Different Mortality in Larval Stage of Ayu *Plecoglossus altivelis* by Birth Dates in the Shimanto Estuary and Adjacent Coastal Waters

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Different life stages of ayu *Plecoglossus altivelis*, including downstream migrating yolk-sac larvae, larvae and juveniles distributed in the estuary or coastal waters, and upstream migrating juveniles, were collected in the Shimanto River and adjacent coastal waters from October 1996 to June 1997. The objective of this study was to examine mortality process of larval and juvenile ayu by comparing the seasonal change in number of newly hatched larvae with the birth date distributions of the later life stages. For yolk-sac larvae during the downstream migration, two-peaks in abundance were found in mid-November and between late December and mid-January. In the later life stages, November hatched larvae and juveniles were few, while larvae and juveniles hatched between late December and early January were more abundant. This indicates a high mortality of the larvae hatched in mid-November 1996. From October to November 1996, water temperatures in the Shimanto Estuary and adjacent coastal waters were over 20°C, in which the survival rate of larval ayu was considerably low. We propose that the unusually high water temperature of the sea in autumn 1996 caused the high mortality of larval ayu hatched in November.

Key words: ayu, mortality, larva and juvenile, birth date, water temperature

Ayu *Plecoglossus altivelis* is an amphidromous fish with a life span of only one year. They spawn in the lower reaches of rivers in autumn. Hatching takes place about two weeks after spawning and yolk-sac larvae drift down into estuarine and coastal waters, where they live throughout the larval and early juvenile stages.^{1–5)} In spring, juveniles ascend rivers, where they grow and mature.

Although the survival rate of ayu after ascending a river is stable, large annual population fluctuation is observed within a river.^{6,7)} This phenomenon suggests that the resource level of ayu in a river of the year may be determined by the mortality during the early life stages. Previous studies have shown that starvation⁸⁾ and high mortality⁹⁾ occur during and after the downstream migration. Moreover, the resource level of juvenile ayu seems to be related to precipitation in the spawning season¹⁰⁾ and the difference in water temperature between the sea and the river in spring.¹¹⁾ However, there is little information about the mortality processes of ayu throughout the larval and juvenile stages.

In this study, to verify the mortality of ayu in larval and juvenile stages, following the methods of Methot¹²⁾ and Yoklavich and Bailey,¹³⁾ we studied the birth date distributions, through otoliths analysis, of three different life stages (ecological division by habit and habitat); 1) downstream migrating yolk-sac larvae, 2) larvae and juveniles distributed in the estuary and coastal waters, and 3) upstream migrating juveniles.

Materials and Methods

Sampling for downstream migrating yolk-sac larvae was conducted at Gudo, in the freshwater lower reaches (fresh water) of the Shimanto River, Kochi Prefecture (Fig. 1). The spawning grounds were located slightly above the station from October to December 1996. Yolk-sac larvae were collected with a conical plankton net (0.5 m mouth-diameter, 0.3 mm mesh). The collection record is shown in Table 1. The net was fixed in the center of flow of the river for 1–10 min to collect the yolk-sac larvae. Collections were made at 19:00, when the downstream migration of larvae is known to occur most intensively in this area.¹⁴⁾ The volume of water filtered by the net was derived from a flow meter fixed at the net mouth. The total number of yolk-sac larvae drifting per second in each survey was estimated by multiplying the density of larvae (n/m³) by the discharge of the river (m³/sec) at 19:00. Out of a total of 19,605 yolk-sac larvae collected, 886 larvae were measured for body length (notochord length) and observed for the degree of yolk absorption. Tsukamoto¹⁵⁾ proposed a yolk index as a criterion related to the time after hatching. We altered this to a yolk consumption index so as the abscissa corresponds with time elapsed. Yolk consumption indices of 0, 2, and 4 correspond approximately to no consumption of yolk, half consumption, and complete absorption, respectively.

Larvae and juveniles distributed in the Shimanto Estuary and adjacent coastal waters were collected using a submerged fish lamp (100 W) at four stations (Isawa and

Fig. 1. Map showing the study sites in the Shimanto River and the adjacent coastal waters.

Solid circle, triangles and square indicate the sampling stations for downstream migrating yolk-sac larvae, the larvae and juveniles distributed in the estuary and the coastal waters, and upstream migrating juveniles, respectively. Double circles indicate the stations where surface water temperature was measured.

Takeshima, in the estuary; Shimoda and Futami, in the coastal waters, Fig. 1, Table 1). Larval and juvenile ayu attracted to the lamp were scooped up with hand-nets (30 cm mouth-diameter, 3 mm mesh; 13 × 25 cm mouth size, 0.5 mm mesh) for 30 min. After measuring body length (notochord length in preflexion larvae and flexion larvae, standard length in postflexion larvae and juveniles), daily growth increments of otoliths were counted by the method described in Tsukamoto and Kajihara.¹⁶ The number of specimens used for measuring body length and age determination with otoliths were 2,766 (estuary, 2,207; coastal waters, 559) and 928 (estuary, 650; coastal waters, 278), respectively. Birth dates (hatch dates) were estimated from the ages and the dates of capture. Age determination was made only for specimens over 10 mm BL, at which larval ayu begin to occur in the bank waters of the estuary and surf zone of the coastal waters.^{1-5,17}

Upstream migrating Juveniles were collected using a cast net (stretched mesh size; 10 mm) at Gudo (Fig. 1, Table 1). Out of a total of 429 ayu caught, 428 juveniles

were measured body length (standard length) and 280 juveniles were used for age determination.

From October 1996 to July 1997, water temperature at the surface was taken between 16:00 and 19:00 at intervals of approximately 5 days at the four stations presented in Fig. 1: Gudo (fresh water); Takeshima and Shimoda (estuary); Shimoda (coastal waters). Water temperatures at 1 m depth intervals from the surface to the bottom were also recorded during sampling of larvae and juveniles in the estuary and coastal waters.

Results

Seasonal Changes of Water Temperature

Figure 2 shows the seasonal changes of surface water temperatures at the four stations from October 1996 to July 1997. Water temperature in the coastal waters was higher than in the fresh water and the estuary between autumn and winter. Water temperature fell below 20°C in mid-November in the fresh water and the estuary, and in early December in the coastal waters. The lowest temperature was recorded in late January for the fresh water and mid-February for the estuary and coastal waters. From mid-April to early July, temperatures were practically the same among the four stations.

Vertical profiles of water temperature for the estuary and coastal waters are shown in Fig. 3. Although the temperatures from the surface to 2 m were lower in the estuary than in coastal waters, temperatures were similar in the deeper layers.

Seasonal Abundance of Downstream Migrating Yolk-sac Larvae

Yolk-sac larvae occurred in the fresh water of the Shimanto River from late October 1996 to mid-February 1997 (Fig. 4A). The peak in abundance of yolk-sac larvae was observed in mid-November, with a gradual decline thereafter until mid-December. Larvae increased slightly in number again from late December to mid-January. The number of fish at the second peak in late December—mid-January was less than one tenth of the number of fish at the first peak in mid-November. Larval size ranged from 5.1 to 7.5 mm BL (Table 1), but less than 0.1% of larvae were over 7 mm BL. The yolk consumption index of larvae ranged from 0 to 3 with a mode at 1 (Fig. 5). Larvae with completed yolk absorption (index=4) were absent.

Table 1. Collection records of larval and juvenile ayu in the Shimanto River and adjacent coastal waters

Life stage of larval and juvenile ayu	Sampling period (interval)	Number of sampling	Number of fish	BL* ¹ range (mm)
Downstream migration	Oct. 3, 1996–Feb. 20, 1997 (5 days)	29	19,605	5.1–7.5
Distribution in the estuary and the coastal waters	Nov. 14, 1996–Apr. 10, 1997 (2 weeks)	10	8,685 (E)* ² 1,256 (C)* ³	5.7–49.2 (E)* ² 12.5–46.8 (C)* ³
Upstream migration	Mar. 3, 1997–June 10, 1997 (10 days)	11	429	36.9–78.6

*¹ Notochord length in preflexion and flexion larvae, standard length in postflexion larvae and juveniles.

*² (E), Estuary.

*³ (C), Coastal waters.

Seasonal Occurrence and Birth Date Distribution of Larvae and Juveniles Distributed in the Estuary and Coastal Waters

Larval and juvenile abundance in the estuary had two peaks; in mid-November and in late January—mid-February (Fig. 6). Larval and juvenile size ranged from 5.7 to 49.2 mm BL (Table 1, Fig. 6). In mid-November when the first peak in abundance was found, yolk-sac larvae were plentiful and the mean size of larvae was 7.4 mm (Fig. 6). Thereafter, fish size increased gradually until April. In the coastal waters, larvae and juveniles were first collected in early December, with low numbers present until early January (Fig. 6). A sudden peak occurred in mid-February, with few fish being collected thereafter. Fish size

Fig. 2. Seasonal changes of the water temperature at the surface in the freshwater lower reaches of the river (Gudo), the estuary (Takeshima and Shimoda), and the coastal waters (Shimoda) from October 1996 to July 1997.

Fig. 3. Vertical profiles of the average temperature in the estuary (closed circles) and the coastal waters (open circles) from December 1996 to January 1997.

ranged from 12.5 to 46.8 mm BL (Table 1, Fig. 6). No yolk-sac larvae were collected.

Birth dates of the specimens ranged from late October 1996 to early February 1997 for the estuary and early November to early February for the coastal waters (Fig. 4B). Birth date distributions showed unimodal patterns in both waters, with a peak in late December for the estuary and early January for the coastal waters. These peaks corresponded to the second abundance peak of downstream migrating yolk-sac larvae (Fig. 4A, 4B). Larvae and juveniles supposedly originating from the prominent peak of downstream migrating yolk-sac larvae in mid-November were far less abundant in these waters.

Seasonal Occurrence and Birth Date Distribution of Upstream Migrating Juveniles

A school of juveniles ascending the river was first found slightly above the collection site (Gudo) by a fisherman on February 25, 1997. Upstream migrating Juvenile ayu were collected at Gudo from early March to mid-June, and numbers caught continuously fluctuated (Fig. 7). Their sizes ranged from 36.9 to 78.6 mm BL (Table 1, Fig. 7).

Birth dates of upstream migrating juveniles ranged from early November 1996 to late January 1997 (Fig. 4C). Their

Fig. 4. Comparison of the seasonal changes of yolk-sac larvae number and the birth date distributions of larvae and juveniles.

A: Seasonal abundance of downstream migrating yolk-sac larvae at a peak hour of 19:00; the estimation based on collections with a plankton net at Gudo. B: Birth date distributions of larvae and juveniles over 10 mm BL collected in the estuary (Isawa and Takeshima) and the coastal waters (Shimoda and Futami) from November 1996 to April 1997. C: Birth date distribution of upstream migrating juveniles collected at Gudo from March to June 1997.

birth date distribution was similar in range and mode to that of larvae and juveniles distributed in the estuary and coastal waters. Specimens hatched in mid-November were also scarce in this sample.

Discussion

The age of larval ayu during downstream migration sometimes exceeds ten days,¹⁵⁾ but most yolk-sac larvae collected at Gudo were just after hatching as shown by the low yolk consumption index of 0 or 1 (Fig. 5). Therefore,

Fig. 5. Frequency distribution of the yolk consumption index of downstream migrating larvae collected at Gudo from October 1996 to February 1997.

Yolk consumption index: 0, yolk not yet consumed; 2, about half of the yolk consumed; 4, completely absorbed.

Fig. 6. Seasonal variation in the catch of larval and juvenile ayu attracted to a fish lamp and collected with scoop nets in the estuary (top) and the coastal waters (bottom).

Horizontal and vertical bars indicate the mean and range of body lengths, respectively.

we conclude that seasonal change in the number of yolk-sac larvae (Fig. 4A) corresponds with the birth date distribution. The number of yolk-sac larvae changed seasonally with two peaks in abundance (Fig. 4A). The first peak in mid-November was prominent, while the second peak between late December and mid-January was much smaller than the first peak. In contrast, the birth date distributions of fish in the estuary and the coastal waters showed only one peak which corresponded to the second peak in abundance of yolk-sac larvae (Fig. 4A, 4B). Unexpectedly, the first peak abundance of yolk-sac larvae was not observed in the birth date distributions in these waters. A nearly identical pattern was found also in the birth date distribution of upstream migrating juveniles (Fig. 4C). These results indicate that larvae hatched in mid-November 1996 suffered high mortality.

In the estuary, numerous larvae were collected in mid-November (Fig. 6). It seems that these larvae were the large cohort hatched in mid-November, because the mean larval size was 7.4 mm BL and a large number of yolk-sac larvae were found in the samples. However, few larvae and juveniles were estimated to have hatched in mid-November by age determination of specimens over 10 mm in size (Fig. 4B). This suggests that the larvae hatched in mid-November suffered a high mortality in the period before reaching 10 mm BL. The dominance of the postlarval and juvenile fish hatched in December and January should have resulted from a low mortality during the larval stage. Tsukamoto⁹⁾ reported a high mortality of larval ayu after downstream migration by tracking released larval ayu marked with fluorescent substances on otoliths. Similar results were obtained in this study. Furthermore, our results indicate that early mortalities of ayu fluctuate with birth dates.

Water temperatures over 20°C have a remarkable influence on the mortality of reared larval ayu.¹⁸⁻²¹⁾ In mid-November, when numerous larvae hatched, the water temperature in the coastal waters was 22–24°C (Fig. 2), seemingly severe conditions for larval ayu. Although the surface water temperature in the estuary fell below 20°C after mid-November, in the waters deeper than 2 m the temperature was as high as in the coastal waters (Fig. 3). As larval ayu aggregate near the bottom after yolk absorp-

Fig. 7. Seasonal variation in the abundance of upstream migrating juvenile ayu, as indicated mean catches with a cast net at Gudo. Horizontal and vertical bars as in Fig. 6.

tion,¹⁷⁾ estuarine conditions in mid-November would have been unsuitable for survival.

Surface water temperature off the mouth of the Shimanto River from October to November 1996 ranged from 24 to 26°C^{*3}; the highest temperature recorded in the past twenty years in November (range and average of temperature in the past twenty years, 20.4–23.7°C and 22.2°C). Though the high mortality of larvae hatched in mid-November 1996 is unusual, we assume that early hatched larval ayu is destined to take a risk of high mortality in exchange for a high growth rate^{2,4,5,22)} due to the high water temperature.

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