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Do the ayu (*Plecoglossus altivelis altivelis*) born in the river with an inlet or large estuary in its mouth perform a homing ?

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Abstract: The distribution of ayu larvae and juveniles from the Kagami River were investigated around Urado Inlet, into which the river flows, from October 2004 to June 2005. The downstream swept larvae were distributed over the inside of inlet, and were never found outside the inlet. Vertically, they tended to be dispersed from the surface to the bottom, and to be concentrated at the surface when more developed. The larvae (yolk-sac to flexion stages) of 4–10 days old (chiefly 4–6 days old) occurred. In shallow waters around Urado Inlet, the larvae and juveniles continued to occur from November to May, in particular were assembled in the Kagami estuary located in the bottom part of inlet in January and February. Their main stages were postflexion around 20 mm BL. These facts suggest that the ayu larvae born in the Kagami River immigrate to shallow waters of the inner part of inlet, where they are nursed until upstream migration, after pelagic life in the inlet without migration into the open sea. Consequently, it is presumable that they perform a homing.

Keywords: *Ayu, larvae and juveniles, Kagami River, Urado Inlet*

Introduction

The ayu *Plecoglossus altivelis altivelis* is amphidromous osmerid fish with an annual life cycle, and spawns in the lower reaches of rivers in autumn. Usually hatched larvae immediately sweep downstream to the sea, where they spend the winter months until ascending rivers as juveniles in spring.

In the 1980s, it was found that abundant ayu larvae were aggregated along surf zones of sandy beaches facing Tosa Bay (SENTA and KINOSHITA, 1986). This discovery played an important roll to advance study on the early life history of ayu in subsequent works. Furthermore, it was shown that amounts of ayu larvae and juveniles remain and grow within the Shimanto (Kochi Prefecture) and Kumano (Wakayama Prefecture) estuaries until spring, and their growth rates estimated were higher in the estuary than outside surf zones (TSUKAMOTO *et al.,* 1989; TAKAHASHI *et al.,* 1990). However, it is incompletely corroborated whether the remainders had never experienced pelagic life in the sea, and little is known about its significance in the entire population (TAKAHASHI *et al.,* 1998, 1999, 2000, 2002, 2003).

Recently, we found ayu larvae remaining in the Kagami River, flowing across central Kochi City (the capital of Kochi Prefecture). In this paper, to clarify mechanism of remaining in the river, larval distribution and migration were detailed in the Kagami estuary and Urado Inlet, being interposed between the river and Tosa Bay.

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Materials and methods

Surveys for collection of the ayu larvae and juveniles, being categorized into two (pelagic and immigration periods), were made monthly from October 2004 to June 2005. For the pelagic larvae, horizontally discrete depth at surface, middle and near the bottom layers and oblique from near the bottom to surface tows with a larva net (1.3 m mouth diameter, 0.5 mm mesh aperture) were carried out at Stns. L1-L3 (inside the Urado Inlet) and L4 (outside the inlet), respectively (Fig. 1). Of which, at only Stn. L3, a spcialized beam trawl (0.25 × 1.5 m-mouth, 1 mm mesh aperture) was used. This net was modified after KUIPERS's (1975) and designed to keep 5 cm apart the lower beam of the mouth from bottom to collect pelagic larvae distributed near the bottom. Towing depths and filtered water volumes (m^3) were checked and calculated using a diver's watch (Log Memory 1473, Casio) and flow meter (2030R, General Oceanics), respectively. No data was near the bottom of Stns. L1 and L2 in November due to unsuccessful tow.

For the immigrated larvae and juveniles, a seine net (1 × 4 m, 1 mm mesh aperture) (KINOSHITA *et al,* 1988) was used at Stns. S1-S10 arranged along shallow waters around Urado Inlet (Fig. 1). Two persons kept the net stretched, and waded backward in the waters, from ankle- to neck-depth along the shore-line for a distance of ca. 50 m (2 min.).

All samples were preserved in 10% sea-water formalin, and sorted ayu specimens were transferred to 80% ethanol and subsequently were measured their sizes by developmental stages (KENDALL *et al.,* 1984). Unlabeled lengths are body lengths (notochord length in yolk-sac, preflexion and flexion larvae, and standard length in postflexion larva and juvenile).

A maximum 30 and 50 specimens from collections in the inlet and shallow waters, respectively, for each station of each sampling date were selected randomly for age determination from otolith (sagitta)(TSUKAMOTO and KAJIHARA, 1987).

Water temperatures and salinities were measured at the surface and bottom of each shallow water station (Stns. S1-S10) and at 0.5 m-intervals from the surface to bottom of each inlet station (Stns. L1-L4) with HSCTS (Model 30, YSI Inc.) and STD (AST500-P, Alec Electronics), respectively.

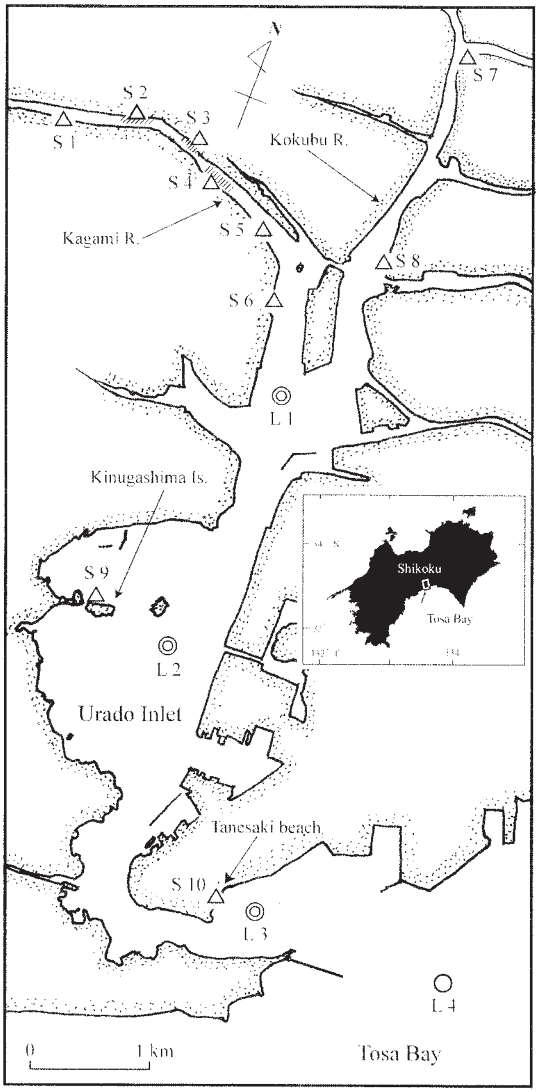

Fig. 1. Chart of Urado Inlet showing stations where the ayu larvae and juveniles were collected form October 2004 to June 2005. For the pelagic larvae, sampling were made at Stns. L1-L3 and L4 (double and open circles), and for the immigrated larvae and juveniles, sampling were made Stns. S1-S10 (triangles). Shaded areas indicated eelgrass beds.

Results

1. Distribution of pelagic larvae in the inlet

1) Physical condition

According to vertical profiles of temperature and salinity, temperature decreased monthly from November to February, and stratification and mixed layers in salinity were formed in- and outsides of the inlet, respectively (Fig. 2). In January and February, outside water mass being higher salinity tended to influx through the bottom layer.

2) Distribution of the larvae

A total of 1,476 ayu yolk-sac (3.4–7.3 mm), preflexion (4.3–8.6 mm), flexion (6.2–13.4 mm) and postflexion (12.0–20.4 mm) larvae were collected from November to February, with a peak in November (Fig. 3). Horizontally, most abundance was found at Stn. L1, but none of larvae was appeared at Stn. L4 in any months. Vertically, the larvae tended to be dispersed throughout the layers from the surface to around 5 m-depth in all months, and in November and December, they were somewhat more densely distributed around 5 m-depth.

3)Compositions of size and developmental stages

Most of samples were composed of chiefly the yolk-sac and preflexion larvae with modes at 5.1–5.5 to 6.6–7.0 mm (Fig. 4). The compositions little changed among months, but somewhat varied both horizontally and vertically. In November and December, larger and more developed larvae were distinctively distributed at Stn. L1 than Stn. L3. Furthermore, the flexion larvae over 8 mm tended to be more abundant at the surface except of Stn. L2 in November.

4) Monthly changes in age and hatching period

Ages and hatching dates of the larvae ranged from 3 to 30 days and from 29 October 2004 to 22 January 2005, respectively (Fig. 5). Modal age was 5 days in any months, and some larvae older than one week also occurred in the inlet. Hatching dates were distributed from late October to late January, and their duration of each month sample was largely isolated, i.e. larvae collected. November, December, January and February were born in late October to early November, late November to early December, middle January and late January, respectively.

2. Distribution of immigrated larvae and juveniles along shallow waters

1) Temperature and salinity

Monthly changes in average water temperature and salinity of four sites are shown in Fig.

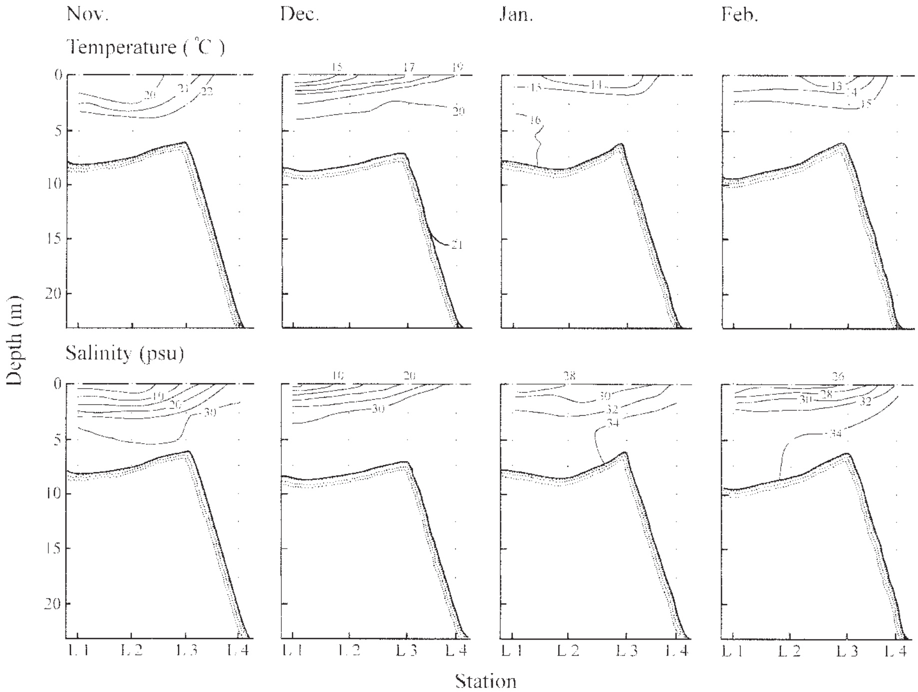

Fig. 2. Monthly changes of vertical isotherms and isohalines on the section of Stns. L1-L4 in Urado Inlet from November 2004 to February 2005.

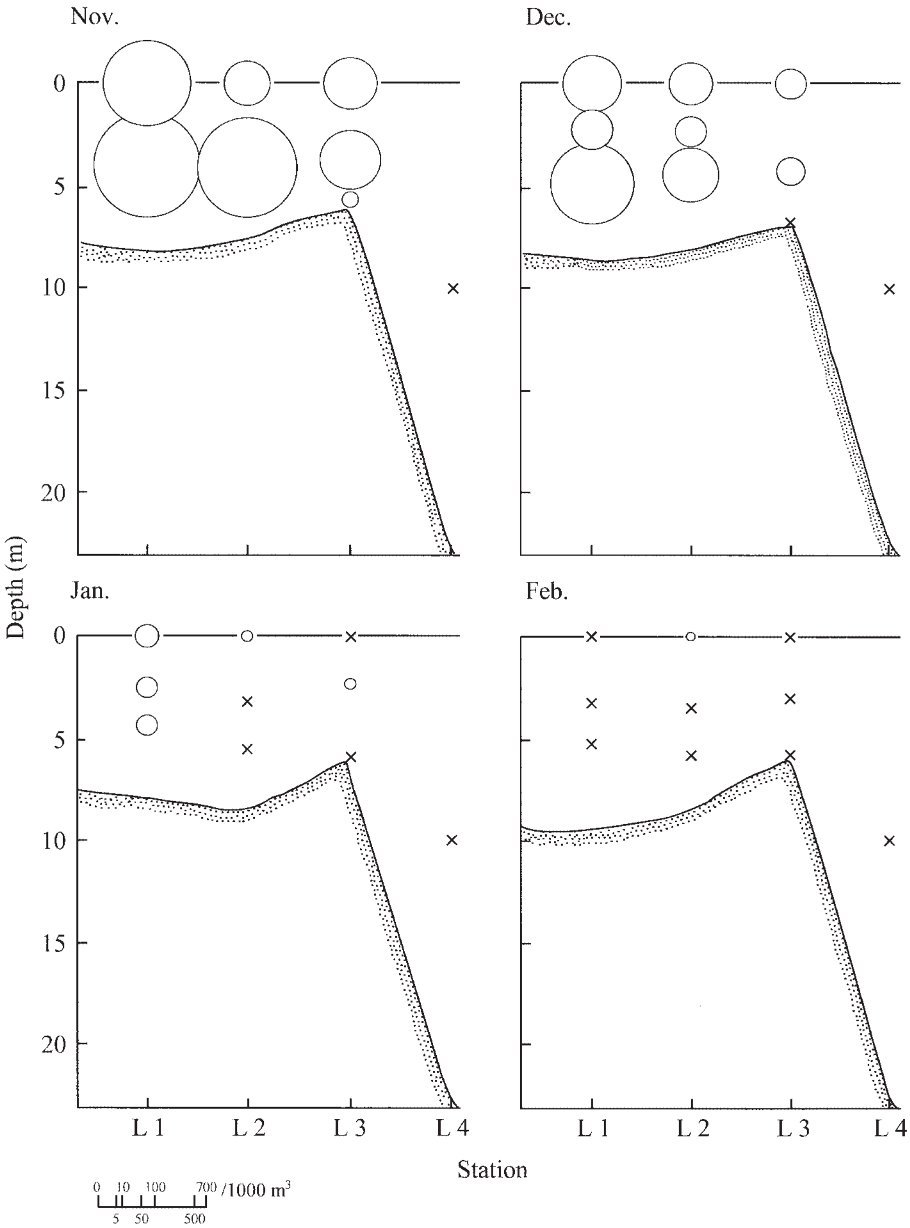

Fig. 3. Monthly changes of vertical distributions of the ayu larvae in Urado Inlet from November 2004 to February 2005. The diameter of each circle is drawn in proportion to the cube root of density (n/1000 m^3) of larvae collected, of which the largest and smallest were 681.1 and 1.0 at the middle layer of Stn. L1 in November and the surface layer of Stn. 2 in February, respectively. Crosses represent no ayu larvae.

6. Average temperature was lowest in February in most of sites, and kept higher in Tanesaki beach (Stn. S10) and Kinugashima (Stn. S9) in November to February and March to May, respectively. Salinity was kept to be highest in Tanesaki beach, and to be higher in Tanesaki beach and Kinugashima than in estuarine sites (Stns. S1-S8). Consequently,

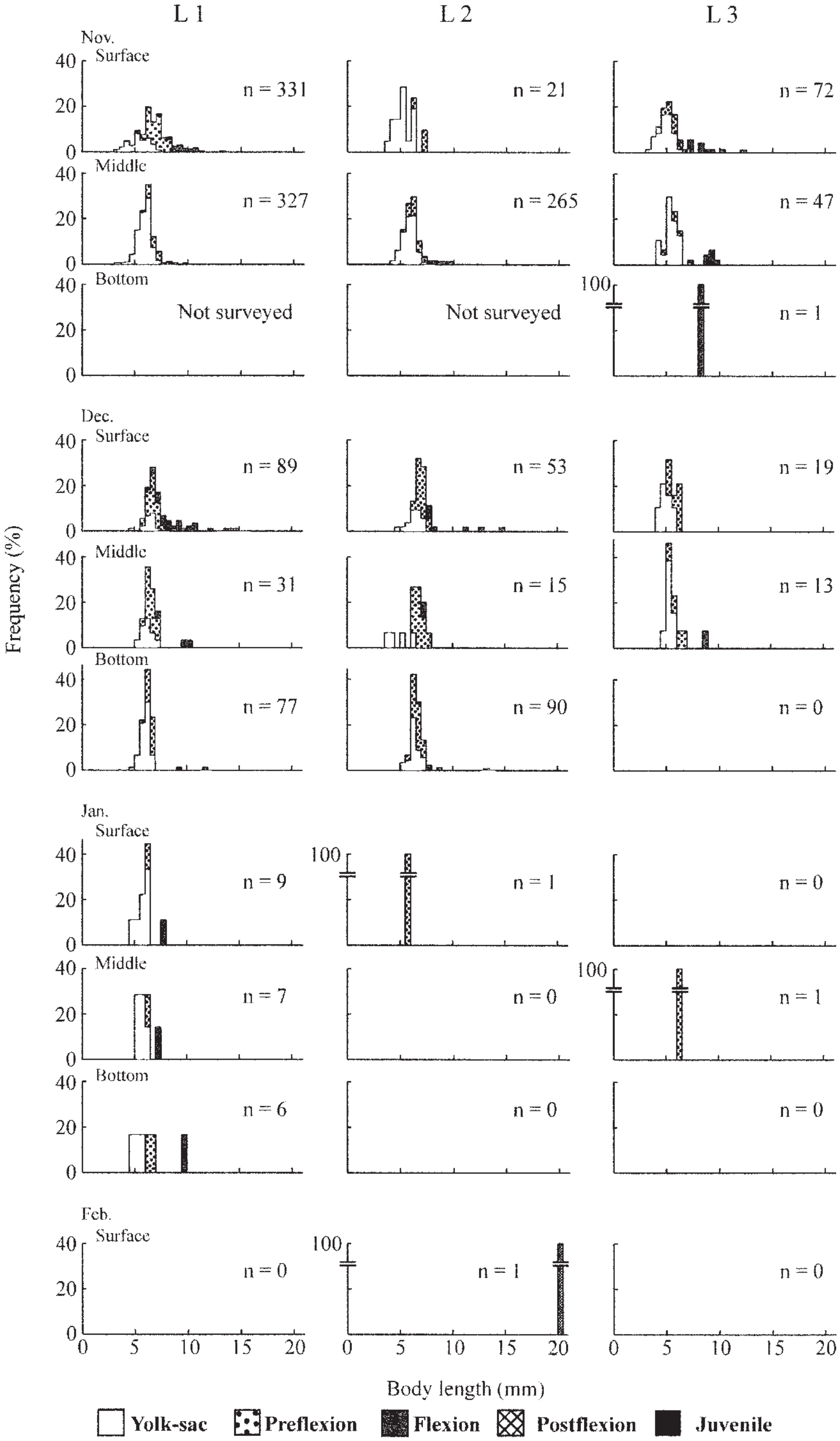

Fig. 4. Monthly, horizontal and vertical comparisons of frequencies of size and developmental stages of the ayu larvae collected with a larva net in Urado Inlet from November 2004 to February 2005.

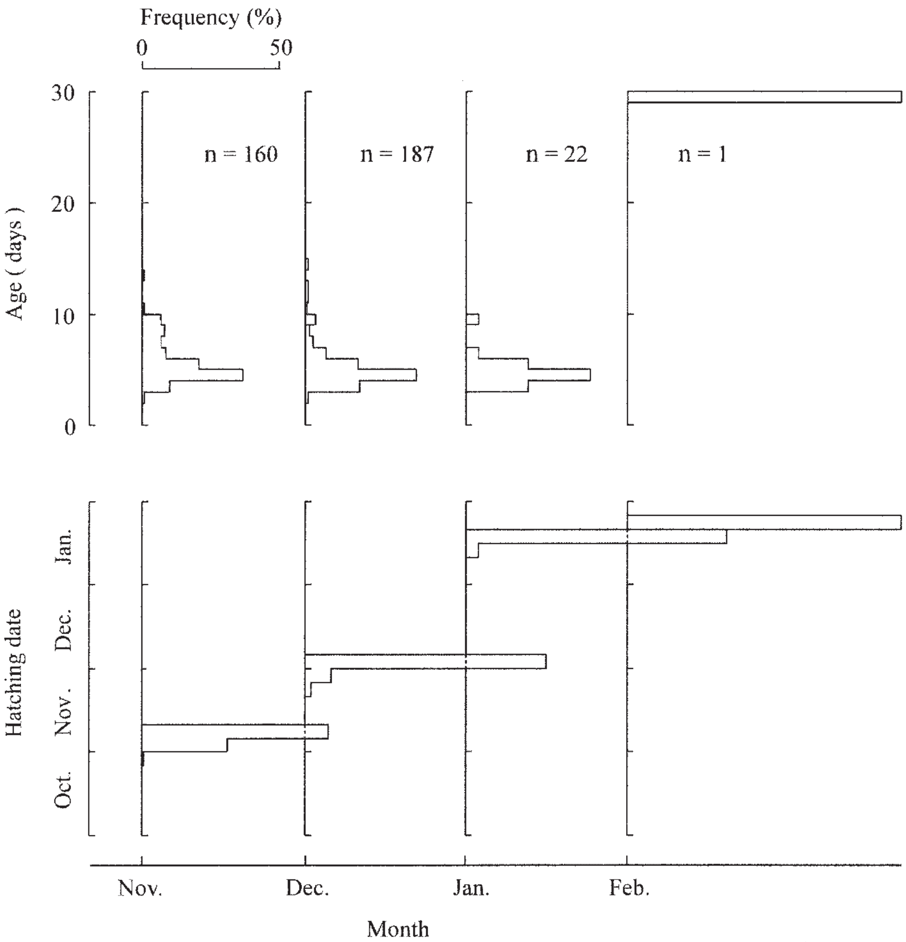

Fig. 5. Monthly changes of age and hatching-date distributions of the ayu larvae collected with a larva net in Urado Inlet from November 2004 to February 2005.

monthly relationship between two physical parameters showed a reciprocal pattern.

2) Distribution of larvae and juveniles

A total of 1,117 larvae and juveniles (6.5–46.0 mm) were collected in the shallow waters around the inlet from November to May with a peak in January. Horizontal distributions were monthly showed in Fig. 7. Between December and February, larvae and juveniles aggregated in the Kagami estuary (chiefly Stn. S4), but almost disappeared from March forward. Conversely, few larvae and juveniles appeared along the coast of Kinugashima (Stn. S9) located in the central inlet, and sporadic occurrences were found along Tanesaki beach (Stn. S10) near the mouth of the inlet.

3) Monthly changes of size and developmental stages

Size and developmental stage compositions of specimens collected from the shallow waters along the inlet were spatially and monthly showed in Fig. 8. Specimens were composed of chiefly the postflexion stage and all juvenile stage in November to Mach and April to May, respectively. In the Kagami estuary (Stns. S1-S6), modal sizes were 12.1–13.0 mm in December, 11.1–12.0 and 14.1–15.0 mm in January, and 12.1–13.0 and 16.1–17.0 mm in February, and increased monthly. In the Kokubu estuary (Stns. S7-S8) and Kinugashima (Stn. S9),

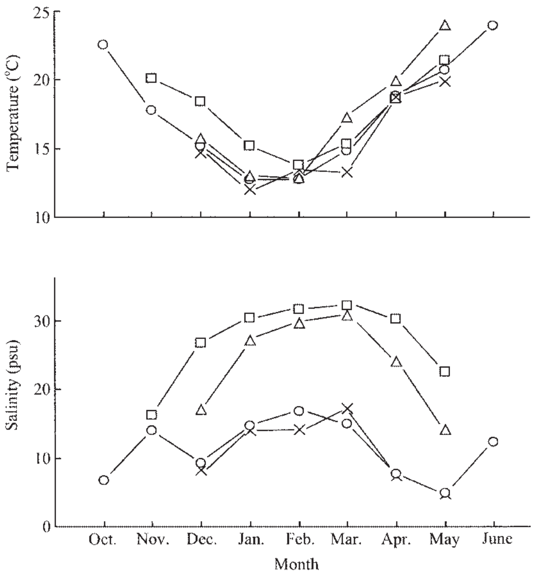

Fig. 6. Monthly changes of mean temperatures and salinities in shallow waters around Urado Inlet from October 2004 to June 2005. Circles, corsses, triangles and squares indicate the Kagami (S1-S6) Kokubu (S7-S8) estuaries, Kinugashima Island (S9) and Tanesaki beach (S10), respectively.

modes were 13.1–14.0 or 14.1–15.0 mm, and little changed monthly. In Tanesaki beach (Stn. 10), chiefly postflexion larvae with a mode at 10.1–11.0 mm appeared in December, thereafter interposing January to March when few collected, and juveniles larger than 30 mm suddenly occurred in April.

4) Comparison of age and hatching date between the estuary and beach

Ages and hatching dates of the larvae and juveniles ranged from 6 to 135 days and from 23 October 2004 to 26 January 2005, respectively (Fig. 9). To examine the duration of residency of the immigrated larva, their age and hatching date distributions were compared for each month between the Kagami estuary (Stns. S1-S6) and Tanesaki beach (Stn. S10), where specimens were more abundant (Fig. 9). In the Kagami estuary, modal age was at 16–20 days in December, subsequently exhibited two peaks at 11–15 and 31–35 days in January, and their range widened toward older with pleural modes in February. Hatching dates were distributed from early November to late January, and distribution overlaps were seen over occurrence period, in particular being distinctive between January and February. In Tanesaki beach, apparently different age groups with modes at 11–20 or 81–85 days were present in December and April, respectively; furthermore, hatching dates were distributed for November in the former and for January in the latter, and never had overlapped between two groups.

Discussion

The ayu pelagic larvae never went outside of the inlet, and were denser in the inner part of the inlet (Fig. 3). On the other hand, CPUE of immigrated larvae and juveniles were considerably greater in the Kagami estuary than in other sites (Fig. 7). Considering overlapped duration of hatching, the swept larvae had led pelagic life for less than one-month in the inlet, and their residence term had been more than two-month until the juvenile stage in the Kagami estuary (Figs. 5, 9). Compared size frequencies between Stn. L1 and Stns. S4-S6, larger and older specimens in the former station overlapped distinctively with smaller and younger ones in the latter stations (Figs. 4, 5, 8, 9). From these facts, it is conceivable that most of ayu born in the Kagami River immigrate and use the shallow waters of the estuary as their nursery ground, immediately after the pelagic life in the inlet, without going out Tosa Bay. Furthermore, their disappearing from the Kagami estuary suggests migrating upstream the river in March. Consequently, it is presumable that the unique migration makes ayu larvae home actively. Abundances of ayu larvae and juveniles along neighboring beaches outside of the Shimanto River mouth compares poorly with those of others (the Shimonokae, Niyodo and Monobe Rivers) flowing into Tosa Bay (SENTA and KINOSHITA, 1986; HAMADA and KINOSHITA, 1988; AZUMA *et al.,* 1989, 2003a, b; KINOSHITA, 1993; FUJITA, 2005). This seems to be attributed to the remaining of ayu larvae in the Shimatno estuary (TAKAHASHI *et al.,* 1990) like the Kagami River of the present study. Hence, it is possible that ayu born in the river with an inlet or large estuary in its mouth stay in the inlet or estuary and can perform the homing, they indeed supporting the stock of

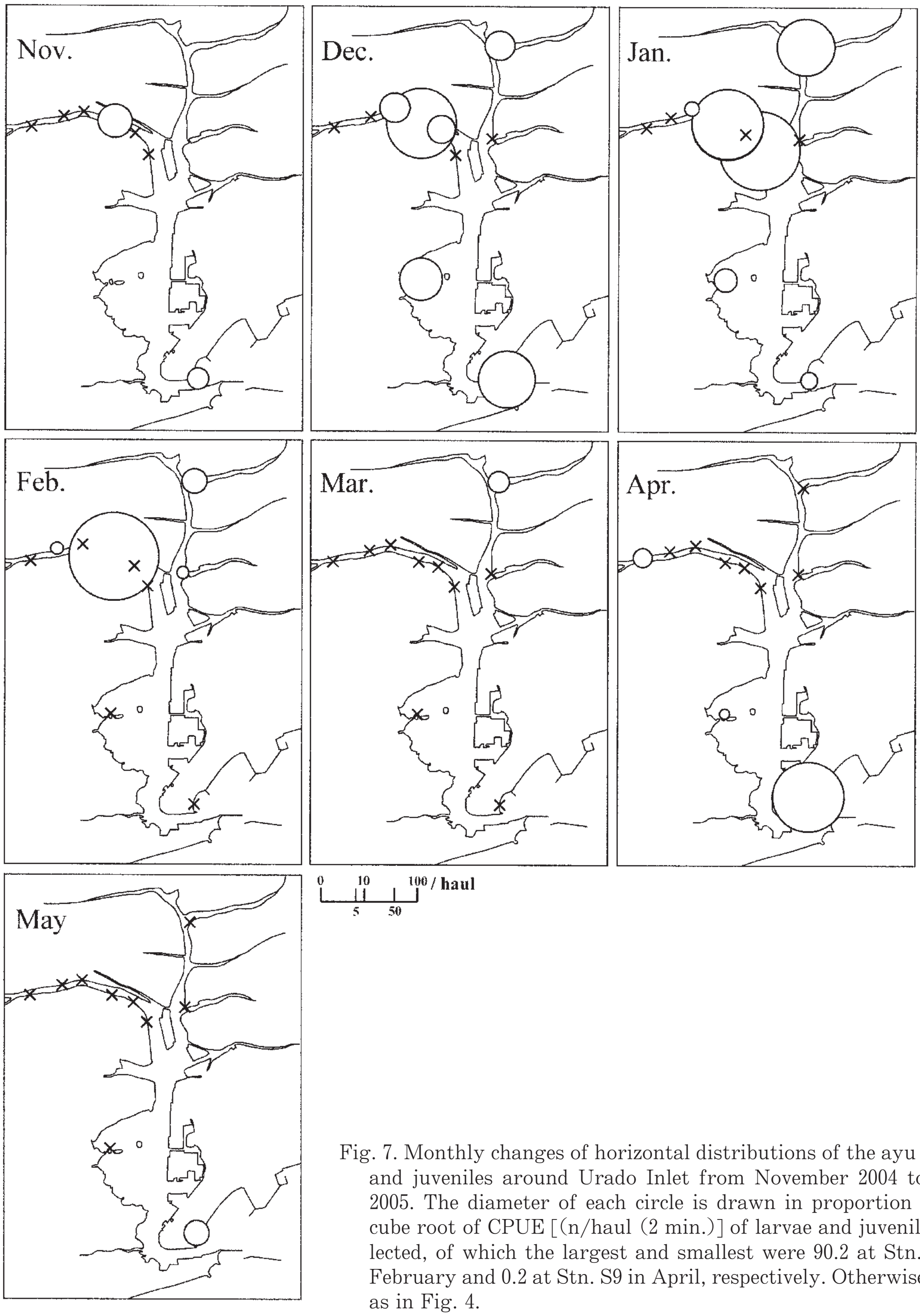

Fig. 7. Monthly changes of horizontal distributions of the ayu larvae and juveniles around Urado Inlet from November 2004 to May 2005. The diameter of each circle is drawn in proportion to the cube root of CPUE [(n/haul (2 min.)] of larvae and juveniles collected, of which the largest and smallest were 90.2 at Stn. S4 in February and 0.2 at Stn. S9 in April, respectively. Otherwise same as in Fig. 4.

each river.

In the present study, a number of larger pelagic larvae could be frequently collected especially at the surface of the inlet (Fig. 4). This phenomenon was seldom found in coastal waters of Tosa Bay and the other waters

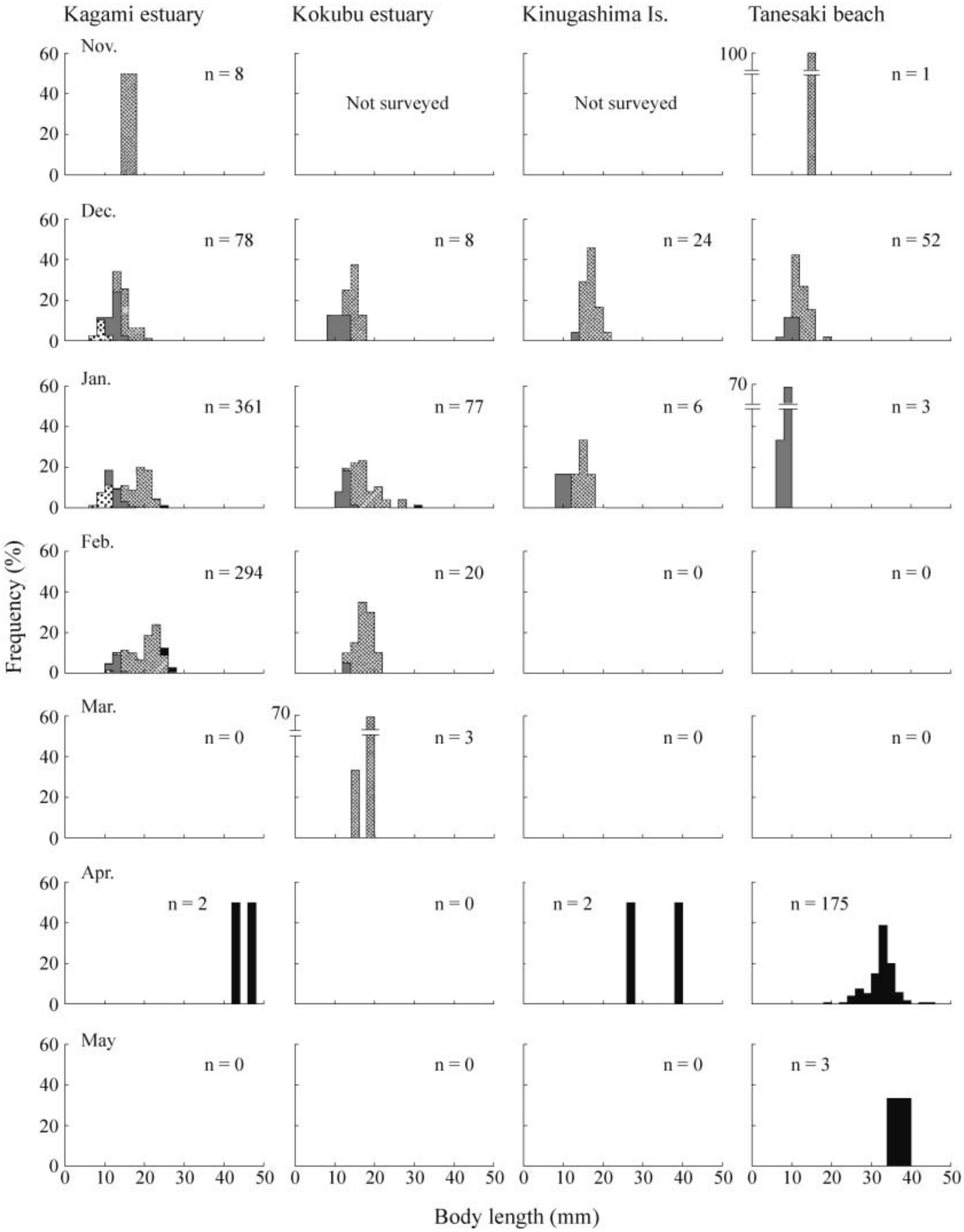

Fig. 8. Monthly and horizontal comparisons of frequencies of size and developmental stages of the ayu larvae and juveniles collected with a seine net in the shallow waters around Urado Inlet from November 2004 to May 2005.

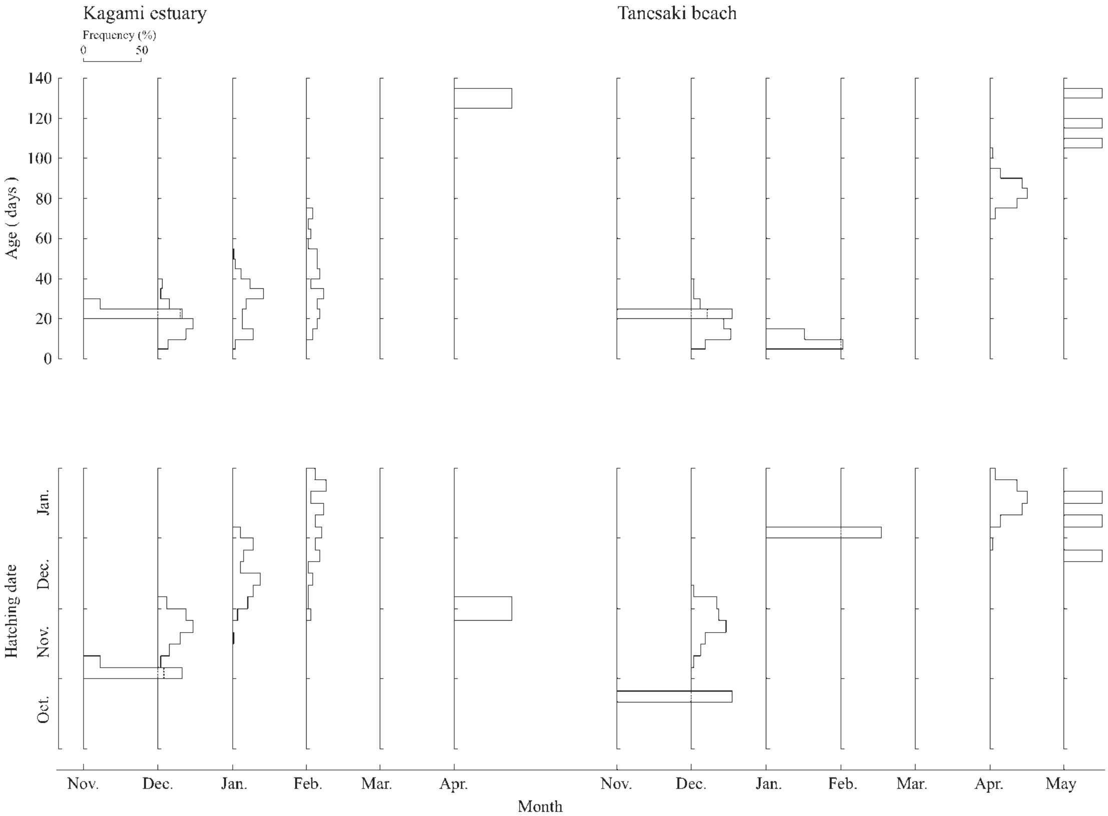

Fig. 9. Comparison of monthly age and hatching-date distributions of the ayu larvae and juveniles collected with a seine net between the Kagami estuary (innermost inlet) and Tanesaki beach (near the mouth of inlet).

(SENTA, 1967; TSUKAMOTO, 1988; YAGI *et al.,* 2006), but was similar to that in Toyama Bay, the Japan Sea (TAGO, 2002). This differentiation could be attributable to consequence of the water column. Inside of Urado Inlet, stratification column in salinity persisted constantly during the present study (Fig. 2). In Toyama Bay, vertical profile of salinity was shown merely at two stations of one survey, and distinctive haloclines were formed at layer shallower than ca. 1 m-depth (TAGO, 2002). Conversely, off the mouth of the TAKAHASHI River, the Inland Sea of Seto, mixed column was developed (SENTA, 1967). In Tosa Bay, when waters were stratified and mixed vertically, larger larvae were marginally and hardly collected, respectively (YAGI *et al.,* 2006). These information possibly reveal that larger larvae also continue to be distributed at the surface in themselves when stratified water column, but was dispersed vertically and there was little chance for them being collected when mixed water column due to their extremely lower density by a severe mortality. In the Shimanto estuary, distribution near the bottom of larger larvae over 10 mm is likely a special example that larvae after consuming yolk-sac to near the bottom of themselves, because their relative specific gravity had to become higher under a brackish environment (KITAJIMA *et al.* 1998).

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References

AZUMA, K., I. KINOSHITA, S. FUJITA and I. TAKAHASHI (1989): GPI isozymes and birth dates of larval ayu, *Plecoglossus altivelis* in the surf zones. Jpn. J. Ichthyol., **35**, 493–496.

AZUMA, K., H. HIRAGA and I. KINOSHITA (2003a): Influence by precipitation to spatial dispersion of ayu larvae swept downstream to sea. Nippon Suisan Gakkaishi, **69**, 352–358.

AZUMA, K., I. TAKAHASHI, S. FUJITA and I. KINOSHITA (2003b): Recruitment and movement of larval ayu occurring in the surf zone of a sandy beach facing Tosa Bay. Fish. Sci., **69**, 355–360.

FUJITA, S. (2005): Ecological study on larvae and juveniles of the two sea basses and the three sparines occurring in the Shimanto estuary, Japan. Bull. Mar. Sci. Fish. Kochi Univ., **23**, 1–57.

HAMADA, R. and I. KINOSHITA (1988): Feeding habit of larval and juvenile ayu, *Plecoglossus altivelis* in the surf zone of Tosa Bay, Japan. Jpn. J. Ichthyol., **35**, 382–388.

KENDALL, A.W.Jr., E.H. AHLSTROM and H.G. MOSER (1984): Early life history stages of fishes and their characters. *In* MOSER, H.G., W.J. RICHARDS, D.M. COHEN, M.P. FAHAY, A.W. KENDALL, Jr., and S.L. RICHARDSON (eds.), Ontogeny and systematics of fishes. Am. Soc. Ichthyol. Herpetol., Spe. Publ., 1, pp. 11–22.

KINOSHITA, I. (1993): Ecological study on larvae and juveniles of sparine fishes occurring in surf zones of sandy beaches. Bull. Mar. Sci. Fish. Kochi Univ., **13**, 21–99.

KINOSHITA, I, S. FUJITA, I. TAKAHASHI and K. AZUMA (1988): Occurrence of larval and juvenile Japanese snook, *Lates japonicus,* in the Shimanto estuary, Japan. Jpn. J. Ichthyol., **34**, 462–467.

KITAJIMA, C., Y. YAMANE, S. MATSUI and T. YOSHIMATSU (1998): Ontogenetic change in specific gravity in the early stages of ayu *Plecoglossus altivelis.* Nippon Suisan Gakkaishi, **64**, 822–829.

KUIPERS, N. (1977): On the efficiency of a two-metre beam trawl for juvenile plaice (*Pleuronectes platessa*). Neth. J. Sea Res., **9**, 69–85.

SENTA, T. (1967): Distribution in the sea and upstream migration of ayu juveniles. Bull. Coast. Oceanogr., **6**, 8–12.

SENTA, T. and I. KINOSHITA (1986): Larval and juvenile fishes occurring in surf zones of western Japan. Trans. Am. Fish. Soc., **114**, 609–618.

TAGO, Y. (2002): Larval distribution of ayu *Plecoglossus altivelis* in the surface layer of estuary regions in Toyama Bay. Nippon Suisan Gakkaishi, **68**, 61–71.

TAKAHASHI, I., I. KINOSHITA, K. AZUMA, S. FUJITA and M. TANAKA (1990): Larval ayu *Plecoglossus altivelis* occurring in the Shimanto estuary. Nippon Suisan Gakkaishi, **56**, 871–878.

TAKAHASHI, I., K. AZUMA, S. FUJITA and I. KINOSHITA (1998): Spatial distribution of larval ayu *Plecoglossus altivelis* in the Shimanto Estuary. Fish. Sci., **64**, 522–525.

TAKAHASHI, I., K. AZUMA, H. HIRAGA and S. FUJITA (1999): Different mortality in larval stage of ayu *Plecoglossus altivelis* by birth dates in the Shimanto Estuary. Fish. Sci., **65**, 206–210.

TAKAHASHI, I., K. AZUMA, S. FUJITA and H. HIRAGA (2000): Differences in larval and juvenile development among monthly cohorts ayu *Plecoglossus altivelis* in the Shimanto Estuary. Ichthyol. Res., **47**, 385–391.

TAKAHASHI, I., K. AZUMA, S. FUJITA and I. KINOSHITA (2002): Habitat shift of ayu *Plecoglossus altivelis altivelis* in early stages from waters adjacent to the bank to the center of flow in the Shimanto Estuary. Fish. Sci., **68**, 554–559.

TAKAHASHI, I., K. AZUMA, S. FUJITA, I. KINOSHITA and H. HIRAGA (2003): Annual changes in the hatching period of the dominant cohort of larval and juvenile ayu *Plecoglossus altivelis altivelis* in the Shimanto Estuary and adjacent coastal waters during 1986–2001. Fish. Sci., **69**, 438–444.

TSUKAMOTO, K. (1988): Migratory mechanisms and behavioral characteristics in ayu. *In* Uyeno, T. and M. Okiyama (eds.), Ichthyology currents. Asakura-Shoten, Tokyo, pp. 100–133.

TSUKAMOTO, K. and T. KAJIHARA (1987): Age determination of ayu with otolith. Nippon Suisan Gakkaishi, **53**, 1985–1997.

TSUKAMOTO, K., K. MOCHIZUKI, T. OHTAKE and Y. YAMASAKI (1989): Distribution, migration and growth of ayu larvae at the mouth of River Kumano. Fish. Engineer., **50**, 47–57.

YAGI, Y., C. BITO, T. FUNAKOSHI, I. KINOSHITA and I. TAKAHASHI (2006): Distribution and feeding habits of ayu *Plecoglossus altivelis altivelis* larvae in coastal waters of Tosa Bay. Nippon Suisan Gakkaishi, **72**, 1057–1067.

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