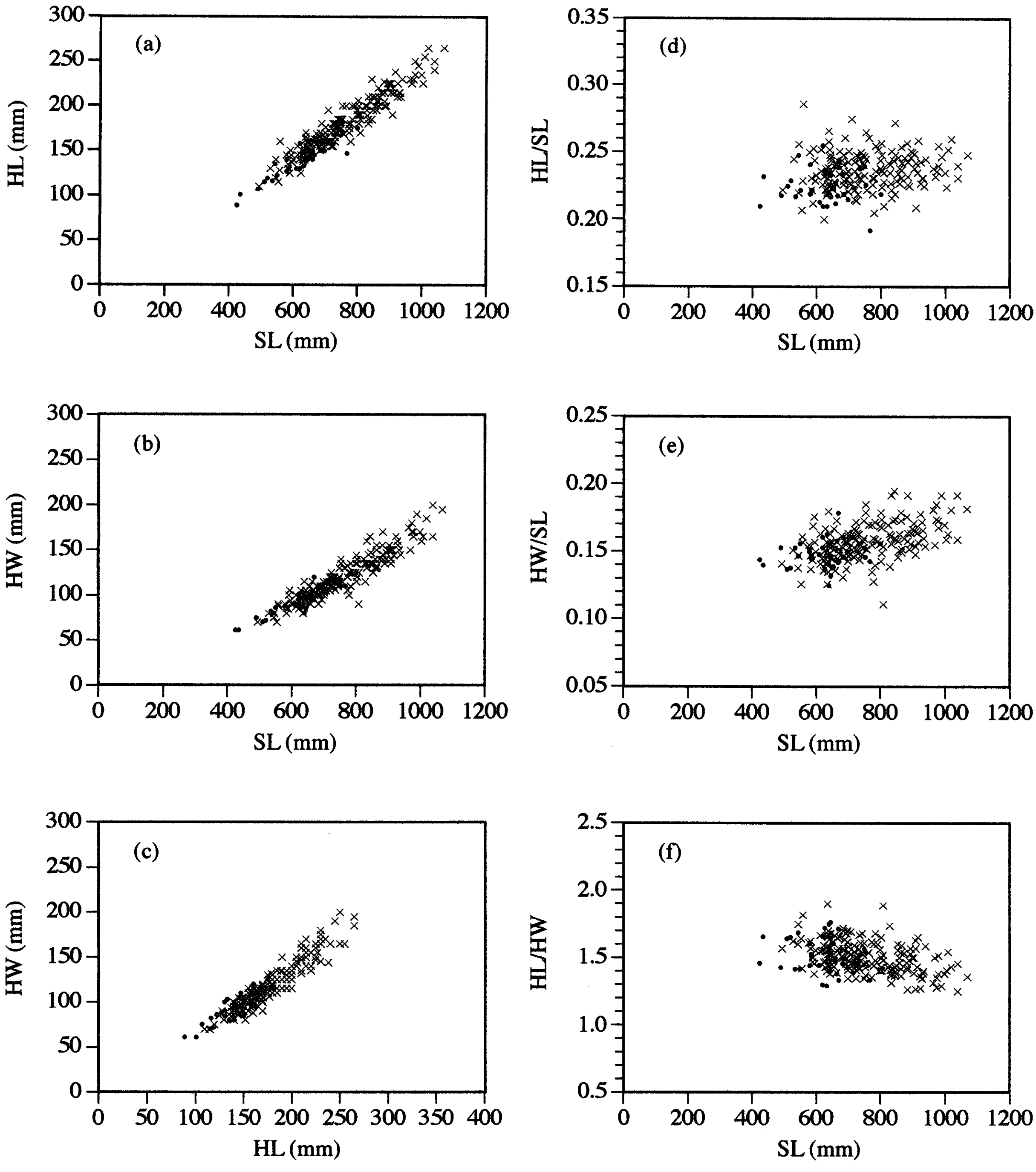

Fig. 4. The changes in body proportion with growth in males (●) and females (×) of *S. biwaensis*. (a) Relationship of head length (HL) to standard length (SL); (b) relationship of head width (HW) to SL; (c) relationship of HW to HL; (d) relationship of HL/SL to SL; (e) relationship of HW/SL to SL; (f) relationship of HL/HW to SL.

Table 2. Pearson correlation coefficients (r) for relationships of SL-HL, SL-HW, HL-HW, SL-HL/SL, SL-HW/SL, and SL-HL/HW.

Combination*	Males (n=43)		Females (n=175)	
	r	p	r	p
SL and HL	0.92	<0.0001	0.95	<0.0001
SL and HW	0.91	<0.0001	0.93	<0.0001
HL and HW	0.85	<0.0001	0.94	<0.0001
SL and HL/SL	−0.03	ns (0.84)	0.12	ns (0.13)
SL and HW/SL	0.21	ns (0.19)	0.48	<0.0001
SL and HL/HW	−0.19	ns (0.22)	−0.44	<0.0001

* SL, standard length; HL, head length; HW, head width; ns, not significant

consequently elevate the trophic positions of the catfish with the growth.

Tomoda (1962) indicated that the proportion of head length to body length increased with growth in *S. biwaensis*. However, such positive correlations between standard length and the proportion of head length to standard length were not found in both the sexes in this study (Table 2, Fig. 4d). It was inferred that Tomoda (1962) would have misread the body size data due to a shortage of the samples that were examined; he only collected 29 samples for *S. biwaensis*.

On the other hand, the proportion of head width to standard length significantly increased with standard length in females ($r=0.48$, $p<0.0001$; Table 2, Fig. 4e). Consequently, the proportion of head length to head width significantly decreased with standard length in females ($r=-0.44$, $p<0.0001$; Table 2, Fig. 4f). Kobayakawa (1992) showed that the proportions of length to width in adult skulls of three Japanese silurids are larger in *S. biwaensis* than in the other two species, *Silurus asotus* and *Silurus lithophilus*. This means that the head of *S. biwaensis* is relatively narrower than that of the other species in dorsal view. The results in this study indicated that this narrow shape of the head of *S. biwaensis* becomes slightly squarer in bigger females likewise that of the other species.

Growth rates of the reared fish and the tagged fish: The catfish, which were hatched from the artificially inseminated eggs, grew to 125 mm SL in fish V for 1.0 year, and 370 mm SL in fish W (137 mm/yr), 410 mm SL in fish X (152 mm/yr), and 196 mm SL in fish Y (73 mm/yr) for 2.7 year (Fig. 5). The fish X and Y were also recorded to be 422 mm SL and 234 mm SL 3.7 year later from the hatching. According to the bibliographical growth data of *S. glanis* compiled by Harka (1984), the growth rate of the catfish varied locally; the one-year-old catfish were 41 cm TL in Ural River (Berg 1949), while the total length of the one-year-old fish in Vág River was 11.1 cm (Sedlár and Geczö 1973). Also in this study, the growth rates of the reared catfish were quite different between the fish X and Y. Such great variations in *Silurus* catfishes may be caused by the

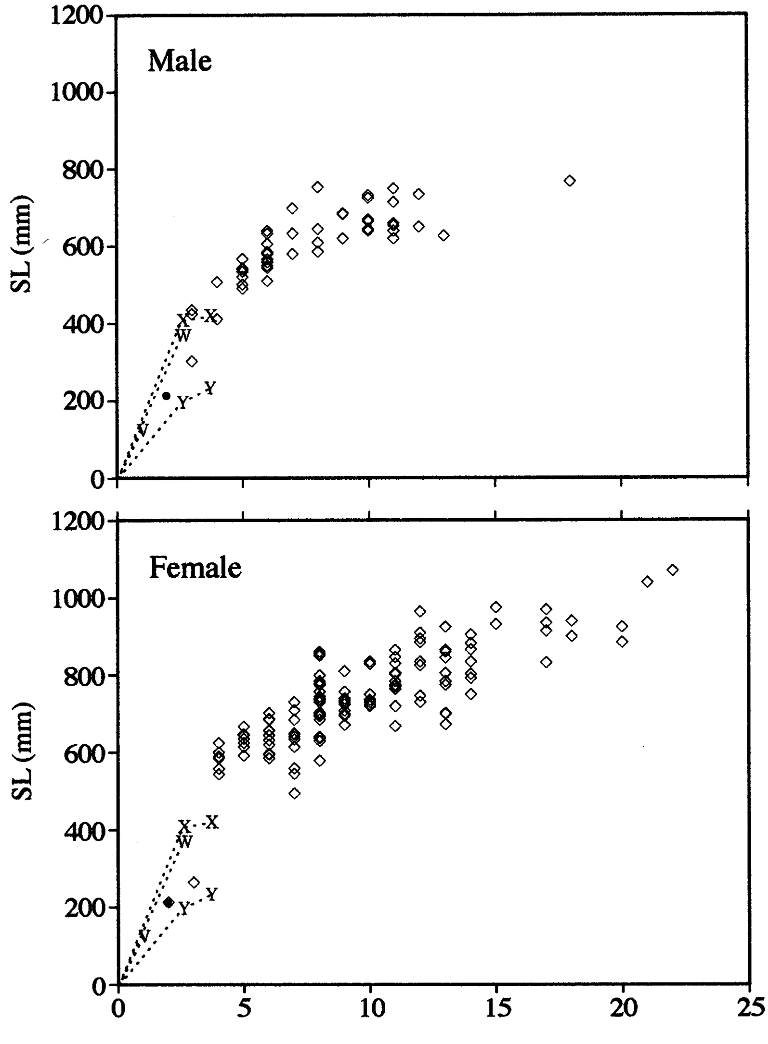

Fig. 5. The relationship between age and growth of the reared catfish, V, W, X and Y. The sex of the reared catfish was not identified. See text for the information on these fish. The relationship between the total number of the transparent zones in vertebral centra (N_{TZ}) and standard length (SL) in the catfish collected from Lake Biwa are also shown. The solid circle means an immature fish whose sex was not identified.

environmental difference of temperature, abundance of prey species, and existence of competitors or predators (Hilge 1985, Rossi et al. 1991, Xie and Sun 1993).

The tagged fish Z grew up 50 mm from 460 mm SL to 510 mm SL in the lake for two years. This growth rate of 25 mm/yr was in contrast with that of the reared catfish. Since the adult males in the spawning ground have been observed to range from 400 to 800 mm in body length (Tomda 1978, Maehata et al. 1990), this tagged catfish was inferred to be a younger adult. The marked difference between the tagged catfish and the reared catfish might suggest that the growth of the adults extremely slows down after the fast growth at the immature stage, although it might also be affected by the environmental difference between the rearing system and the natural ecosystem.

The transparent zone in the vertebral centra as a potential age indicator: We found that narrow transparent zones stratified alternately with wide opaque zones in vertebral centra of *S. biwaensis* as shown in Figure 6 (The fish Z instanced for this figure had a total of six transparent zones). There were significant positive correlations between the total number of the transparent zones (N_{TZ}) and the standard length in both males and females (Pearson correlation coefficients; males, $n=53$, $r=0.80$, $p<0.0001$; females, $n=134$, $r=0.81$, $p<0.0001$; Fig. 5). Accordingly, it was considered that these transparent zones increase with the growth of the catfish. Figure 5 shows that at the same body size class the ages of the reared catfish were in accordance with the N_{TZ} of the catfish collected from the lake particularly in males. This result presents the possibility that these transparent zones are annual rings.

Here, the length from the center to the edge of the centra along the horizontal axis was referred to as the radius (Ra; mm) of the centra (Fig. 6). The edge of the centra was surrounded by a lipidic stratum, but we measured the radius to the exclusion of the width of this stratum. This radius increased in proportion to the standard length in *S. biwaensis* (Fig.7). The relationship between standard length (mm) and the centrum radius was expressed as follows:

Male: $Ra=0.012SL-1.452$
($n=53$, $R=0.94$, $p<0.0001$)
Female: $Ra=0.013SL-1.722$
($n=134$, $R=0.94$, $p<0.0001$)

A striking sexual difference was not found for these relationships.

The season of the increment formation of the transparent zones was not identified in this study, since the samples were captured almost only from spring to summer and the seasonal change of the marginal increment of the centra could not be examined; most of the samples of which vertebral centra were examined were captured from April to August (120 females and 45 males), and only two females and two males were captured from September to January. We observed that a transparent zone had already been formed in the centra of the fish V which had been reared in a field pond for 1.0 year from hatching. Also considering that the annual rings of fish are generally supposed to be formed in winter when the growth ceases (Chugunova 1963), we expect that the transparent zone might be formed before the spawning season, probably in winter.

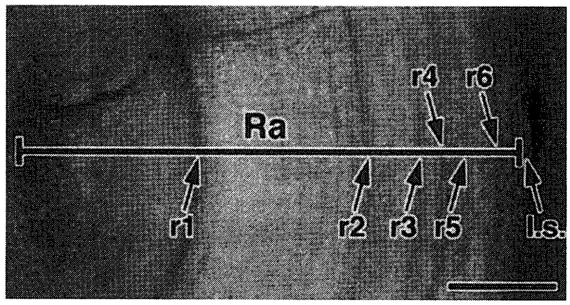

Fig. 6. The conic hollow side on the vertebral centra of the tagged catfish Z. See text for the information on the fish. The radius (Ra; mm) of the centrum was measured along a horizontal axis from the center to the edge. The lipidic stratum (l.s.) and the transparent zones (r1-r6) are shown with the arrows. Scale bar, 1mm.

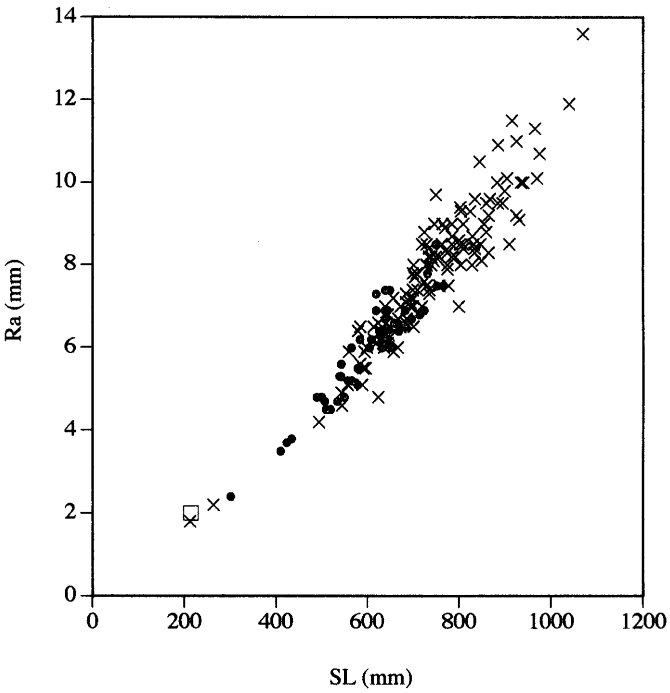

Fig. 7. The relationship between standard length (SL) and radius of vertebral centra (Ra) in males (●) and females (×) of *S. biwaensis*. The individual of which sex was not identified (□) are also shown.

Hereafter, it is necessary to examine the seasonal change of the marginal increment of the centrum by seasonal sampling of the catfish in the lake and the long-term rearing experiment from the hatching to the adult stage. The proof of the periodicity in the increment formation should demonstrate that this character is an unquestionable age indicator.

ACKNOWLEDGEMENT

We thank M. Ueno, J. Hiroi, and S. Ishida for their advice and support in the preparation of this manuscript, and T. Maki and N. Arai for their cooperation in the measurement of the body size of the reared catfish. We are also grateful to S. Matsuoka for his support in collecting the catfish from Lake Biwa, and Á. Harka and S. Kiyashko for the information about the *Silurus* catfishes inhabiting Eurasia.

REFERENCES

Berg, L. SZ. 1949. Ribi preszhin vod SzSzSzR i szopredelnih sztran. II. Moszkva-Leningrad, U.S.S.R. (In Russian).

Chugunova, N. I. 1963. Age and growth studies in fish (translated from Russian). Israel Program for Scientific Translations, Jerusalem, Israel.

Harka, Á. 1984. Studies on the growth of sheatfish (*Silurus glanis* L.) in river Tisza. Aquacultura Hungarica (Szarvas) 4: 135–144.

Harka, Á. and Bíró, P. 1990. Probable sources of biased estimates of growth in wels (*Silurus glanis* L.) using fin rays. Aquacultura Hungarica (Szarvas) 6: 35–39.

Hilge, V. 1985. The influence of temperature on the growth of the European catfish (*Silurus glanis* L.). Sonderdruck aus Zeitschrift für angewandte Ichthyologie 1: 27–31.

Kobayakawa, M. 1985. External Characteristics of the eggs of Japanese catfishes (*Silurus*). Japan. J. Ichthyol. 32: 104–106.

Kobayakawa, M. 1989. Systematic revision of the catfish genus *Silurus*, with description of a new species from Thailand and Burma. Japan. J. Ichthyol. 36: 155–186.

Kobayakawa, M. 1992. Comparative morphology and development of bony elements in the head region in three species of Japanese catfishes (*Silurus*: Siluridae; Siluriformes). Japan. J. Ichthyol. 39: 25–36.

Kubo, I. and Yoshihara, T. 1969. Suisan-Shigengaku (Fisheries Resource Science). Kyoritsu-Shuppan Publisher, Tokyo, Japan (In Japanese).

Maehata, M., Nagata, Y., Matsuda, M., Akiyama, H. and Tomoda, Y. 1990. Reproductive behavior of the Biwa-sheatfish, *Parasilurus biwaensis*. Japan. J. Ichthyol. 37: 308–313 (In Japanese with English abstract).

Orlova, E. L. 1987. Features of the growth and maturation of the catfish *Silurus glanis* in the delta of the Volga River with regulated flow. Voprosy Ikhtiologii 27: 945–955 (In Russian).

Rossi, R., Trisolini, R., Rizzo, M. G., Dezfuli, B. S., Franzoi, P. and Grandi, G. 1991. Biology and ecology of an exotic species, the sheatfish (*Silurus glanis* L.) (Osteichthyes, Siluridae) in the lower part of the Po River. Atti della Società Italiana di Scienze Naturali e del Museo Civico di Storia Naturale di Milano 132: 69–87 (In Italian with English abstract).

Sedlár, J. and Geczö, V. 1973. Beitrag zur Kenntis des Alters und Wachstums des Welses (*Silurus glanis* Linnaeus, 1758, Osteichthyes: Siluridae) aus einigen Gewasern der Sudslowakei. Vestnik Cs. Spol. Zool. 37: 195–211 (In German).

Takai, N and Sakamoto, W. 1999. Identification of local populations of Lake Biwa catfish *Silurus biwaensis* in Japan on the basis of $\delta^{13}C$ and $\delta^{15}N$ analyses. Can. J. Zool. 77: 258–266.

Tomoda, Y. 1962. Studies of the fishes of Lake Biwa-ko–I, Morphological study of the three species of catfishes of the genus *Parasilurus* from Lake Biwa-ko, with reference to their life. Japan. J. Ichthyol. 8: 126–146 (In Japanese with English abstract).

Tomoda, Y. 1978. Lake Biwa and Catfish, Series Japanese Wild Animals 10. Chobunnsha Press, Tokyo, Japan (In Japanese).

Xie, X. J. and Sun, R. 1993. Pattern of energy allocation in the southern catfish (*Silurus meridionalis*). J. Fish Biol. 42: 197–207.