Full Paper Journal of National Fisheries University 71 (4) 141-151 (2022)

Growth of immature Japanese lates, *Lates japonicus* in the Tomouchi River of the Gokase estuary, Kyushu Island, Japan, by the mark and recapture method

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Abstract : Growth of immature *Lates japonicus* in eelgrass (*Zostera japonica*) beds of the Tomouchi River located at around 4.3 km upstream from the river mouth of the Gokase River, Kyushu Island, Japan was studied by the mark and recapture method and scale reading from September 1998 to March 2004. Newly occurring 0-year-old *L. japonicus* specimens of 13.9–78.0 mm SL (standard length) in *Z. japonica* beds of the Tomouchi River in August or September reached sizes ranging 58.8–125.7 mm SL by April and 203.4–232.8 mm SL between October and November of the following year. Monthly changes in specific growth rates of individuals demonstrated that rapid growth months of immature fish were limited to the period of high water temperature (22–28° C) from June to October. Also, it was supposed that the large-sized fish of the 0-year-old fish migrated away from *Z. japonica* beds after December, however a few fish remained in *Z. japonica* beds until the following November.

Key words : Growth; Japanese lates; *Lates japonicus*; Immature fish; Gokase estuary,

Introduction

Within the family Latidae fishes, one species of the genus *Hypopterus*, 11 species of the genus *Lates* and one species of the genus *Psammoperca* have been reported[1]. Except for *Lates japonicus*, these species distribute in the waters between about lat. 30° N and about lat. 30° S in the tropical and subtropical climate, although *L. japonicus* occur only along the Pacific coast of southern Japan, in the temperate climate[1, 2]. *L. japonicus* is endemic to the Pacific coast of southern Japan[3, 4], and is found in estuaries and coastal waters of Miyazaki and Kochi Prefectures[3]. It has been designated as an "endangered species" by the Ministry of the Environment[6]. This species has extremely low genetic diversity at the species level indicating the threatened status of it[7]. There have been many ecological studies on this fish, including distribution[3, 8–10], occurrence of larvae and juveniles[11], general life history[2], histological observation of mature female[12], feeding events[13], population structure[7], and effect of water temperature and salinity on feeding and growth[14]. However, there are no studies on the seasonal and individual growth of immature *L. japonicus* in natural waters. For accumulation of basic ecological data and for the future conservation of *L. japonicus*, seasonal growth of immature fish was examined by the mark and recapture method.

Materials and Methods

Study area and methods

Fieldwork was conducted in the Tomouchi River, a tributary of the Gokase River, Miyazaki Prefecture, southeastern Kyushu Island, Japan. The study area was located at around 4.3 km upstream from the river mouth of the Gokase River (Fig. 1). Eelgrass, *Zostera japonica* grows in an 80 m upstream stretch and a 60 m downstream stretch from the Tomouchi Bridge (32° 36'33"N, 131° 41'42"E), varying with a width of 18–26 m.

The collections were conducted at low tide in the flood

Received date: 30 November 2022, Accepted date: 2 February 2023
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tide, once a month from September 1998 to April 2003 and twice a month from May 2003 to March 2004. A coarse meshed beach seine (4 mm × 4 mm square mesh, 26 m wide and 2 m deep with a 3 m long purse-bag at its center)[15] was used for collecting immature *L. japonicus*. The seine was spread on *Z. japonica* beds, crossing the river and pulled by two persons so that the mouth was around 3 m wide and towed over a length of 13 m long. Therefore, the area of 1 haul of a seine operation was approximately 40 m^2. Each collection consisted of 16 to 32 hauls. Monthly changes in the number of individuals of immature *L. japonicus* per haul of the seine operation were estimated. After the collection, water temperature and salinity of the surface and bottom layer were measured, below the center of Tomouchi Bridge.

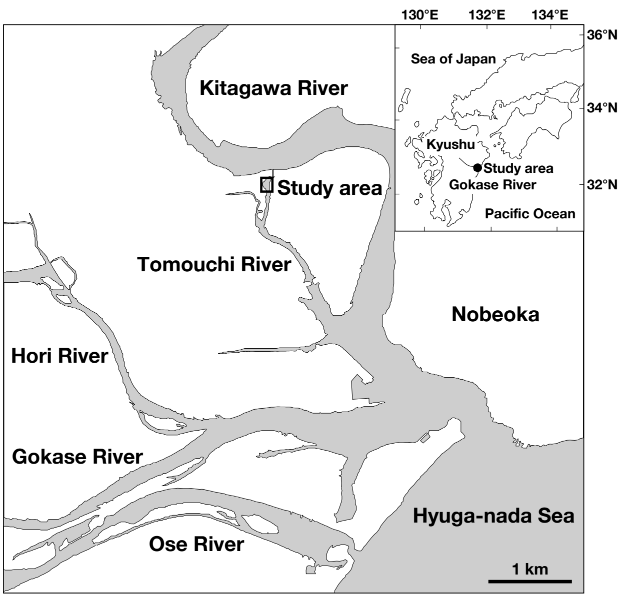

Fig. 1. Location of the study area in the Tomouchi River of the Gokase estuary, Kyushu Island, Japan.

Standard length (SL) and total length (TL) were measured to the nearest 0.1 mm. Marking involved the removal of the first dorsal spines and the second dorsal spine or soft rays in different combinations for specimens larger than ca. 40 mm SL except for in October, November and December 2002 (Table 1). In these months, no marked 88, 110, 62 individuals larger than ca. 40 mm SL were caught, and 71 (81%), 71 (65%) and 23 (37%) individuals were randomly marked, respectively. From September 1998 to November 1999, a few ctenoid scales from the left side of the body in the region behind the pectoral fin were sampled for age determination from all specimens larger than ca. 40 mm SL. Also, from December 1999 to January 2004, a few scales were similarly sampled from specimens larger than ca. 40 mm SL, that were caught for the first time. Scales were observed using a binocular microscope with a magnification of 20.

To compare growth rates for subsequent recapture, specific growth rates (SGR) were calculated as follows:

$$SGR (\%) = 100 (\ln L_2 - \ln L_1) T^{-1}$$

where, L_1 is the SL of the fish when captured, L_2 is the SL when recaptured, and T is the recapture interval (days).

Data analyses

Data were analyzed with non-parametric statistical tests (Kruskal-Wallis test and Spearman's correlation coefficient by ranks) using JMP 9 (SAS Institute Inc.). For all statistical test, significance was assessed at P = 0.05.

Table 1. Number of individuals of the total catch, marked and recaptured immature *Lates japonicus* and their recapture rates (%) in each year class, in the Tomouchi River, Kyushu Island, Japan, from September 1998 to March 2004

Year class	1998	1999	2000	2001	2002	2003
Total	158	30	53	110	694	703
Marked	81	18	35	94	201	352
Recaptured	44	8	16	26	129	197
Recapture rate (%)	54.3	44.4	45.7	27.7	64.2	56.0

Results

Water temperature, salinity and occurrence of immature fish

In this study area, water temperature ranged annually from minima of 13–15°C in January to maxima of 26–28°C in August (Fig. 2). Because the study area was located in the tidal reach, water levels varied more than over 1 m between the low and high tide. Salinities in the bottom layer ranged from 20 to 31 ppt at low tide in spring and winter (Fig. 3). However, in the wet and typhoon seasons after the heavy rain, salinities of the bottom layer changed to approximately 0 ppt at low tide (Fig. 3). *Z. japonica* started to grow luxuriantly usually in May, and attain a maximum height of more than ca. 80 cm from August to September. After that, *Z. japonica* withered, and their length was less than 30 cm from January to March.

Annual total numbers of immature *L. japonicus* caught in the study area were 112 (39.0–123.5 mm SL) in 1998, 79 (14.2–211.2 mm SL) in 1999, 47 (39.9–104.1 mm SL) in 2000, 94 (20.3–123.4 mm SL) in 2001, 535 (11.5–232.8 mm SL) in 2002, 855 (17.7–203.4 mm SL) in 2003 and 31 (55.1–104.9 mm SL) in 2004. Monthly changes in the number of individuals of immature *L. japonicus* per haul of the seine operation were shown in Fig. 4. A large number of this fish was caught usually between September and December although the values sharply fluctuated by year. Also, the values gradually decreased after December. No specimens of *L. japonicus* were caught from March to September in 2000, and from January to March in 2001, May 2001, August 2001, August 2002 and February 2004.

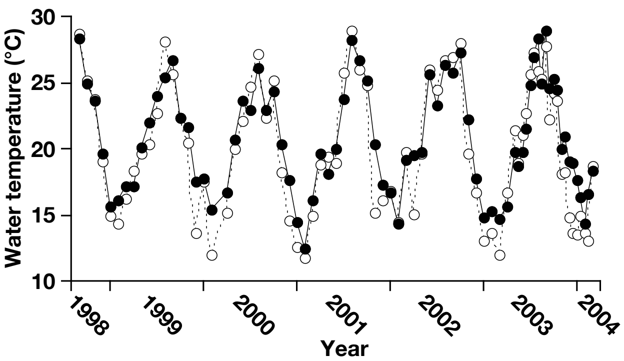

Fig. 2. Monthly changes in water temperature in the Tomouchi River, Kyushu Island, Japan, from September 1998 to March 2004 (---○---, surface layer; —●—, bottom layer).

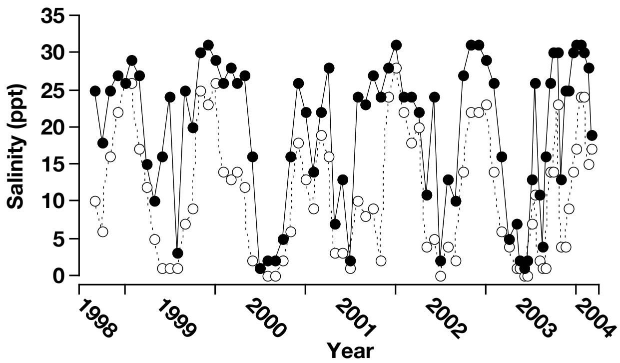

Fig. 3. Monthly changes in salinity in the Tomouchi River, Kyushu Island, Japan, from September 1998 to March 2004 (---○---, surface layer; —●—bottom layer).

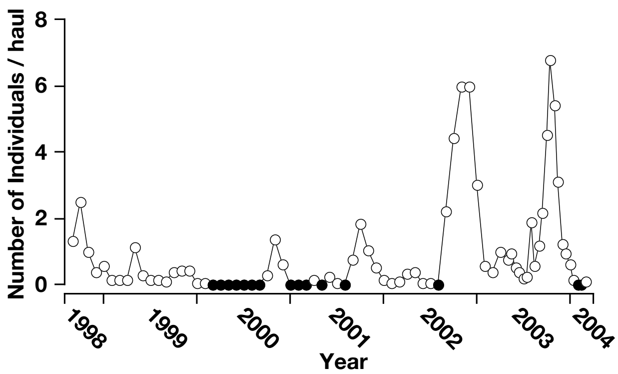

Fig. 4. Monthly changes in the number of individuals of *Lates japonicus* per haul of seine in the Tomouchi River, Kyushu Island, Japan, from September 1998 to March 2004 (○, specimens were caught; ●, specimens were not caught).

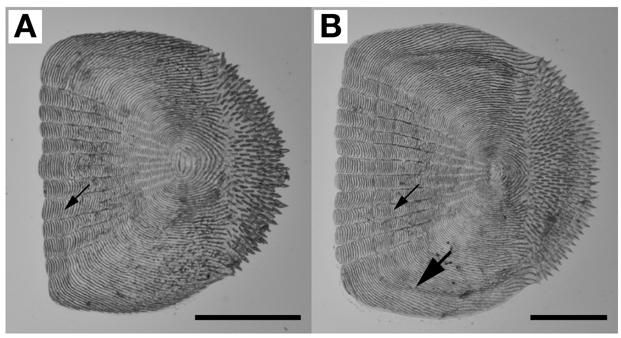

Fig. 5. Ctenoid scales of the same fish of *Lates japonicus* caught in the Tomouchi River, Kyushu Island, Japan, on 1 May (A, 78.1 mm SL) and on 12 June (B, 94.4 mm SL) in 1999. Large arrow shows the clear check, small arrow shows the unclear check. Scale bar indicates 1 mm.

Annual ring formation on scale

A scale of *L. japonicus* at 78.1 mm SL caught on 1 May 1999 was shown in Fig. 5A. The widely spaced ridges spread radially from the focal area, and the narrowly spaced ridges spread radially in the outer part of the widely spaced ridges. The unclear check was visible on the boundary between the wide spaced ridges and the narrowly spaced ridges. A scale of the same fish at 94.4 mm SL caught on 12 June 1999 was shown in Fig. 5B. The widely spaced ridges recommence to spread radially from the outer part of the narrowly spaced ridges. The check was clearly visible on the boundary between the narrowly spaced ridges and the wide spaced ridges (Fig. 5B). Numbers of this check considered as the ring mark were read for each scale of all the specimens from September 1998 to November 1999, and the relationships between month of collection and SL were shown in Fig. 6. No fish had the clear check on the scale caught from September 1998 to April 1999. One clear check was formed in 11 % (n = 2) of specimens in May 1999, 100% (n = 10) of specimens from June to August 1999. The scales of the large-sized fish 203–211 mm SL had one check although the scales of the small-sized fish 35.6–71.5 mm SL had no checks from September to November 1999. These results indicated that the checks on the scales were formed once a year between May and June. The checks can therefore be defined as annual rings for the 1-year-old fish.

General growth of immature fish

Age of the individuals of *L. japonicus* was determined by scale reading. The specimens less than 40 mm SL, for which scales were not sampled regarded as 0-year-old fish. Relationships between mean values of SL for each year group and the collection dates were shown in Fig. 7. The first months when the small-sized fish were caught in the study area, were September 1998 (39.0–78.0 mm SL), September 1999 (20.1 mm SL), October 2000 (39.9–87.7 mm SL), September 2001 (27.9–77.3 mm SL), September 2002 (13.9–68.6 mm SL), August 2003 (17.7–58.1 mm SL), respectively. They reached 62.6–106.1 mm SL in December 1998, 48.6–76.6 mm SL in December 1999, 54.6–92.0 mm SL in December 2000, 27.7–109.9 mm SL in December 2001, 25.5–122.7 mm SL in December 2002, 55.4–112.6 mm SL in December 2003, respectively. The mean SL values of the 0-year-old fish reduced gradually from December to March, except for the 2000-year-class. By spring of the next year, they reached 71.9–89.1 mm SL in April 1999, 77.5–84.2 mm SL in April 2001, 70.7–121.1 mm SL in April 2002, 58.8–125.7 mm SL in April 2003, respectively. Furthermore, they grew to 148.6 mm SL in July 2002, 170.2–203.4 mm SL in September 1999 and 2003, 203.4–232.8 mm SL in October 2002 and 2003, 203.6–211.2 mm SL in November 1999.

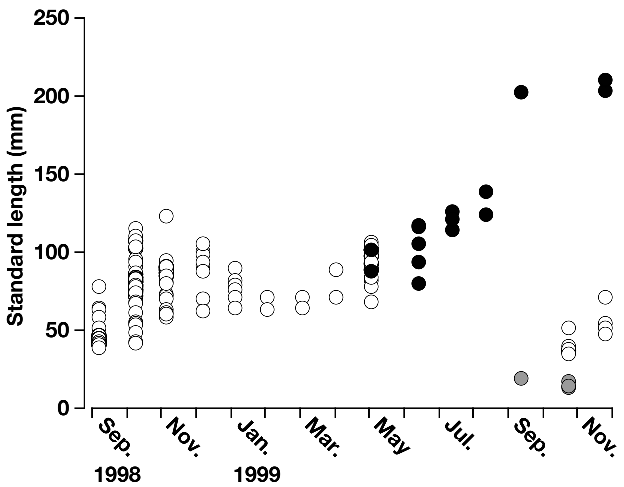

Fig. 6. Monthly changes in standard length of *Lates japonicus* caught in the Tomouchi River, Kyushu Island, Japan, from September, 1998 to November, 1999 (○, no ring marks; ●, 1 ring mark; ●, unobserved).

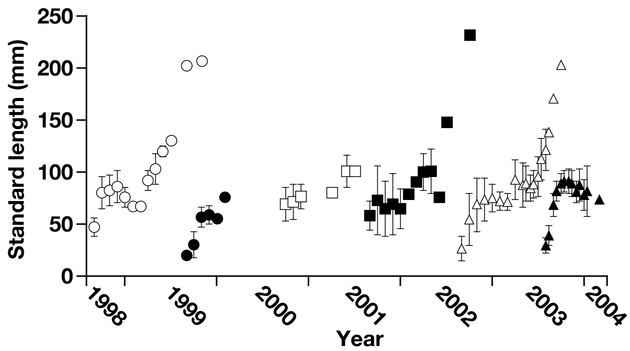

Fig. 7. Relationship between collection date and mean standard length of *Lates japonicus* in each year class caught in the Tomouchi River, Kyushu Island, Japan, from September 1998 to March 2004 (○, 1998-year-class; ●, 1999-year-class; □, 2000-year-class; ■, 2001-year-class; △, 2002-year-class; ▲, 2003-year-class). Vertical lines indicate standard deviations.

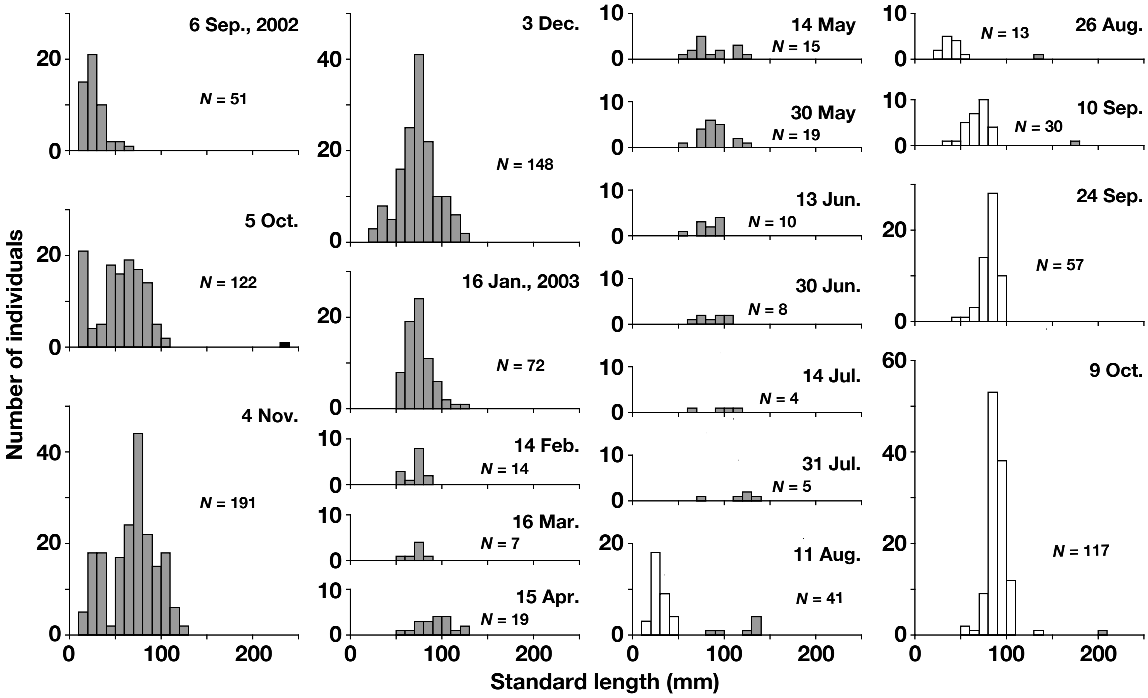

Fig. 8. Standard length frequency distribution of *Lates japonicus* caught in the Tomouchi River, Kyushu Island, Japan, from September 2002 to October 2003 (■, 2001-year-class; ▩, 2002-year-class; □, 2003-year-class).

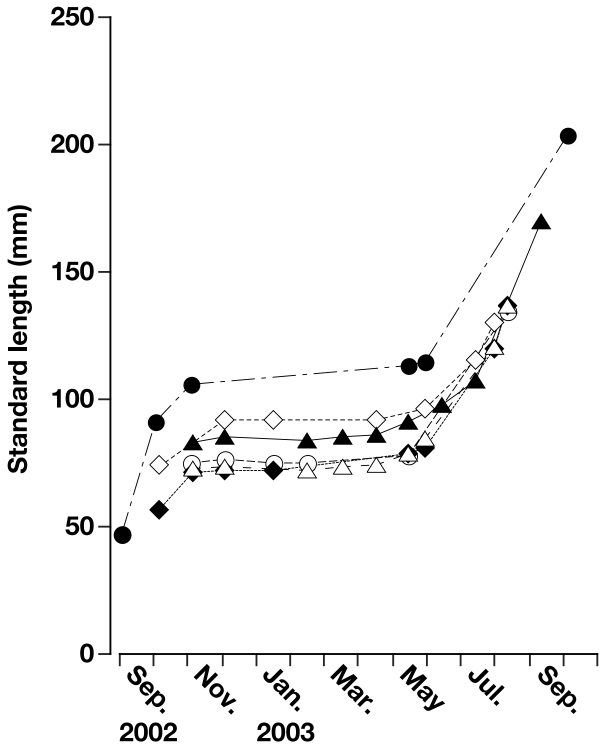

Fig. 9. Individual growth of the 2002-year-class *Lates japonicus* in the Tomouchi River, Kyushu Island, Japan, from September 2002 to October 2003. Identification number of the fish was indicated the removal of the first dorsal spines and the second dorsal spine or soft rays in different combinations, and shown as follows:—·-●-·—, IV-5; ----○----, IV-I,2; ·······◆·······, IV-5,7; -----◇-----, IV-I,5; —▲—, VI-I,9; ---△---, VII-4,6.

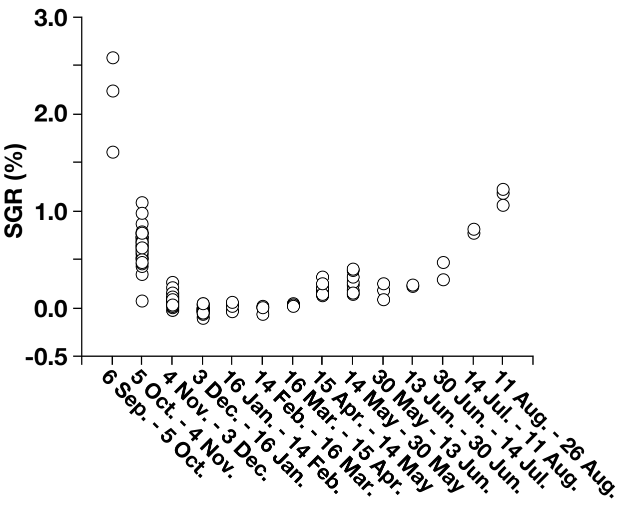

Fig. 10. Specific growth rates (SGR) of the 2002-year-class *Lates japonicus* estimated from the subsequent recapture data of specimens in the Tomouchi River, Kyushu Island, Japan, from September 2002 to August 2003.

Occurrence and growth of 2002-year-class fish

The percentage of recaptured *L. japonicus* of the 2002-year-class was maximum, total number of that year class had the second largest value (Table 1), and specimens were caught consecutively from September 2002 to August 2003 (Fig. 4). Details of the occurrence and growth of this fish were described using the data of the 2002-year-class. SL frequency distribution of *L. japonicus* caught in the study area from September 2002 to October 2003 was shown in Fig. 8. On 6 September 2002 fish of 13.9–68.6 mm SL occurred in the study area and on 5 October there were two peaks of individuals in 10–20 mm SL and 60–70 mm SL, and on 4 November 2002 in 20–40 mm SL and 70–80 mm SL. After January 2003, the number of fish caught in the study area decreased gradually and they reached 85.6–136.8 mm SL on 11 August 2003. They reached to 139.0 mm SL on 26 August, 170.2 mm SL on 10 September, 203.4 mm SL on 9 October 2003. The 2003-year-class fish of 17.7–46.5 mm SL first occurred in samples on 11 August 2003.

Individual growth patterns of six specimens that were recaptured 5–8 times were shown in Fig. 9. They grew rapidly from September to October 2002 and from June to October 2003, and showed minimal growth between December 2002 and April 2003.

To elucidate the individual growth patterns, SGR for specimens which were subsequently recaptured was shown in Fig. 10. SGR among the 14 time intervals were significantly different (Kruskal-Wallis test, χ^2 = 164.2, P < 0.001). SGR had high values from September to October 2002 and from July to August 2003, and were approximately 0 from December 2002 to March 2003. Furthermore, relationships between the median values of water temperature of the bottom layer and SGR for the subsequent recapture, indicated that SGR had higher values in the higher water temperature periods (Spearman's correlation coefficient by ranks, r_s = 11.21, P < 0.001; Fig. 11).

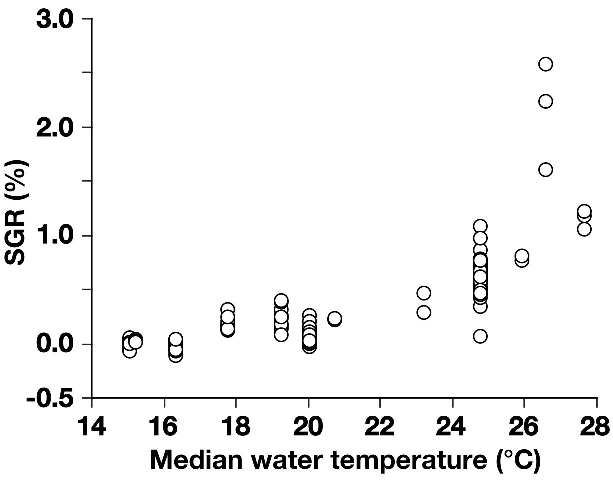

Fig. 11. Relationship between median values of water temperature and specific growth rates (SGR) of the 2002-year-class *Lates japonicus* for subsequent recapture in the Tomouchi River, Kyushu Island, Japan, from September 2002 to August 2003.

Discussion

Growth of immature *L. japonicus*, in *Z. japonica* beds in the Tomouchi River located at around 4.3 km upstream from the river mouth of the Gokase River, Kyushu Island, Japan was clarified by the mark and recapture method. The first months when the small-sized fish of the 0-year-old fish were caught in the study area, were September in 1998 (39.0–78.0 mm SL), September in 1999 (20.1 mm SL), October in 2000 (39.9–87.7 mm SL), September in 2001 (27.9–77.3 mm SL), September in 2002 (13.9–68.6 mm SL), and August in 2003 (17.7–58.1 mm SL), respectively (Figs. 4, 6, 7). It seemed that the amount of occurrence of immature *L. japonicus* in *Z. japonica* beds in Gokase estuary fluctuated yearly (Fig. 4). Two peaks of the number of individuals in 10–20 mm SL and 60–70 mm SL on 5 October 2002, 20–40 mm SL and 70–80 mm SL on 4 November 2002 in the SL frequency distribution (Fig. 8), indicate that the migration into *Z. japonica* beds occurred several times. In the Shimanto estuary, the larvae (4.3–7.6 mm SL) and juveniles (8.1–28.0 mm SL) occurred in *Z. japonica* beds located at around ca. 2–4 km upstream from the river mouth of the Shimanto River, from late July to middle August between 1985 and 1987[11]. Also, the larvae (ca. 5 mm TL) were found to migrate several times into *Z. japonica* beds of the Shimanto estuary from middle July to late September between 1998 and 1999[2]. In these studies, the seine having a mesh width of 1 mm was used[16], while the seine having a mesh width of 4 mm was used in this study. Therefore, the differences in the first occurrence month and size between the Gokase estuary and the Shimanto estuary are considered to be due to the differences in the mesh size of the seines.

Newly occurred 0-year-old *L. japonicus* in *Z. japonica* beds of the Gokase estuary in August or September reached 58.8–125.7 mm SL by the following April, and 203.4–232.8 mm SL between October and November. The postlarvae (3.8–4.1 mm SL) were collected from the surf zone of Tei beach facing Tosa Bay, Kochi Prefecture on July 10, 1982[11]. In the Shimanto estuary, all larval and juvenile *L. japonicus* were collected at sites with *Z. japonica* beds, they exceeded 50 mm SL in October and 100 mm SL by the next April at least in the estuary[11]. Also, young *L. japonicus* grow to about 12 cm TL until the onset of the next rainy season in the Shimanto estuary[2]. Therefore, the general growth pattern of this fish in the Gokase estuary and that in the Shimanto estuary were similar. Furthermore, monthly changes in SGR by the mark and recapture method demonstrated that the months of rapid growth of immature *L. japonicus* were limited to the period of high water temperature (22–28°C) from June to October in our study. These results were supported by the rearing examination for the effect of water temperature and salinity on feeding and growth of this fish, the suitable water temperature range was 22 to 28°C, and the optimal water temperature range was 26 to 28°C for feeding and growth[14]. In addition, we reported that immature *L. japonicus* were euryhaline and at salinities ranging from 9 to 34 ppt showed similar feeding and growth rates, based on the daily feeding rates, SGR of body weight and also on the feeding efficiencies[14]. Age and growth of the related species barramundi, *L. calcarifer* has been investigated, in five river systems in northern Australia using scales taken at the time of tagging and upon recapture[17]. A seasonal pattern of growth was apparent from the marginal increment data and from the seasonal growth data of the age 0+ fish[17]. It seemed that the growth of the 0-year-old fish appeared to be most rapid during the wet months (January to March), when the water temperature ranged from 28 to 32°C, and slowed down markedly from May onwards[17]. Therefore, it seems that the rapid growth of *L. japonicus* only in the high water temperature season was similar to that of *L. calcarifer*.

The values of the number of individuals per haul of seine gradually decreased after December in the Gokase estuary (Fig. 4). Besides, the mean SL values of the 0-year-old fish reduced gradually from December to March, except for the 2000-year-class (Fig. 7). It was supposed that the large-sized fish of the 0-year-old fish migrated away from *Z. japonica* beds in the study area after December. Also, it seems that a few wintering fish remained in *Z. japonica* beds in the Gokase estuary until November of the following year (Figs. 6–8). In the Shimanto estuary, whereas all larval and juvenile *L. japonicus* were collected at the sites with *Z. japonica* beds, they exceeded 50 mm SL in October and 100 mm SL by the next April at least in the estuary[11]. This suggests that they seldom move out of these waters during the larval and young period[11]. Therefore, *L. japonicus* is concluded among "residents" [18] of the waters with *Z. japonica* beds in the estuary, utilizing this habitat at least for the period of postlarva to young[11]. Similarly, most young *L. japonicus* stay in *Z. japonica* beds until the onset of the next rainy season when they have grown to about 12 cm TL in the Shimanto estuary[2]. It seems that immature *L. japonicus* in the Gokase estuary had a slightly longer period of remaining in *Z. japonica* beds than that in the Shimanto estuary.

This fish which may have hatched in the sea began to occur in the estuary from late July, i.e., after the passing of the wet season[11]. On the other hand, it has been suggested that *L. japonicus* spawn in river estuaries and/or in shallow coastal waters near river mouths based on the histological observation of one mature female caught in the Oyodo River estuary, Miyazaki Prefecture, Japan[12]. However, there are no records of collections of fertilized eggs and of newly hatched larvae of *L. japonicus* in Japan. Therefore, the life history of *L. japonicus* remains unclear.

Early life history of the related species barramundi, *L. calcarifer* has been studied in rivers and coastal waters of Papua New Guinea[19–21] and north-eastern Queensland[22].

It seems that *L. calcarifer* has a catadromous life style and spawns in the coastal waters of western Papua New Guinea from November to January based on the collection of mature females and eggs[19, 21]. The larvae of *L. calcarifer* left coastal waters when less than 5 mm TL, migrating through the mangrove zone to coastal swamps where they remained until they were approximately 200 mm TL[19]. Also, the abundance of the 1-year-old class in the Papua New Guinean Daru coastal region was maximal in March–April, and then gradually decreased throughout the rest of the year[20]. The 2-year-old class showed a similar distribution pattern to that of the 1-year-old class. After leaving the nursery swamps, the 0-year-old class became distributed throughout the Daru coastal region and by the end of their first year the fish had moved as far as the Fly River estuary[20]. Therefore, it seems that juveniles left coastal nursery swamps when about 6 months old and by the end of their first year had become distributed throughout the coastal and estuarine regions, and during their second or third year they moved into inland waters, although there is a residual population of all age classes that remain resident in coastal waters[20]. In north-eastern Queensland, the early life history of *L. calcarifer* has been studied by Russell and Garrett[22]. The larvae in the size range 2.8–5.2 mm TL were collected from the plankton in two estuaries in north-eastern Queensland from 31 October 1979 until 13 February 1980. After leaving the plankton, *L. calcarifer* moved into nearby brackish and freshwater swamps[22]. These areas acted as nursery grounds, offering both protection from predators, and abundant prey in the form of insect larvae, other fish and crustaceans. These habitats exhibit a wide range of salinity (freshwater–44 ppt) and surface water temperature (23–36°C)[22]. Juveniles commenced migration from these swamps into permanent tidal creeks around April where they remained for up to 9 months before dispersal into the estuary, up rivers or along coastal areas. Juveniles were resident in tidal creeks that had been subjected to human interference through habitat alteration[22]. During this study there was no evidence of juvenile *L. calcarifer* in offshore habitats, or inshore and estuarine mudflats, sea-grass beds and along beaches. Large number of juveniles were only located in semipermanent coastal swamps, tidal creeks and the freshwater reaches of rivers[22]. The swamp habitats and tidal creeks containing *L. calcarifer* exhibited a wide range of surface salinities, with the former ranging from freshwater to 44 ppt and latter from freshwater to 38 ppt. Surface water temperatures of both habitats varied from 23 to 36°C[22]. Destruction of nursery swamps may pose a serious threat to local *L. calcarifer* stocks near centers of human populations along the eastern Queensland coast[22]. It seems that *Z. japonica* beds form important nurseries for *L. japonicus* in Japan, similar to the use of swamps for *L. calcarifer*. Conservation of nursery *Z. japonica* beds in estuaries is therefore important for the conservation of *L. japonicus* in Japan.

Acknowledgment

The authors extend thanks to the successive presidents of Tomishima freshwater fishermen's cooperative association, H. Kamakura, N. Yokoyama and H. Uchida for their agreement to our study. Mr. K. Hoshino of Oita Marine Palace Aquarium and Dr. I. Ikeda and the students of Department of Applied Aquabiology, National Fisheries University for their assistance in collecting specimens. Also, we extend thanks to Dr. Y. Suda of National Fisheries University for his lending seine from 1998 to 2000. This study was financially supported by Research group of the Kitagawa River in the River Ecology Research group of Japan from 2000 to 2002.

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個体識別法による五ヶ瀬川水系友内川における
アカメ未成魚の成長

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宮崎県五ヶ瀬川水系友内川の感潮域に繁茂するコアマモ群落（五ヶ瀬川河口から約4.3 km上流）において，1998年9月－2004年3月に，個体識別法と鱗による年齢査定を併用して，アカメ未成魚の成長を調べた。このコアマモ群落では，8，9月に体長13.9－78.0 mmの0歳魚が出現し，それらは翌年の4月には58.8－125.7 mmに，10，11月には203.4－232.8 mmに達した。個体識別した個体の瞬間成長率の変化から，アカメ未成魚が急速に成長するのは，高水温の6－10月（22－28℃）に限られることが明らかになった。また，アカメ0歳魚の多くは12月以降コアマモ群落を離れるが，そこで冬を越した少数の個体は11月まで留まると考えられた。