Doctoral Dissertation

Comparison of Early Life Histories of Euryhaline Fishes
in Estuaries between Vietnam and Japan

by

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Contents

List of main papers

Main papers used in creating the dissertation

Peer-reviewed papers
1. Tran, T.T., H.D. Tran & I. Kinoshita (2017), Occurrence of two types of larvae of the Asian seaperch (*Lateolabrax*) in the estuaries of northern Vietnam, Ichthyol. Res., 64(2): 244–249.

Conference presentations
1. Tran, T.T., H.D. Tran & I. Kinoshita, Occurrence of two type larvae of the Asian seaperch (*Lateolabrax*) in the northern estuaries of Vietnam, 49th Ann. Meet. Ichthyol. Soc. Jpn., Gifu, 25 September 2016
2. Tran, T.T., I. Kinoshita & H.D. Tran, Simultaneous occurrence of larvae and juveniles of *Acanthopagrus latus* and *A. schlegelii* (Sparidae) in the estuary of northern Vietnam, 10th Internat. Kuroshio Sci. Symp., Albay, Philippines, 25 November 2016
3. Tran, T.T., S. Tojima, I. Kinoshita, S. Fujita & Y. Hirota, Comparison of larval growth and development in an estuarine nursery of the seaperch (*Lateolabrax japonicus*) among the neighboring rivers in Ariake Bay, 11th Internat. Kuroshio Sci. Symp., Kochi, Japan, 26 July 2017
4. Tran, T.T., S. Tojima, I. Kinoshita, S. Fujita & Y. Hirota, Comparison of larval growth and development in an estuarine nursery of the *Lateolabrax japonicus* among the neighboring rivers in Ariake Bay, 50th Ann. Meet. Ichthyol. Soc. Jpn., Hakodate, 16 September 2017

Summary

General introduction.   Estuarine fish communities are composed chiefly by euryhaline fishes, especially their larvae and juveniles.   Of them, the seaperches (*Lateolabrax*, Lateolabracidae) and porgies (*Acanthopagrus*, Sparidae) are widely distributed from tropical to temperate coasts of Southern Asia and East Asia, demonstrating biodiversity.   In this study, to understand latitudinal variation of biotope functions of estuaries for larvae and juveniles emphasizing euryhaline fishes, estuarine larval and juvenile fish communities are compared between Vietnam as a tropical waters and Japan as a temperate ones and the larvae and juveniles of the seaperches and porgies are compared ontogenetically and ecologically between the above sites.

Topography and environment.   This study was conducted at the Tien Yen and Kalong estuaries facing the Gulf of Tonkin in northern Vietnam, inner estuaries in Ariake Bay and Shimanto estuary facing Tosa Bay of southern Japan.   Water temperatures were the lowest in Ariake Bay, followed by Shimanto and northern Vietnamese estuaries, salinity phenomena were almost similar among the three waters, and turbidities were much higher in Ariake Bay.   Furthermore, water temperatures were not so higher in Vietnam in spite of lower than the Tropic of Cancer, being like to be influenced by a cold current from the Yellow Sea.

Comparison of larval and juvenile community.   To clarify the common or different characteristic of the larval and juvenile fish communities in estuaries between Vietnam and Japan, monthly collections were conducted in the center of the current with larva net and the bank waters with seine net.

In the Tien Yen estuary, a total of ca. 2,000 and 3,000 fishes of more than 30 and 37 species from 17 and 21 families were collected in the center of the current and bank waters, respectively, from October 2014 to April 2015.   Gobiidae spp. (86.1% of the total abundance), *Luciogobius* sp. (4.7%), *Acanthopagrus* (2.5%), Tetradontidae sp. (1.5%) and *Omobranchus* sp. (1.2%) in the center of the current; *Acanthopagrus latus* (43.0%), *Gobiopterus brachypterus* (30.1%), *Oryzias curvinotus* (9.5%), *Acanthopagrus schlegelii* (5.5%) and *Gerres japonicus* (3.0%) in the bank waters were dominant in the community.

In the Yabe estuary of Ariake Bay, a total of ca. 9,000 fishes of 13 species from 8

families were collected in the center of the current from February to April 2015. The ichthyofauna was dominated almost entirely by the gobiid *Acanthogobius hasta* (91.7%). *Trachidermus fasciatus* (3.7%) was ranked second, followed by Gobiidae sp. (2.7%).

In the Shimanto estuary, a total of ca. 400 and ca. 10,000 fishes of more than 13 and 49 species from 8 and 24 families were collected in the center of the current from October 2015 to February 2016 and in the bank waters during the period of October to March from 2014 to 2018, respectively. *Plecoglossus altivelis altivelis* (35.2%), *Luciogobius* spp. (27.4%), *Sebastiscus marmoratus* (18.1%), *Engraulis japonica* (12.0%) and *Lutjanus* sp. (4.2%) in the center of the current; *P. a. altivelis* (37.9%), *Leucopsarion petersii* (25.0%), *Gymnogobius scrobiculatus* (11.0%), *Mugil cephalus cephalus* (6.9%) and *Gymnogobius castaneus* (6.5%) in the bank waters were dominant in the community.

The species richness was significantly greater in the bank waters than in the center of the current in both Vietnamese and Japanese estuaries. Gobiidae was the most dominant in terms of both species diversity and abundance in the estuarine ichthyofaunas.

Larval and juvenile community of Vietnamese estuary was composed of not only tropic but also temperate species, and was resemble to Shimanto estuary rather than Ariake estuary, where endemic and relic fishes are distributed in drastically turbid waters.

Comparison of early life history of the Asian seaperches (*Lateolabrax*). Larvae and juveniles of *Lateolabrax* sp. occurred from December to April in estuaries of northern Vietnam, the southernmost locality for this genus distribution. The larvae and juveniles appeared in the bank waters in both the Tien Yen and Kalong estuaries, and in the center of the current in the latter. Their morphological, meristic and pigmentation characters were closer to those of Chinese *Lateolabrax* than *L. japonicus*, so Vietnamese *Lateolabrax* is likely situated as a population of Asian continental *Lateolabrax*. Morphometric and pigmentation characters of larvae from the two estuaries differed, suggesting that *Lateolabrax* of northern Vietnam are diversified and consist of at least two different breeding stocks.

To examine a biodiversity of early life history of *L. japonicus* in Ariake Bay, their ontogeny was compared among neighboring habitats. Of larvae and juveniles from three estuaries and a surf zone, recruits into the most symbolized estuarine river flowing into the bay showed significant more difference in morphology and growth.

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This differentiation can demonstrate indeed a plasticity to make any cohort stocks survive to sustain the unique Ariake population.

When the larvae and juveniles were compared among Vietnam, Ariake Bay and Shimanto estuary, some differences were found.   There were significant differences in morphology between Vietnamese and Japanese seaperches and between the fishes in Ariake Bay and Shimanto estuary; however, some morphometric and meristic characters of Ariake Bay population tended to fall midway between values for the Vietnamese and Shimanto ones.   The growth was the fastest in the specimens from Vietnam, followed by Shimanto estuary and Ariake Bay.   Their hatching dates were concentrated to days around the new moon in all the sites.   *Lateolabrax* fed mainly on calanoid copepods and their food habit changed with the growth in both Vietnam and Japan.   There was a little difference in the seasonal occurrence between Vietnam and Japan.   The size and developmental stage compositions were common to both Vietnam and Japan, which are chiefly composed the larval and juvenile stages, suggesting that estuaries provide worldwide a nursery ground for the transformation stage of seaperch.   Therefore, distribution of *Lateolabrax* larvae and juveniles could show characteristic but common phenomena by different oceanography.

These results indicate that *Lateolabrax* could experience their early stages from the cool temperate to tropical regions, implying the potential biodiversity of this fish genus in the world.

Comparison of early juveniles of porgies (*Acanthopagrus*).   *Acanthopagrus latus* and *A. schlegelii* are closely related species distributed in northern tropical to temperate coastal waters of eastern Asia.   In northern Vietnam early juveniles of both the species occurred in the Tien Yen estuary, from December to March (*A. schlegelii*) or December to April (*A. latus*), when temperatures ranged from ca. 16 to 25°C, which is observed twice (spring and autumn) a year in estuaries or surf zones facing Tosa Bay of Japan, and *A. latus* and *A. schlegelii* early juveniles are abundant opposite for each season. Thus, a thermoperiodicity is common worldwide to early juveniles of the two *Acanthopagrus*.   The two species occurred as the same developmental stage, being markedly more abundant and larger sizes in *A. latus*.   The early juveniles inhabited over bank waters of the estuary.   There was little variation in developmental stage and size among stations for both the species.   The two *Acanthopagrus* species from

Vietnam spawn for a same season and their early juveniles simultaneously used a same nursery ground, so they probably could not interbreed to keep species due to isolating spawning ground.

Although the growth was not much difference between the two species, the osteological development proceeded at smaller size in *A. schlegelii* than *A. latus*. Hence, their development than growth were more regular in the inhabitation such as bank waters and tend to be more stimulated in the higher temperatures.

Acanthopagrus latus juveniles fed mainly on cyclopoid, followed by harpacticoid and calanoid copepods and there were almost similar in food composition among different sizes. Whereas, food habit of *A. schlegelii* juveniles changed with growth. Initially, the cyclopoid was the most important prey for *A. schlegelii*, followed by calanoid and harpacticoid copepods; however, as size increase, the number percentage of the former decreased whereas that of the two latter increased, consequently, the larger than 16 mm juveniles fed chiefly on harpacticoid, followed by cyclopoid copepods. The occurrence of benthic food such as gammarid in stomach indicates that the juveniles of both the species transform to demersal habit from the smallest sizes that first appeared in the bank waters of the estuary.

When juveniles of *A. latus* were compared between Tien Yen and Shimanto estuaries, there are significant mean differentiations in body parts larger than ca. 11 mm specimens between the two areas; growth and development were significantly faster in *A. latus* juveniles from Tien Yen than those from Shimanto estuary. The water physical parameters when the juveniles were collected were not much difference between the two areas, suggesting that these ontogenetic differences in early juveniles between Vietnam and Japan seem to reflect genetic, not phenotypic modification.

Early juveniles of *Acanthopagrus* are usual components of estuarine ichthyofauna and their larvae seem to settle dispersedly into banks, not migrating with growth, following a spring tidal current, in both tropical and temperate regions. It seems utilization of estuary in early stages of life history by this fish genus is a worldwide phenomenon.

In conclusion, this study reveals that early life histories of euryhaline fishes could show characteristic but common phenomena by different oceanography, thus it should be biodiversity.

Chapter 1.   General introduction

Estuaries are known in many parts of the world as nursery grounds for a wide variety of fishes that inhabit much wider areas as adult (e.g., Mulkana, 1966; Blaber and Blaber, 1980; Blaber and Milton, 1990; Able and Fahay, 1998; Elliott and Hemingway, 2002; Fujita et al., 2002; Ikejima et al., 2003; Yagi et al., 2011).   These previous studies seem to show the differences in assemblage compositions and biotope functions between individual estuaries and among regions or climatic zones but it is of note that there have been no studies comparing the early stages of estuarine fish assemblages over large geographical areas.

Estuaries are dynamic and heterogenous ecotones where extreme variability in hydrographic environment occurs with tremendous influences on residents and their trophic structures (Costa et al., 2002; Kaiser et al., 2005; Yagi et al., 2011). Accordingly, estuarine fish communities are composed chiefly by euryhaline fishes, especially their larvae and juveniles, being adaptable to wide-salinity waters.   Of them, seaperches (*Lateolabrax*, Lateolabracidae) and porgies (*Acanthopagrus*, Sparidae) (Nelson et al. 2016) are widely distributed from tropical to temperate coasts of Southern Asia and East Asia (Katayama, 1984; Yamada et al., 2007; Iwatsuki, 2013), demonstrating biodiversity (Kinoshita et al., 1995; Yokogawa and Seki, 1995; Nakayama et al., 1996; Yokogawa et al., 1997; Nakayama, 2002; Zhao et al., 2005; Iwatsuki, 2013).   Both fishes are important for commercial and sport fishing.   In Japanese coasts, much works have been done on the early life histories of these euryhaline fishes, which indicate that the larvae and juveniles commonly used estuarine habitats as their nurseries, being usually dominated in the estuarine ichthyofauna (Kinoshita, 1993; Kinoshita and Fujita, 1988; Kinoshita et al., 1995; Fujita et al., 1988, 2002).   These studies also revealed that the larvae and juveniles of seaperches and porgies vary in ecology and morphology across different habitats and show relationships with water conditions; however, difference in early stage traits of these fishes among latitudinal cohorts have been poorly reported (Kinoshita et al., 1995).

During the survey in northern Vietnam, the fishes of *Lateolabrax* and *Acanthopagrus* species were collected.   In observation, we found that there are differentiation in morphology and ecology of larvae and juveniles of the given fishes

between Vietnam and Japan.　　These findings should help to clarify the difference in biotope functions of estuaries for early stages of fishes between Vietnam and Japan which have different oceanographic conditions.

In this study, to understand latitudinal variation of biotope functions of estuaries for larvae and juveniles of fishes emphasizing euryhaline fishes, estuarine larval and juvenile fish communities are compared between Vietnam as a tropical waters and Japan as a temperate ones and the larvae and juveniles of *Lateolabrax* and *Acanthopagrus* fishes are compared ontogenetically and ecologically between the above sites.

Chapter 2. Topography and environment

2.1. Vietnam

The Tien Yen River system is the southernmost locality for this study (Fig. 1). The salt usually reaches approximately 10 km above the mouth of this river (21°18'N, 107°24'E), which flows into the Gulf of Tonkin in northern Vietnam. The maximum depth is approximately 10 m. The estuary was vertically stratified and received tidal exchange of water (Fig. 2). During the period of October 2014 to May 2015, water temperatures fluctuated between 16.0°C (early February) and 30.1°C (May), while salinities ranged from >0 to 30 (Figs. 2, 3). Turbidities ranged from <1 to 30 NTU from October to April, with extremely higher values recorded in May (2–130 NTU) (Figs. 2, 3).
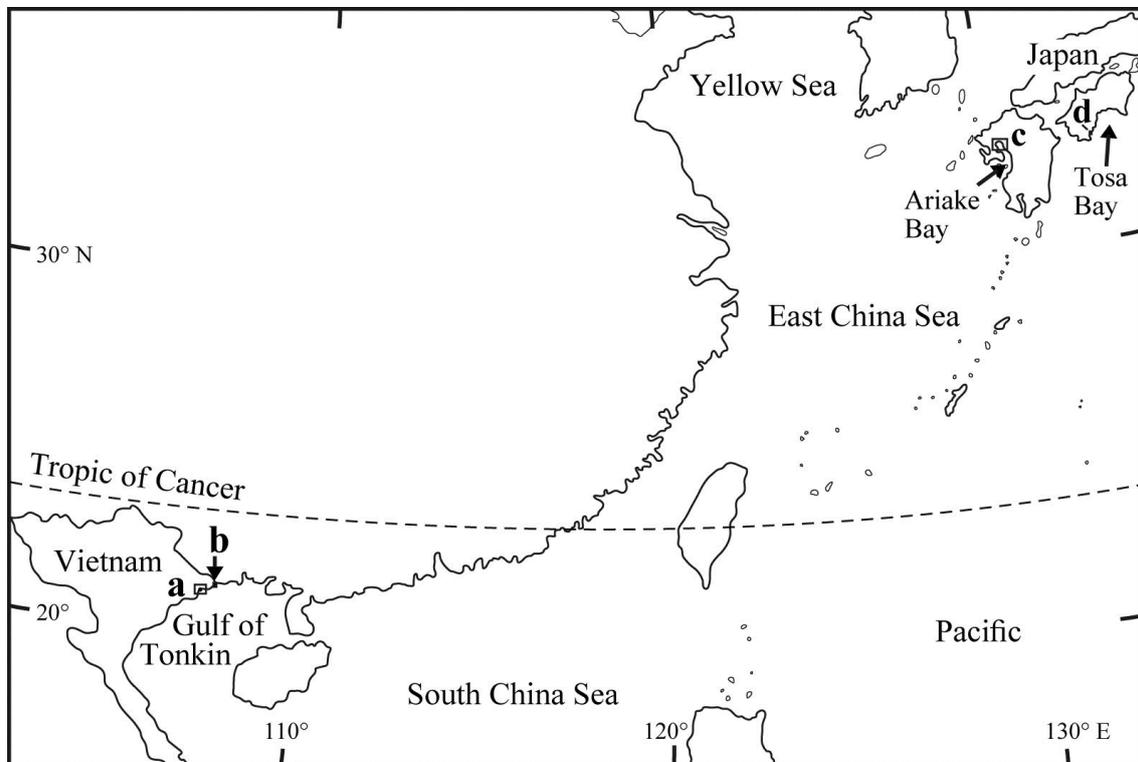
Fig. 1. Study sites: **a,** Tien Yen River and **b,** Kalong River in northern Vietnam; **c,** Ariake Bay and **d,** Shimanto River in southern Japan.
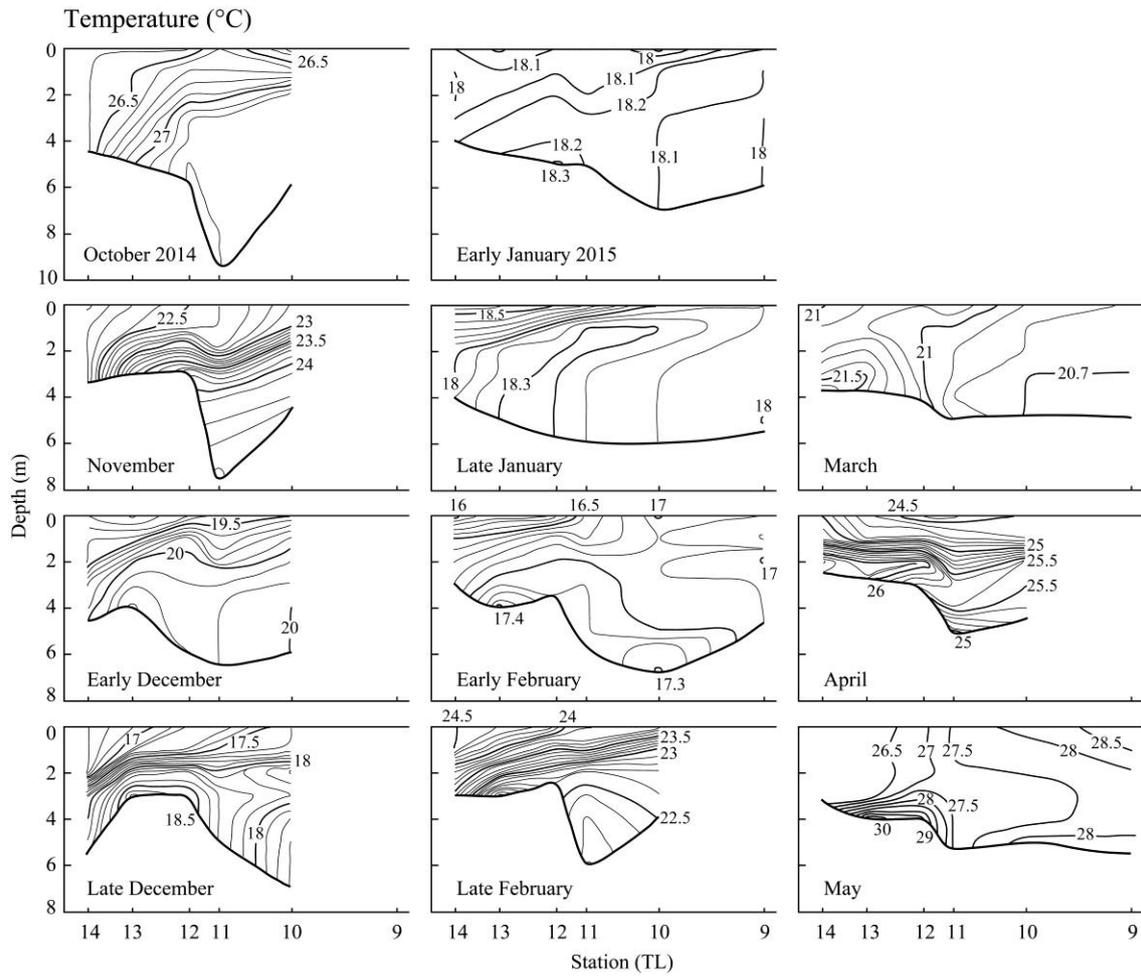
Fig. 2.　Seasonal changes in the vertical profiles of physical parameters in the Tien Yen estuary from October 2014 to May 2015.　Station (TL), see Fig. 10.
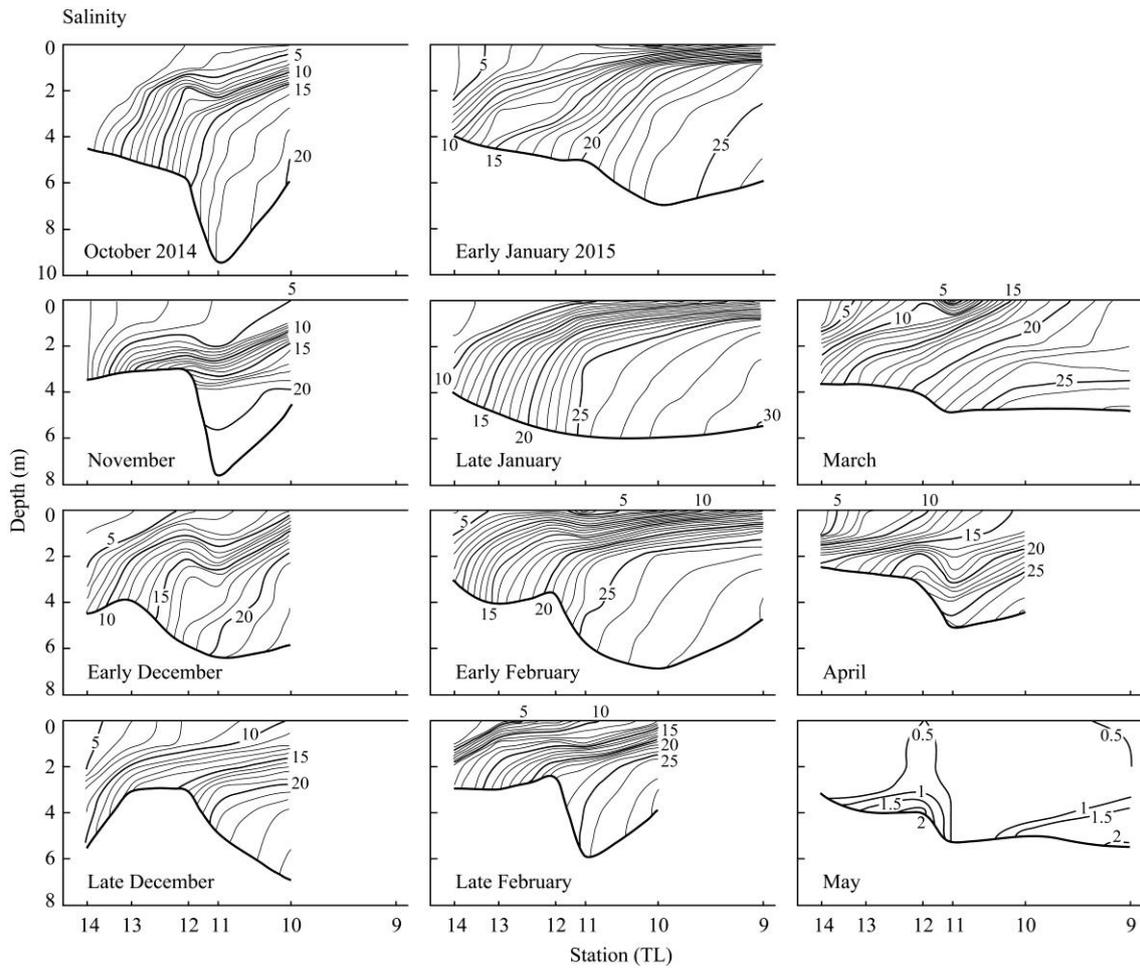
Fig. 2.　Continued.
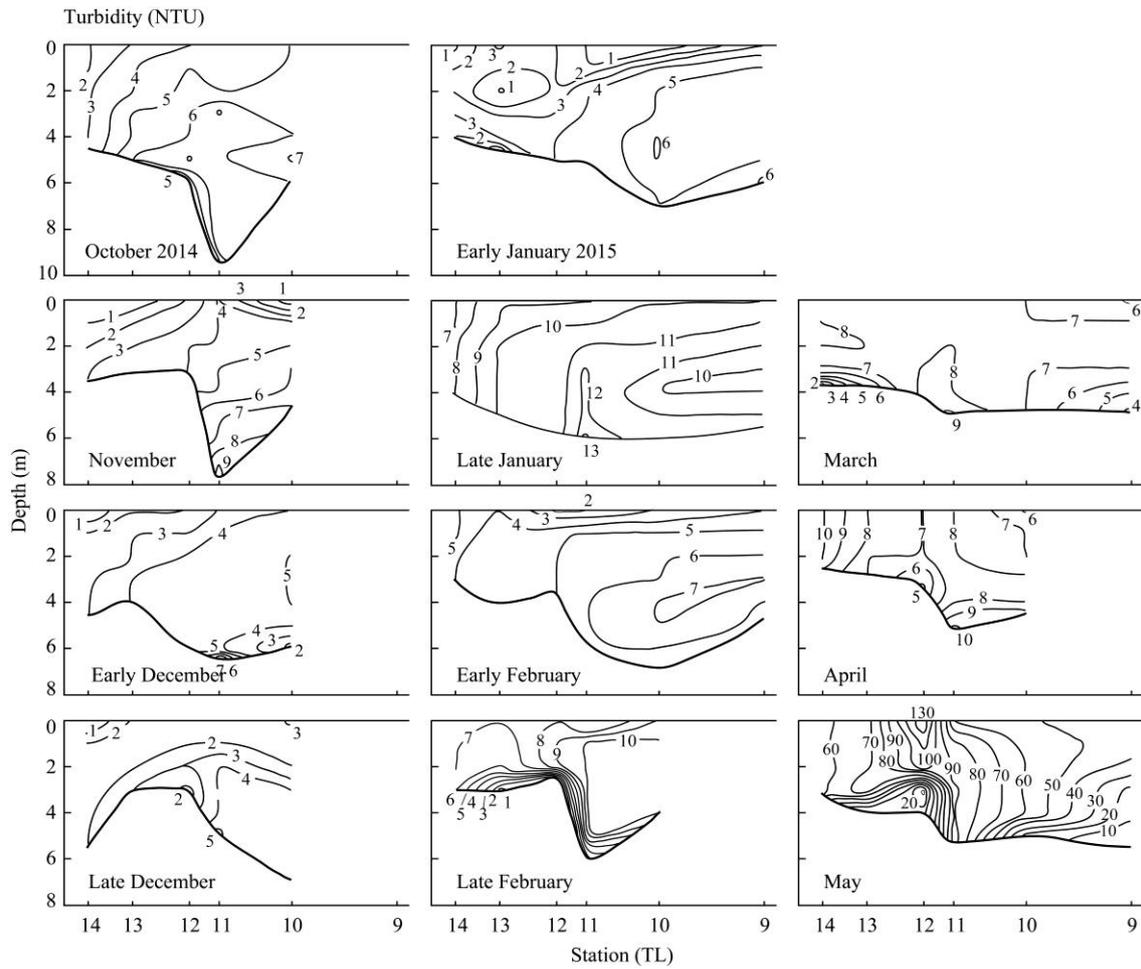
Fig. 2. Continued.
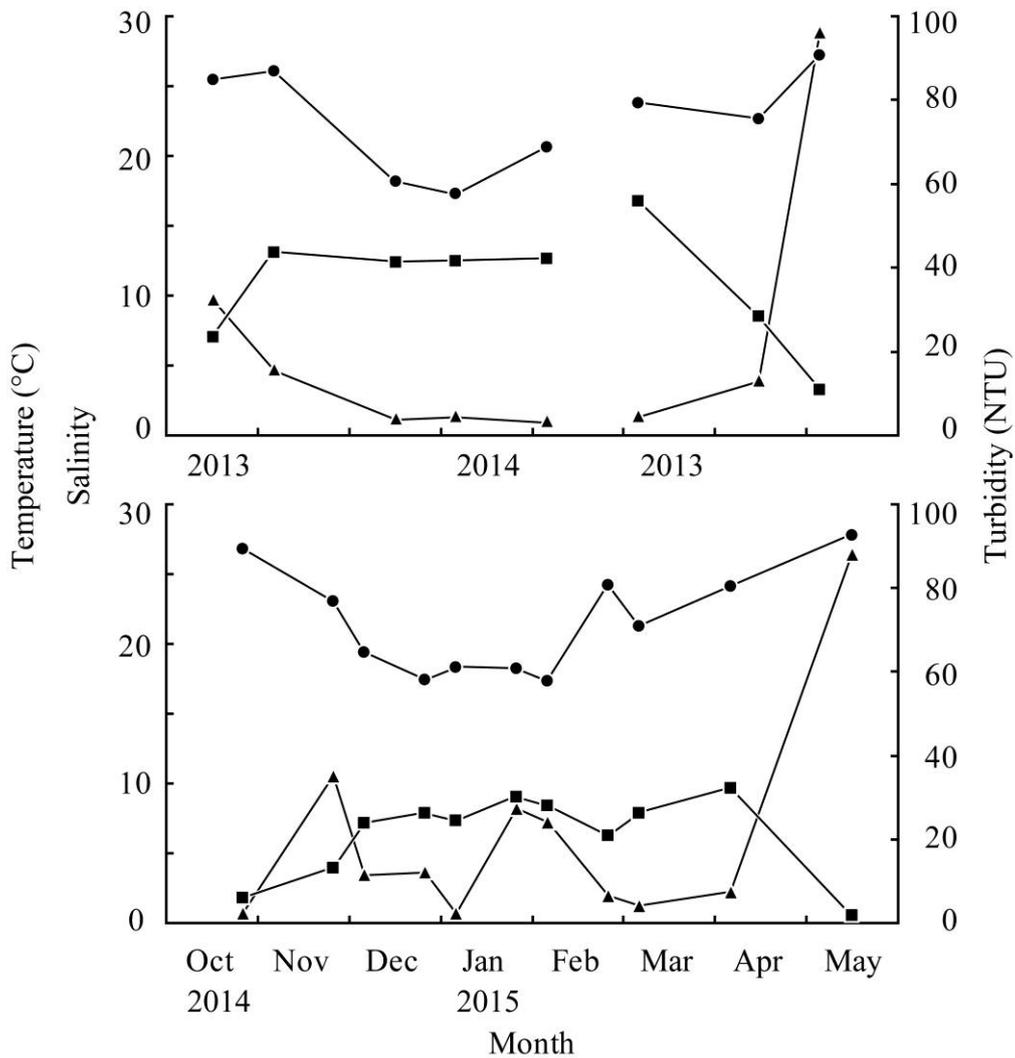
Fig. 3. Seasonal changes in means of water temperatures (*circles*), salinities (*squares*) and turbidities (*triangles*) in the bank waters of the Tien Yen estuary, northern Vietnam from March 2013 to May 2015.

The Kalong River flows into the northernmost Vietnam coast on the Gulf of Tonkin (Fig. 1). The estuary (21°25'N, 107°57'E) has a large area of tidal flats with an average tidal range of 3–4 m (Vietnam Administration of Seas and Islands, Marine Hydrological Center, 2010). The maximum depth is approximately 8 m. Based on water temperature and salinity, the estuary was vertically well mixed and received tidal exchange of water, except for a stratification on temperature in April (Fig. 4). During the period of October 2014 to May 2015, water temperatures fluctuated between 15.2°C (February) and 28.7°C (May), while salinities ranged from >0 to 33.2, and turbidities from <1 to 57 NTU (mostly <20) (Figs. 4, 5).

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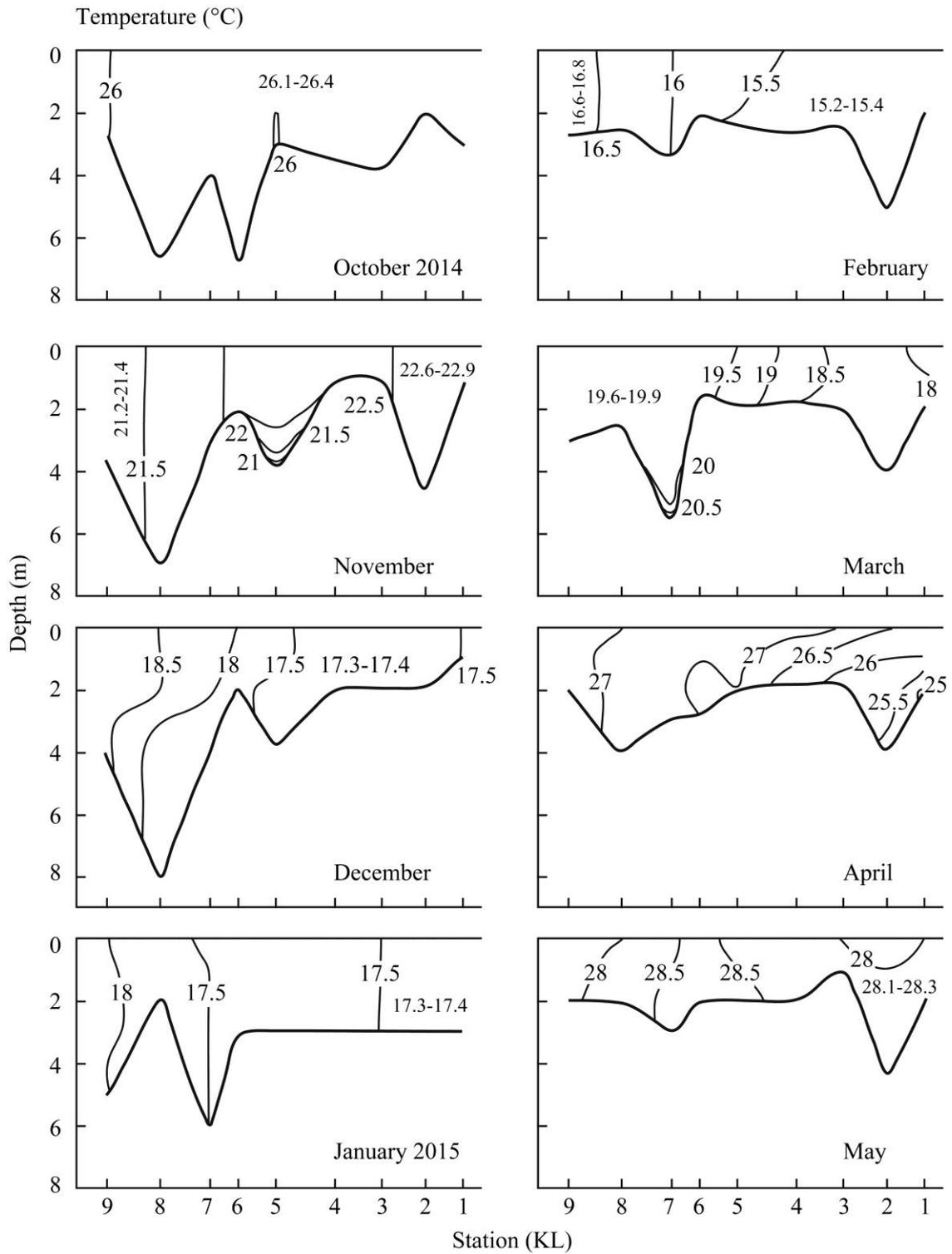
Fig. 4.   Seasonal changes in the vertical profiles of physical parameters in the Kalong estuary from October 2014 to May 2015.   Station (KL), see Fig. 10.

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Fig. 4.   Continued.

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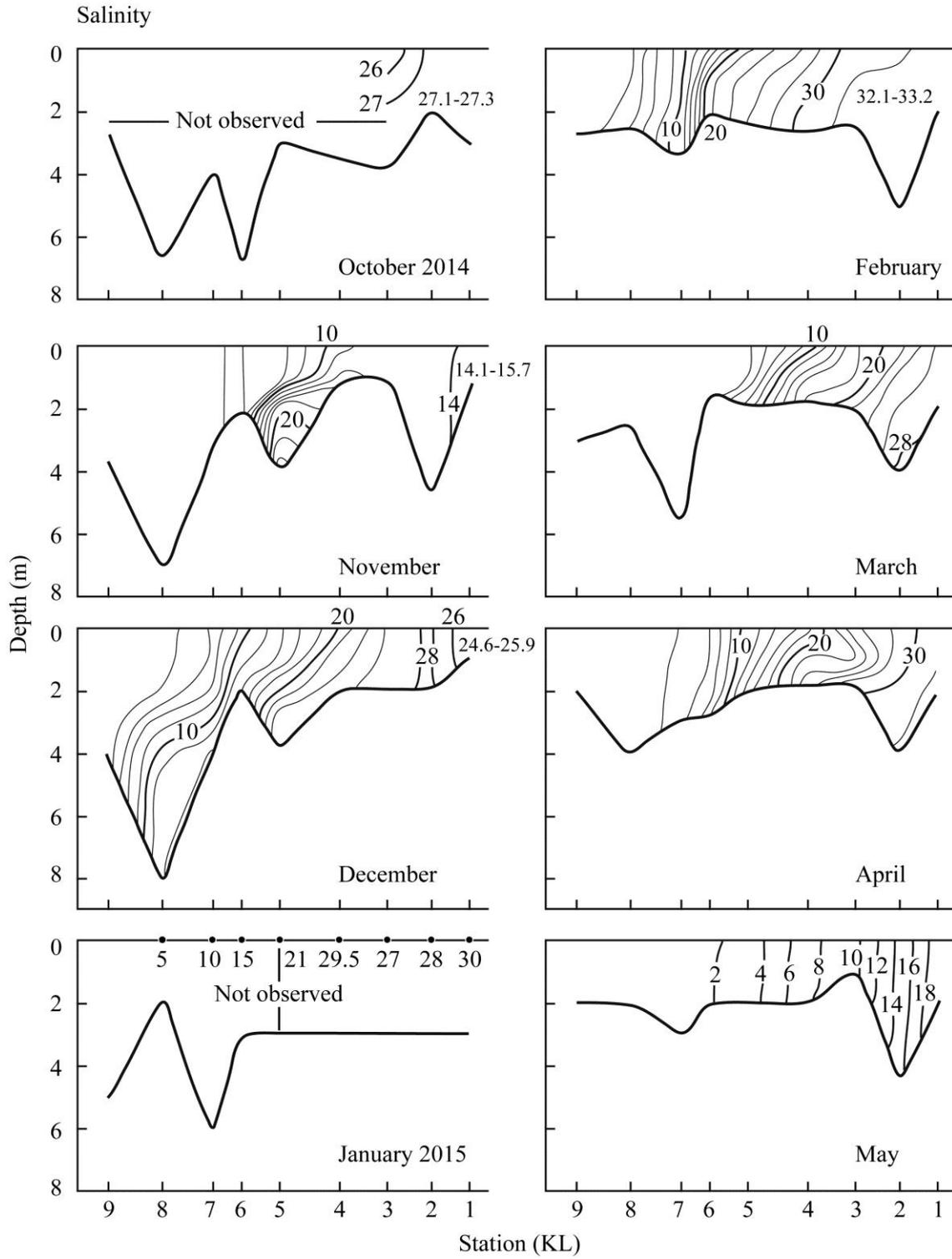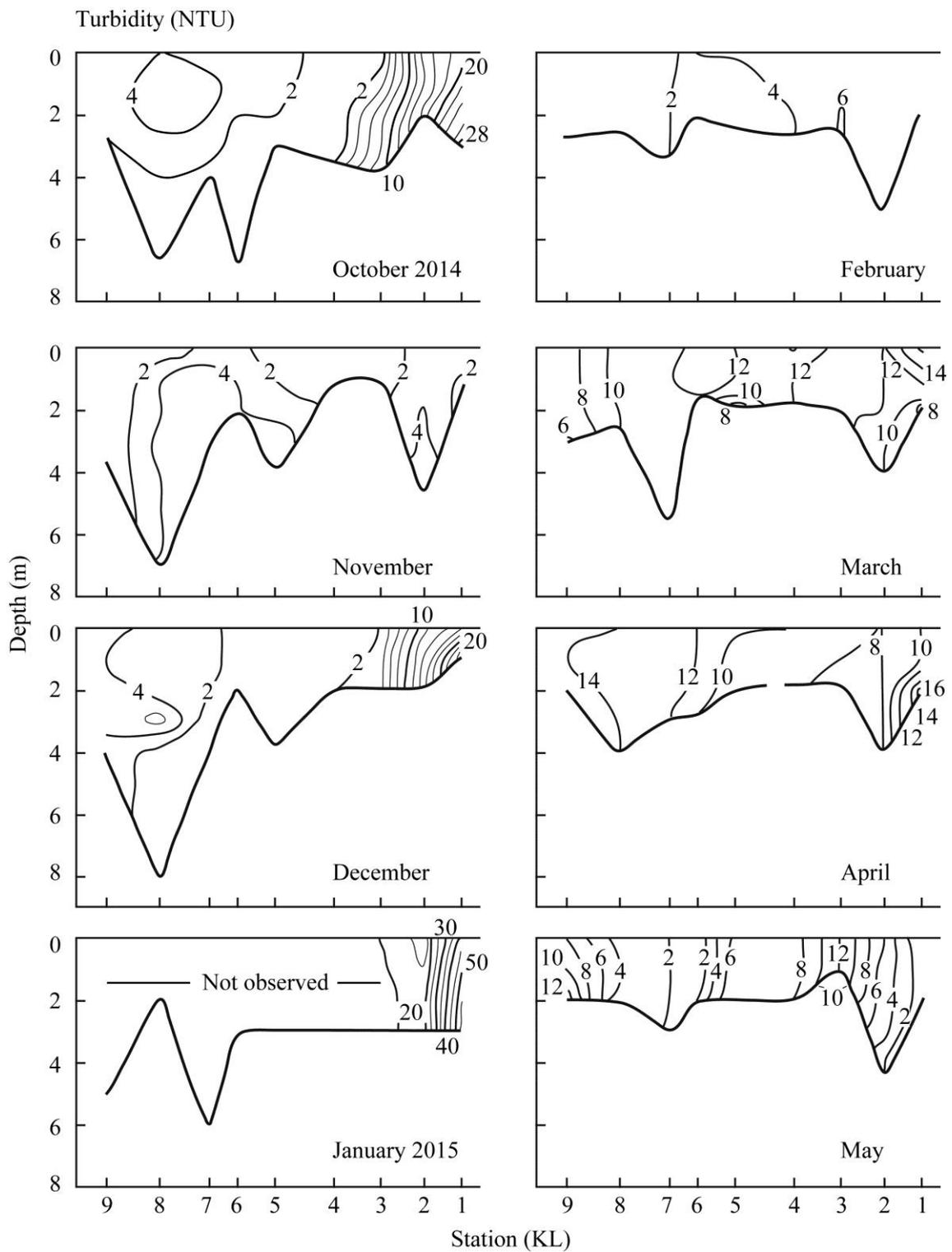
Fig. 4.   Continued.
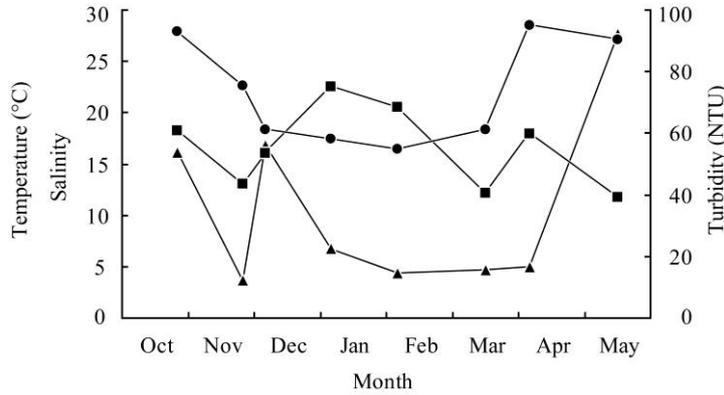
Fig. 5. Bank waters of the Kalong estuary, northern Vietnam from October 2014 to May 2015. Otherwise same as Fig. 3.

2.2. Ariake Bay

Ariake Bay in Kyushu Island, southwestern Japan, is the northernmost locality for this study (Fig. 1). The bay has the largest area of tidal flats with the highest tidal range in Japan (Inoue, 1980). During February to April 2015, the Yabe estuary flowing into the bay, was usually stratified in the lower part (Stns. 42–46) and well mixed in the upper part; the water temperatures increases from 9.0 to16.1°C, salinities fluctuated between >0 and 28.2 and turbidities is lower (10–40 NTU) in February and higher in March and April, extending to over 200 NTU (Fig. 6).
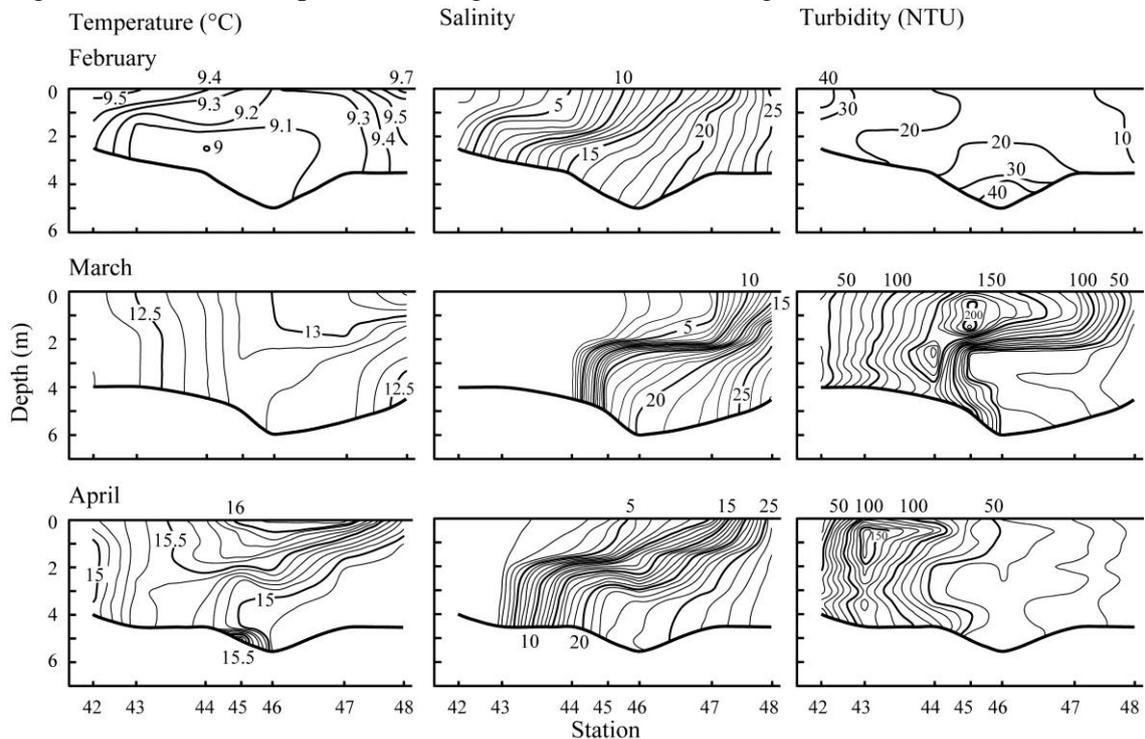
Fig. 6. Seasonal changes in the vertical profiles of physical parameters in the Yabe estuary of Ariake Bay from February to April 2015. Station, see Fig. 10.

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In this bay, each river estuary shows different water characteristic (Fig. 7).　The Yabe estuary is less turbid and has lower current speed, while Rokkaku and Hayatsue estuaries are much turbid and recorded higher current speed (Fig. 7).　The waters in all estuaries were brackish, whereas salty waters were observed in a surf zone of Miike beach outside of the estuary (Fig. 7).
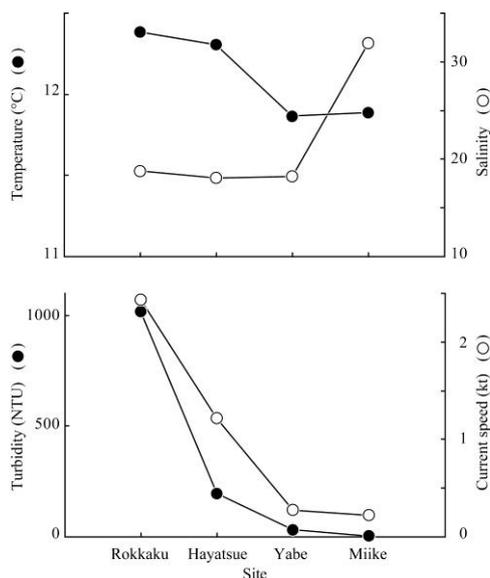

Fig. 7.　Means of physical parameters in the Rokkaku, Hayatsue and Yabe estuaries, and Miike sand beach of Ariake Bay in March 2017.　Site names, see Fig. 10.

2.3.　Shimanto estuary

The Shimanto River flows into Tosa Bay in Shikoku Island, southeastern Japan (Fig. 1).　The salt wedge usually reaches approximately 6 km above the mouth of river (32°56'N, 132°59'E).　The maximum width is 0.6 km and maximum depth is approximately 17 m (Fujita et al., 2002).　Based on water temperature and salinity, the estuary was vertically stratified in layer of surface to ca. 2 m depth and well mixed in layers deeper than 2 m (Fig. 8).　During the period of October to March, water temperatures fluctuated between ca. 10°C (February) and 25°C (October), salinities ranged from >0 to 34, and turbidities were less than 10 NTU (Figs. 8, 9).

Among the study sites, water temperatures were the lowest in Ariake Bay, followed by Shimanto and Vietnamese estuaries, salinity phenomena were almost similar among the three waters, and turbidities were much higher in Ariake Bay than Shimanto and Vietnamese estuaries.　Furthermore, water temperatures were not so higher in Vietnam in spite of lower than the Tropic of Cancer, being like to be

influenced by a cold current from the Yellow Sea (Sverdrup et al., 1961; Wyrtki, 1961; Endo, 1987; Tran et al., 2012).
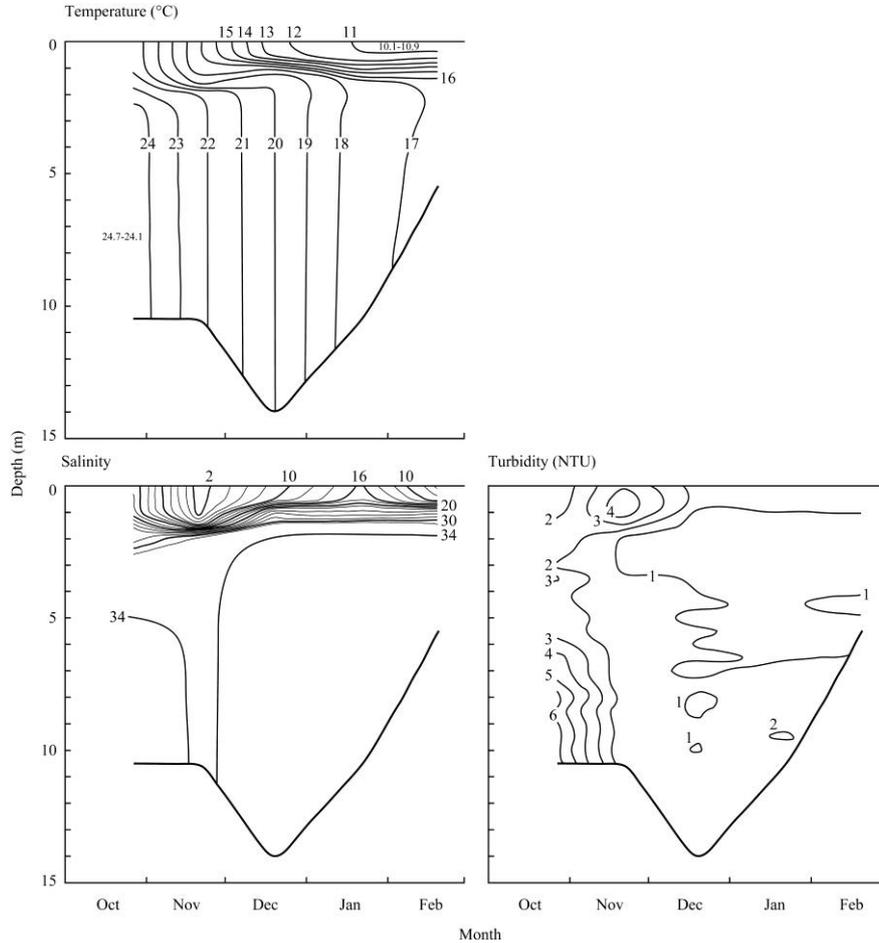
Fig. 8.   Seasonal changes in the vertical profiles of physical parameters in the Shimanto estuary from October 2015 to February 2016.
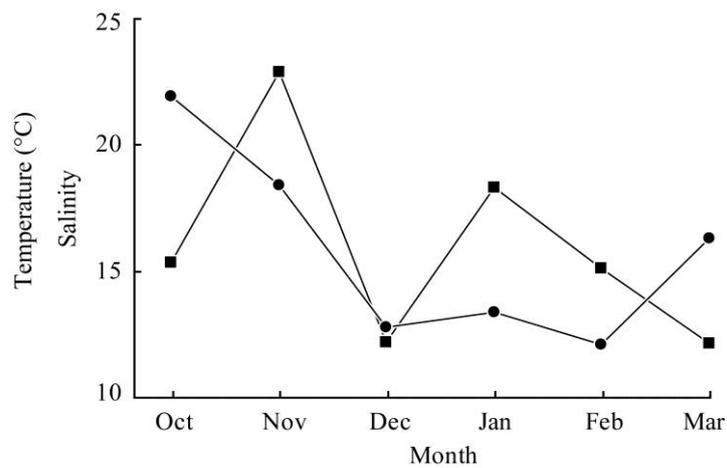
Fig. 9.   Seasonal changes in means of water temperatures (*circles*) and salinities (*squares*) in bank waters of the Shimanto estuary from October 2014 to March 2018.

Chapter 3.   Materials and methods

3.1.   Methods

3.1.1.   Sampling

In Vietnam

Samples used in this study were collected in the Tien Yen (Fig. 10a) and Kalong (Fig. 10b) River systems facing the northern coasts of the Gulf of Tonkin in Vietnam. Schedule and methods for samplings in each river are shown in Table 1.
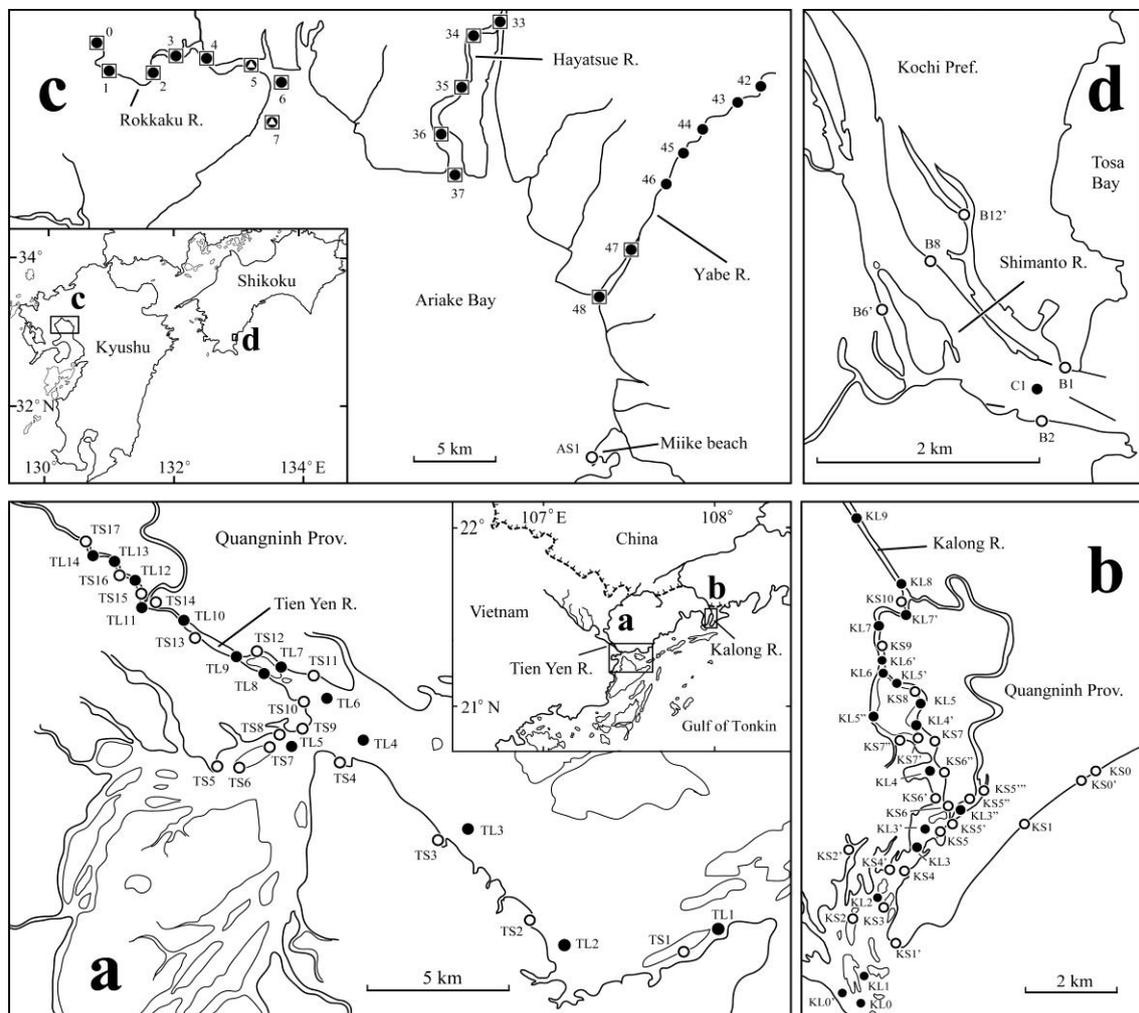
Fig. 10.   Charts showing the stations where fish larvae and juveniles were collected in the Tien Yen (**a**) and Kalong (**b**) estuaries of northern Vietnam, and three neighboring river estuaries and a sand beach in Ariake Bay (**c**) and the Shimanto estuary (**d**) of southern Japan.   Collections were made in the bank waters by a seine net (*open circles*) and in the center of the current by larva nets (*solid circles*), a near-bottom net (*open triangles*) and a beam trawl (*open squares*).

Table 1. Schedule and methods for samplings in the two estuaries of northern Vietnam

Estuary	Year	Month	Collection category	Station	Method
Tien Yen	2010	Nov–Dec	Cc	TL4–10	Sf
	2011	Jan–Feb*	BW	TS5–12	
	2013	Mar–Dec	BW	TS8–17	
	2014	Jan–Feb			
		Oct–Nov	Cc	TL9–14	Sf, Nb, Sp
		Dec*			
	2015	Jan–Feb*	BW	TS13–17	
		Mar–Sep			
	2017	Jan–Mar	Cc	TL1–4, 11	Sf
			BW	TS1–4	
Kalong	2010	Nov–Dec	Cc	KL0–8	Sf
	2011	Jan–Feb*	BW	KS0–8	
	2012	Mar	BW	KS0–8	
	2014	Sep–Dec	Cc	KL1–9	Sf
	2015	Jan–Aug	BW	KS1–10	

* bimonthly, *other* monthly
BW bank waters, *Cc* center of current, *Nb* near bottom, *Sf* surface, *Sp* step

Collections of fish larvae and juveniles were made in the bank waters near the shore using a seine net (1×4 m, 1 mm mesh-aperture, Fig. 11a) (Kinoshita et al., 1988). In the center of the current using a larva net (1 m mouth-diameter, 0.5 mm mesh-aperture, Fig. 11b), horizontal tows at the surface were made at each station in both the estuaries from 2010 to 2015 and step tows from bottom to surface layer in 2017; during the periods of October 2014 to September 2015 in the Tien Yen estuary, to clarify larval and juvenile community, step tows and horizontal tows at the near bottom layers were also performed at Stns. TL9, TL11 and TL14.

The water temperature (°C), salinity and turbidity (NTU) were measured at surface and bottom layers (sampling periods of 2010 to 2012) or middle layers (2013–2015) of each bank water station and at 1 m-depth intervals from the surface to bottom of each station in the center of the current using a Water Quality Checker (WQC-22A, TOA DDK) during the sampling period of 2010 to 2015 and at 0.5 m-depth intervals from surface to bottom of each station in both the biotopes using a Compact-CTD (Alec Electronics) in 2017.

Volume of water filtered (m^3) were measured and calculated using a flow meter (2030R, General Oceanics) attached to the larva net.
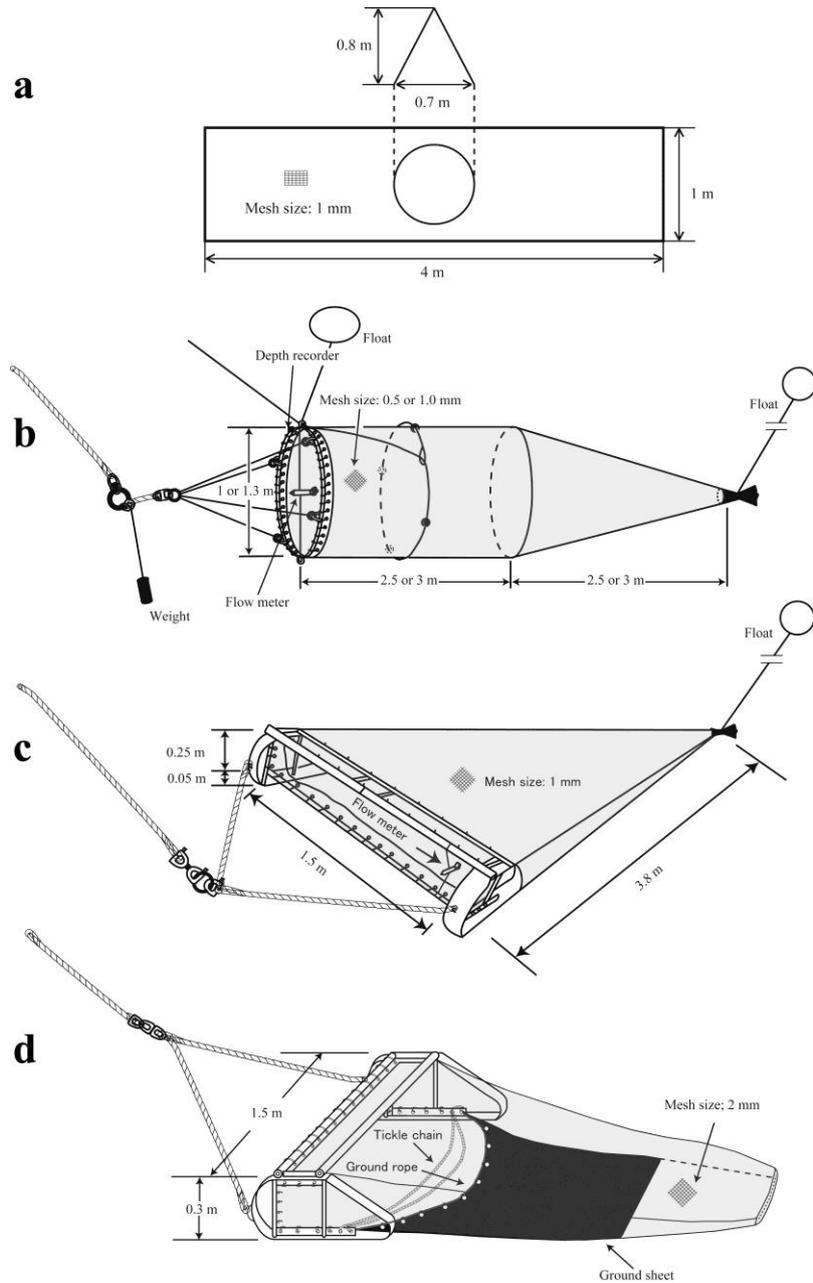
Fig. 11.   Gears used to collect fish larvae and juveniles in this study: **a** a small seine net used in the bank waters of the Tien Yen, Kalong, Shimanto estuaries and Miike beach; **b** system of surface, middle, oblique and step tows by larva nets, **c** near-bottom net for near-bottom tows and **d** beam trawl for bottom tows.

In Ariake Bay

Seasonal surveys for dynamic sampling of fishes were made in the period of February to April 2015 in the Yabe estuary, in March 2017 in the three neighboring river estuaries (Rokkaku, Hayatsue and Yabe), and Miike sand beach and in April 2017 in Rokkaku estuary (Fig. 10c).

Oblique tows of larva net (1.3 m mouth-diameter, Fig. 11b) were performed in the center of the current of 3 estuaries representing different characteristic waters and their respective fish habitat.   Mesh-apertures of the nets were 1 mm in the Rokkaku and Hayatsue estuaries to avoid clogging of the nets by suspended particulates, and 0.5 mm in the Yabe estuary.

Using beam trawl (with 0.25×1.5 m, 2 mm mesh-aperture, Fig. 11d, modified after Kuipers, 1975) collections of demersal fishes were made in the 3 estuaries (Fig. 10c) in March 2017.   Of the sampled areas, tidal collections were carried out at Stn. 7 in March and Stn. 5 (Fig. 10c) in April 2017 by discrete-depth horizontal tows at surface and middle layers with the larva net, and by a specialized beam trawl (near-bottom net, with 0.25×1.5 m, 1 mm mesh-aperture, Fig. 11c) of the near bottom layer and the beam trawl (Fig. 11d) of the bottom layer.   The specialized beam trawl was modified after Kuipers (1975), and was designed to keep the lower beam of the mouth 5 cm off the bottom (Ebrahim et al., 2006).

In the surf zone of Miike beach, fishes were collected in the bank waters (Fig. 10c) using the seine net (Fig. 11a).

In Shimanto estuary

Monthly collections were made at five stations along the bank waters (Fig. 10d) during the period of October to February from 2014 to 2018 using the seine net (Fig. 11a) and by horizontal tows at the surface of one station in the center of the current (Fig. 10d) using a larva net (1.3 m mouth-diameter, 0.5 mm mesh-aperture, Fig. 11b)   from October 2015 to February 2016.

During the samplings in Japan, the water temperatures, salinities and turbidities were measured at the surface and bottom of each bank water station in Shimanto estuary using a YSI (Model 30/50 FT) and at 0.5 m-depth intervals from surface to bottom using a Compact-CTD (Alec Electronics) at the station in the center of the current in the Shimanto estuary and each station in Ariake Bay.   The current profile was measured with an ADCP (WHSZ12000-I-UG12, RD Instruments) at a depth of 1 m.   Depth of the oblique tows and volume of water filtered (m^3) were measured and calculated using a Divers Watch (Log Memory 1473, Casio) and flow meter (2030R, General Oceanics) attached to the net, respectively.   Towing distance of the beam trawl of the bottom tows was calculated from measures of latitude to longitude recorded by GPS.

All samples were preserved in 10% formalin solution.   Fishes were sorted from the samples and transferred to 80% ethanol.

3.1.2.   Identification and measurements

Fishes were measured for size by developmental stages (Kendall et al., 1984) to the nearest 0.1 mm using an ocular stereomicroscope and caliper.   In this study, unlabeled lengths indicate body lengths (BL) (notochord length for preflexion and flexion larvae, and standard length for postflexion larvae, juveniles and adults).   To describe larvae and juveniles of *Lateolabrax* and *Acanthopagrus* species, various measurements (standard, head, snout, pre-dorsal, pre-anal, caudal peduncle, upper jaw, dorsal and anal fin-spine lengths, eye diameter and body and caudal peduncle depths) were made by developmental stages.

3.1.3.   Osteology analyses

All available size groups were randomly picked for osteology analyses.   Fishes were cleared and double stained with alcian blue 8 GX and alizarin red S according to the protocol of Dingerkus and Uhler (1977).   By this method, the cartilage parts were stained with blue color and an ossified bone with red color (Fig. 12).   Osteological development of the vertebral column and all fin supports were observed and noticeable changes, for example, the initial appearance of cartilage, the full complement of cartilage, the beginning of ossification and the full complement of ossified structures for respective elements (Fig. 12), were counted.   Osteological terminology followed Matsuoka (1987).
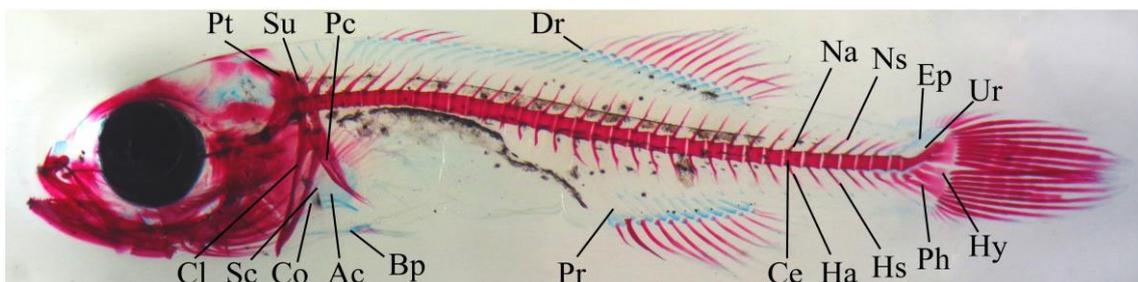
Fig. 12.   A photograph showing ossification in a larva of *Lateolabrax japonicus* (15.3 mm BL, Yabe estuary).   Blue parts are cartilage stained with alcian blue 8 GX and red are ossified bones stained with alizarin red S.   Major characters of cartilage and bone in vertebral column and fin-supports are indicated.   *Ac* actinost, *Bp* basinpterygium, *Ce* centrum, *Cl* cleithrum, *Co* coracoid, *Dr* distal radial, *Ep* epural, *Ha* Haemal arch, *Hs* Haemal spine, *Hy* hypural, *Na* neural arch, *Ns* neural spine, *Pc* postcleithrum, *Ph* parhypural, *Pr* proximal radial, *Pt* posttemporal, *Sc* scapula, *Su* supracleithrum, *Ur* uroneural.

3.1.4. Daily aging estimation using otolith

Age determinations from otoliths (sagitta and lapillus) were performed in *Lateolabrax* (Fig. 13) and *Acanthopagrus* species (Fig. 14). The left and right side otoliths were removed from specimens under a dissecting microscope and fixed on a microscope slide face up with epoxy resin and cover by cover glass.

Increments outside the nucleus of otoliths were counted under a light microscope at 400–600 magnification and average of three replicate counts in each otolith was used for estimating a ring number. Based on relationship between the increments of sagitta and lapillus (Fig. 15), both were used for estimating the age. The hatching dates were estimated from age (days) and back calculating from the dates of capture. Otolith radius was measured along the longest axis of the otolith.
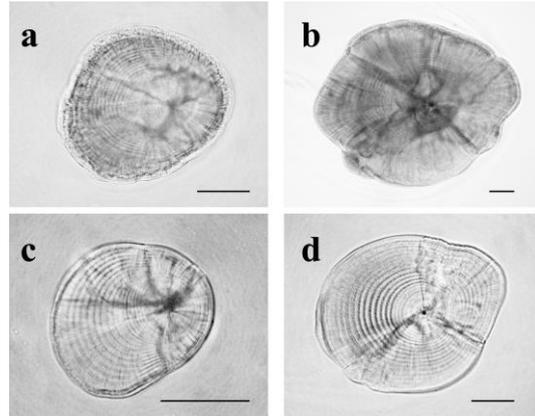
Fig. 13. Lapillus (left side) and sagitta (right) of *Lateolabrax* sp. (**a**, **b**; 14.9 mm BL) in Kalong estuary and *L. japonicus* (**c**, **d**; 9.3 mm) in Shimanto estuary. A scale bar indicates 50 μm.
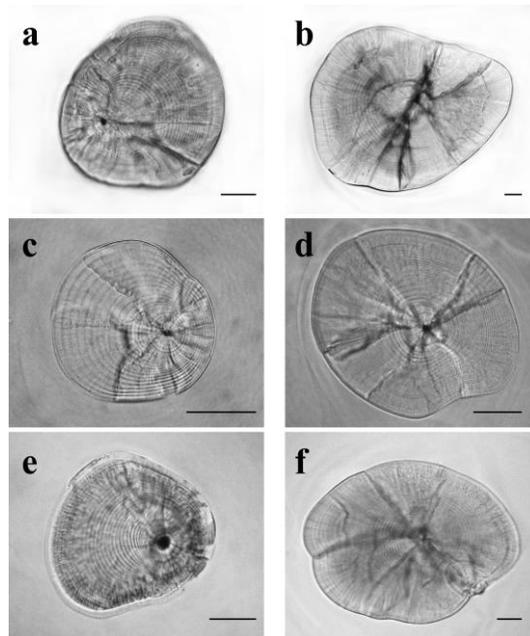
Fig. 14. Lapillus (left side) and sagitta (right) of *Acanthopagrus latus* in Tien Yen (**a**, **b**; 13.1 mm BL) and Shimanto (**c**, **d**; 8.8 mm) estuaries and *A. schlegelii* (**e**, **f**; 10.2 mm) in the former. A scale bar indicates 50 μm.
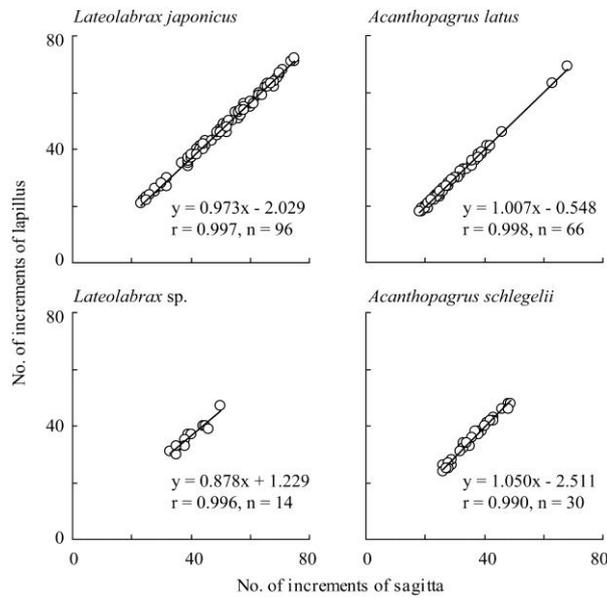
Fig. 15. Relationship between the number of increments in sagitta and lapillus.

3.1.5. Food habit analyses

Analyses of food habits were made using the same samples used for the specimens for osteology and otolith analyses. The stomachs were opened and food organisms were separated and examined under the stereomicroscope. Prey organisms were counted and identified to the major taxonomy category using Chihara and Murano (1997) as a taxonomic guide for most prey. Feeding incidence (FI) was calculated as the percentage of the number of fish with food (FN) in relation to total number (TN) examined ($FI = 100 \, FN \, TN^{-1}$).

3.1.6. Statistical analysis

Morphometric and meristic data of samples were evaluated for heterogeneity of variances using ANCOVA and ANOVA with a post-hoc Tukey's test, respectively. The slopes of age-body length, body length-otolith radius and body length-count of the osteological change (cumulative percentage) relationships were compared between the sites by ANCOVA.

3.2. Materials

3.2.1. Fish communities

Fish communities were observed using the samples collected in both two biotopes of the Tien Yen estuary from October 2014 to April 2015; in the center of the

current of Yabe estuary from February to April 2015; in both the bank waters (during period of October to March from 2014 to 2018) and the center of the current (October 2015 to March 2016) of the Shimanto estuary.   Most of *Plecoglossus altivelis altivelis* from the bank waters of the Shimanto estuary were observed by Dr. K. Azuma.

Family names and orders of fishes followed Nelson et al. (2016), except for the gobies followed Nelson (2006), and genus and species names were in accordance with Nakabo (2013) and ordered alphabetically.

3.2.2.   *Lateolabrax*

The morphology of *Lateolabrax* species were examined using various specimens. Age determinations were done on the specimens collected in March 2012 in Kalong estuary, March and April 2017 in Ariake Bay and 2015–2018 in Shimanto estuary.

The food habit were analyzed using various available size specimens collected during the period of 2010 to 2015 in northern Vietnam, March and April 2017 in Ariake Bay and 2015–2018 in Shimanto estuary.

The distribution of seaperches were observed using samples collected during the period of 2013 to 2015 in the Tien Yen estuary, 2014–2015 in Kalong estuary, March 2017 in Ariake Bay and 2014–2018 in Shimanto estuary.

3.2.3.   *Acanthopagrus*

The morphology of *Acanthopagrus* were examined using various specimens. A total of 50 specimens from each species in each river were randomly selected for age in day estimation.   Subsequently, most of them were used for osteology and food habit analyses.   Distribution of *Acanthopagrus* were examined using the samples collected in the bank waters during the period of October 2014 to September 2015 in Tien Yen estuary of Vietnam and from October 2014 to March 2018 in Shimanto estuary.

Chapter 4. Comparison of larval and juvenile community

4.1. Results

4.1.1. Vietnam

The fish community was examined using the specimens collected in the center of the current with a larva net and in the bank waters with a seine net in the Tien Yen estuary from October 2014 to April 2015. The numerical percentages of fishes, their developmental stages, size range and seasonal occurrence are shown in Table 2. A total of ca. 5,000 fishes of more than 51 species from 25 families were collected. Higher species richness of larvae and juveniles were recorded from the bank waters than from the center of the current (Table 2; Fig. 16). Although dominant taxa were different between the two biotopes, Gobiidae was, in general, the most dominant in terms of both species diversity and abundance.

In the center of the current. A total of ca. 2,000 fishes of more than 30 species from 17 families were collected. Gobiidae spp. were the most common, accounting for 86.1% of the total abundance. *Luciogobius* sp. (4.7%) was ranked second, followed by *Acanthopagrus* (2.5%), Tetradontidae sp. (1.5%), *Omobranchus* sp. (1.2%). The other species were less than 1% of the total abundance. The strong seasonal fluctuations in the density were associated with changing number of species (Fig. 16). The maximum density was 418 in April, followed by 109 in early February (Fig. 16). The number of species fluctuated seasonally from 3 (late December) to 17 (April) (Fig. 16). The fishes were mostly preflexion and flexion larvae. Length frequency distributions for developmental stages of the 5 dominant species are shown in Fig. 17. Their length mostly did not exceed 6 mm BL, being relatively narrow ranges.

In the bank waters. A total of ca. 3,000 fishes of more than 37 species from 21 families were collected. Of them, *Acanthopagrus latus* was the most common, accounting for 43.0% of the total abundance. *Gobiopterus brachypterus* (30.1%) was ranked second, followed by *Oryzias curvinotus* (9.5%), *Acanthopagrus schlegelii* (5.5%), *Gerres japonicus* (3.0%), *Chelon* sp. (2.5%), *Sardinella* sp. (1.0%). The other species were less than 1% of the total abundance (Table 2). The maximum number of fishes per haul was 254 (late February), followed by 281 (early February) and 235 (April). The number of species fluctuated from 5 (October and late November) to 19 (April) (Fig. 16).

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Table 2.　List of fishes collected in the center of the current with a larva net and the bank waters with a seine net in the Tien Yen estuary from October 2014 to April 2015

Biotopes		Center of current			Bank waters			
Species number		≥30			≥37			
Total number of individual		2197			3135			
Mean density (n 10^3 m^{-3}) or CPUE (n haul^{-1})		78			107			
Family name	Species name	%	Stage	Range of BL (mm)	%	Stage	Range of BL (mm)	Month
Engraulidae	*Stolephorus indicus*				0.22	D	18.6–22.2	10
Clupeidae	*Konosirus punctatus*				0.26	D–E	11.6–23.8	2–4
	Sardinella sp.	0.55	B	3.4–5.2	1.02	C–E	9.5–21.5	1–3, 12
	Clupeidae sp.	0.73	A–B	1.8–6.0	0.03	B	8.5	4
Cyprinidae	Cyprinidae sp.	0.64	B–D	5.1–9.1	0.48	D–E	7.4–26.4	3, 4, 10, 12
Plecoglossidae	*Plecoglossus altivelis*	0.55	B	5.3–9.5	0.16	C–E	13.5–59.1	1–3, 12
Ambassidae	*Ambassis* sp.				0.38	E	4.9–23.3	10–12
Mugilidae	*Chelon* sp.				2.46	E	9.2–25.4	2–4, 12
Blenniidae	*Omobranchus* sp.	1.18	B	2.4–4.1				3, 4
Atherinidae	*Hypoatherina* sp.				0.35	C–D	6.2–10.3	4
Adrianichthyidae	*Oryzias curvinotus*	0.05	D	7.2	9.47	D–E	5.1–25.6	1–4, 11, 12
Zenarchopteridae	*Zenarchopterus* sp.				0.29	D–E	7.5–13.3	4
Carangidae	Carangidae sp.	0.14	B	2.6–3.1				4
Soleidae	Soleidae sp.	0.14	C–E	3.5–5.6	0.03	E	7.4	1, 2
Syngnathidae	*Hippichthyes* sp.	0.14	D	10.8–14.5				4, 11
Callionymidae	*Repomucenus* spp.	0.09	D	3.6–3.9	0.03	E	20.6	2
Gerreidae	*Gerres erythrourus*				0.10	E	10.9–11.4	1, 11, 12
	G. japonicus	0.23	C–D	4.0–5.2	2.97	C–E	4.6– 8.8	4
Lateolabracidae	*Lateolabrax* sp.				0.19	D–E	10.3–14.4	1, 2
Teraponidae	*Pelates* sp.	0.05	E	12.7	0.03	E	11.2	1, 12
Leiognathidae	*Nuchequula nuchalis*	0.05	D	7.6	0.03	D	7.0	4
Eleotridae	*Butis amboinensis*				0.32	E	9.0–41.2	1–4, 10
Gobiidae	*Acanthogobius* sp.				0.03	E	10.1	2
	Acentrogobius viganensis				0.03	E	21.8	4
	Brachygobius aggregatus	0.05	E	6.7	0.19	E	6.5–11.3	2, 4
	Favonigobius sp.				0.13	E	11.9–21.7	2, 12
	Gobiopterus brachypterus				30.11	E	6.7–19.6	1–4, 11, 12
	Luciogobius sp.	4.69	B	1.4–3.7				1, 2, 10, 12
	Pseudogobius javanicus				0.48	E	7.0–27.5	2–4, 12
	P. spp.	0.05	E	6.5	0.64	E	6.7–12.6	2, 4, 12
	Redigobius bikolanus				0.03	E	17.1	2
	Rhinogobius sp.				0.03	E	10.0	4
	Tridentiger sp.				0.13	E	10.0–12.8	4
	Gobiidae spp.	86.07	A–D	1.6–6.1	0.26	E	6.2– 7.2	1–4, 10–12
Platycephalidae	Platycephalidae sp.	0.05	C	5.4	0.03	E	28.8	3, 11
Scorpaenidae	*Hypodytes* spp.	0.14	B–D	2.6–4.3				4, 11
	Sebastiscus sp.	0.50	B	2.7–3.6				1, 2
Sillaginidae	*Sillago sihama*				0.29	E	10.6–31.4	1, 10–12
Sparidae	*Acanthopagrus latus*				43.00	E	9.0–26.1	1–4, 12
	A. pacificus				0.06	E	9.4– 9.7	4
	A. schlegelii				5.52	E	8.0–18.0	1–3, 12
	Acanthopagrus	2.46	B–C	1.7–5.2				1, 2, 12
	Rhabdosargus sarba				0.13	E	11.3–16.9	2, 3
Tetradontidae	Tetradontidae sp.	1.50	B	1.2–2.4	0.10	E	10.2–11.9	1–4, 12

Stage: *A* Yolk–sac, *B* Preflexion, *C* Flexion, *D* Postflexion, *E* Juvenile or adult.

% Of total abundance of all fish sampled in each respective biotope.

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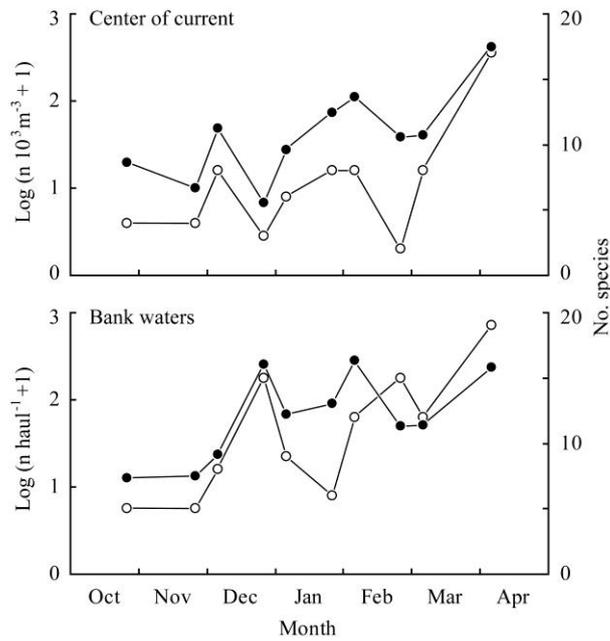
Fig. 16.   Seasonal fluctuations in mean of density and number per haul (*solid dots*), and the total number of species (*open dots*) of the larval and juvenile fishes collected in the two habitats of the Tien Yen estuary from October 2014 to April 2015.
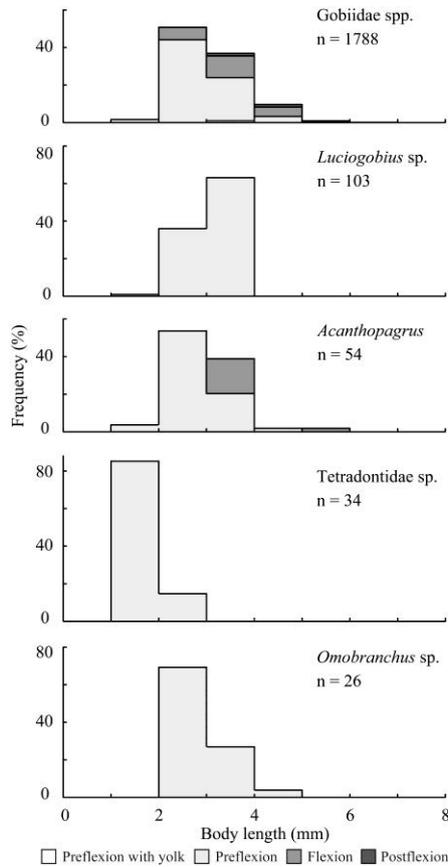

Fig. 17.   Size frequency distributions for the developmental stages of the dominant species collected in the center of the current with a larva net in Tien Yen estuary from October 2014 to April 2015.

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Fishes collected in the bank waters were mostly postflexion larvae and juveniles, with the exception of adults of some species belonging to Ambassidae, Adrianichthyidae and Gobiidae (Table 2). Length frequency distributions for developmental stages of the 10 dominant species are shown in Fig. 18. Of them, *Oryzias curvinotus*, *Gerres japonicus* and *Sardinella* sp. appeared at various stages, which from postflexion to adult in the former and flexion to juvenile in the two latter species. Most of individuals of the other species were juvenile stage. Larvae and juveniles of most species never exceeded 30 mm BL, with the modes did not exceed 20 mm BL. A few species were represented by individuals larger than 30 mm, such as *Plecoglossus altivelis*, *Butis amboinensis*, and *Sillago sihama* (Table 2).
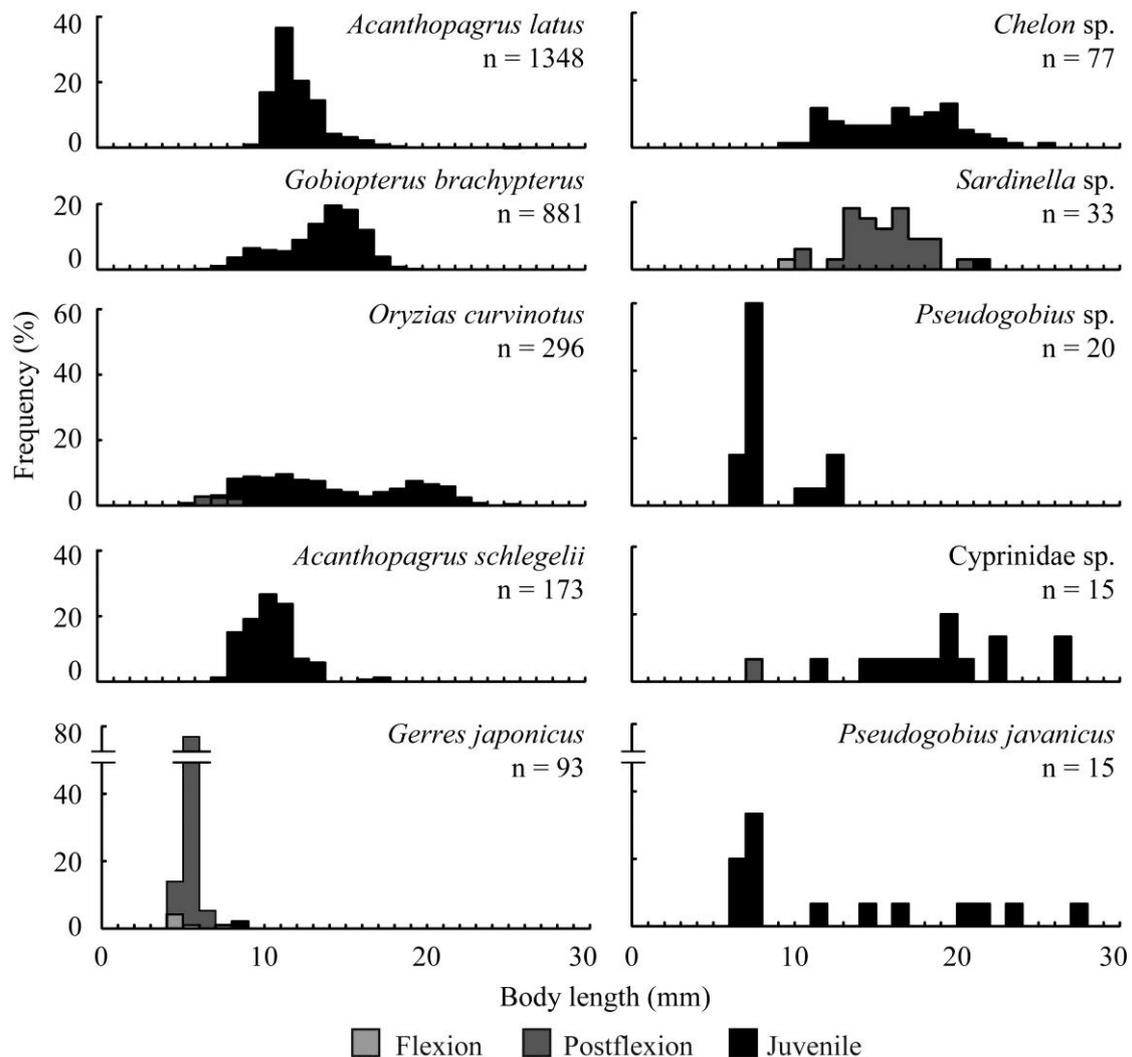

Fig. 18. Size frequency distributions for the developmental stages of the dominant species collected in bank waters with a seine net in Tien Yen estuary from October 2014 to April 2015.

4.1.2. Ariake Bay

The fish community was examined using the specimens collected in the center of the current with a larva net in the Yabe estuary from February to April 2015.   The numerical percentages of fishes, their developmental stages and size range are shown in Table 3.   A total of ca. 9,000 fishes of more than 13 species from 8 families were collected.   The ichthyofauna was dominated almost entirely by the gobiid *Acanthogobius hasta* (91.7% of the total abundance).   *Trachidermus fasciatus* (3.7%) was ranked second, followed by Gobiidae sp. (2.7%).   The other species were less than 1% of the total abundance.   Gobiidae was the most dominant in terms of both species diversity and abundance.

Both the fish density and number of species seasonally increased from 4 to 7112 and 2 to 12, respectively, from February to April (Fig. 19).   The fishes were preflexion with yolk to juvenile stages (chiefly postflexion and juvenile).   Length frequency distributions for developmental stages of the five dominant species are shown in Fig. 20. The size and developmental stage ranges were wide in most of dominant species, except for Gobiidae sp.

Table 3.   List of fishes collected in the center of the current with a larva net in the Yabe estuary from February to April 2015.   Otherwise same as Table 2

| Family name	Species name	%	Stage	Range of BL (mm)
Anguillidae	*Anguilla japonica*	0.05	E	50.9–53.2
Engraulidae	*Engraulis japonica*	0.84	B–D	5.5–20.8
Cyprinidae	Cyprinidae sp.	0.05	B	5.6– 7.7
Mugilidae	*Mugil cephalus cephalus*	0.05	E	23.2–26.5
Paralichthyidae	*Paralichthys olivaceus*	0.01	E	10.9
Lateolabracidae	*Lateolabrax japonicus*	0.18	D–E	11.0–21.7
Gobiidae	*Acanthogobius flavimanus*	0.61	A–E	3.5–16.3
	A. hasta	91.71	B–E	3.9–13.7
	Gymnogobius breunigii	0.01	C	9.4
	G. macrognathos	0.09	D	8.0–13.1
	Luciogobius sp.	0.01	D	10.3
	Gobiidae sp.	2.72	B	2.3– 3.9
Cottidae	*Trachidermus fasciatus*	3.67	B–E	7.3–20.8
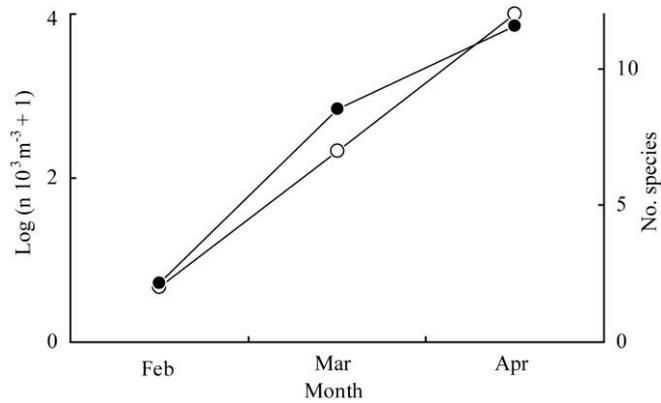
Fig. 19. Seasonal fluctuations in mean of density (*solid dots*) and the total number of species (*open dots*) of larval and juvenile fishes collected in the center of current of Yabe estuary from February to April 2015.
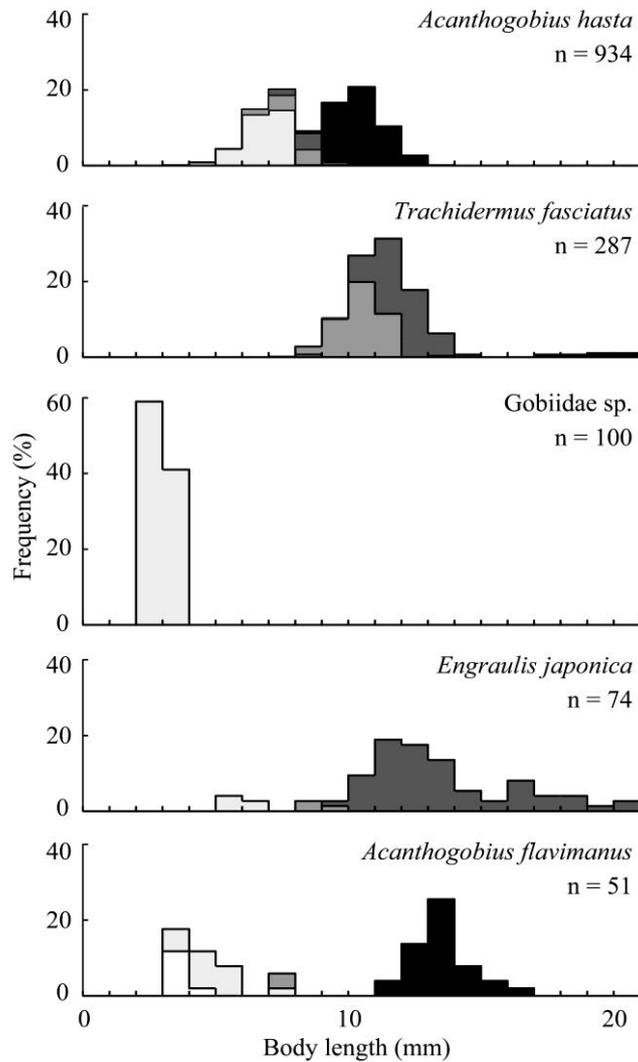

Fig. 20. Size frequency distributions for the developmental stages of the dominant species collected in the center of the current with a larva net in the Yabe estuary from February to April 2015. Otherwise same as Figs. 17 and 18.

4.1.3. Shimanto estuary

The larval and juvenile fish community was examined using the specimens collected in the center of the current with a larva net and in the bank waters with a seine net in the Shimanto estuary during the period from October to March. The numerical percentages of fishes, their developmental stages, size range and seasonal occurrence are shown in Table 4. A total of ca. 11,000 fishes of more than 53 species from 25 families were collected. Higher species richness of larvae and juveniles were recorded from the bank waters than from the center of the current (Table 4; Figs. 21, 22). Although dominant taxa were different between the two biotopes, Gobiidae was, in general, the most dominant in terms of both species diversity and abundance (Table 4).
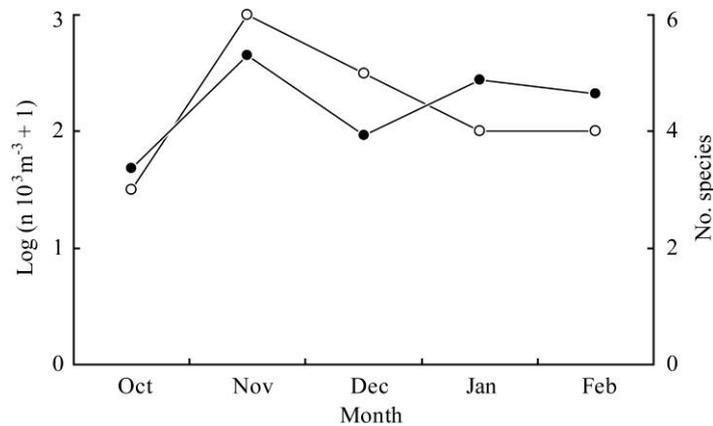

Fig. 21. Seasonal fluctuations in density (*solid dots*) and the total number of species (*open dots*) of larval and juvenile fishes collected in the center of current of Shimanto estuary from October 2015 to February 2016.
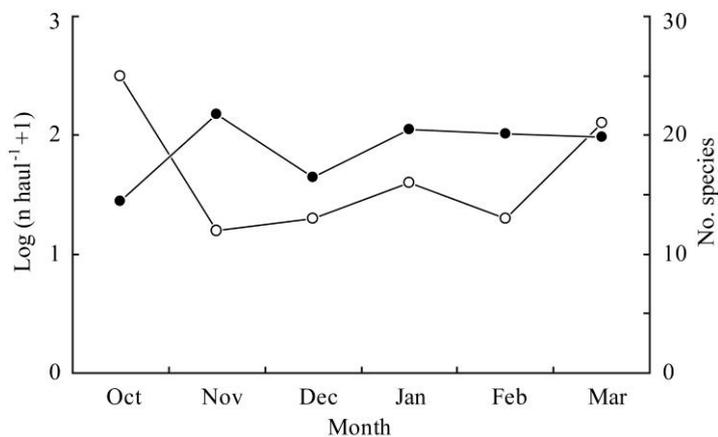

Fig. 22. Seasonal fluctuations in mean of number per haul (*solid dots*) and number of species (*open dots*) of the larval and juvenile fishes collected in the bank waters of the Shimanto estuary from October 2014 to March 2018.

Table 4. List of fishes collected in the center of the current with a larva net and the bank waters with a seine net in the Shimanto estuary. Otherwise same as Table 2

Biotopes		Center of current			Bank waters			
Periods					Oct. 2014–Mar. 2015			
		Oct. 2015–Feb. 2016			Oct. 2015–Mar. 2016			
					Oct. 2016–Mar. 2017			
					Oct. 2017–Mar. 2018			
Species number		≥13			≥49			
Total number of individual		409			10941			
Mean density (n 10^3 m^{-3}) or CPUE (n haul^{-1})		214			88			
Family name	Species name	%	Stage	Range of BL (mm)	%	Stage	Range of BL (mm)	Month
Elopidae	*Elops hawaiensis*				0.33	E	26.7–35.8	10–12
Megalopidae	*Megalops cyprinoides*				0.01	D	26.2	10
Anguillidae	*Anguilla japonica*				0.01	E	53.8	12
Engraulidae	*Engraulis japonica*	11.98	D	17.2–29.1	0.06	D–E	10.1–16.8	3, 10, 11
	Stolephorus indicus				0.01	E	18.9	11
Clupeidae	*Etrumeus teres*				0.03	B–D	8.7–13.9	1
	Sardinella zunasi				0.01	B	6.7	2
	Sardinops melanostictus	0.49	E	22.8–24.5				12
Cyprinidae	Cyprinidae sp.				0.01	E	18.2	3
Plecoglossidae	*Plecoglossus altivelis altivelis*	35.21	A–C	4.4–12.4	37.93	B–E	5.3–40.1	1–3, 10–12
Myctophidae	*Lampanyctus* sp.				0.03	B–D	4.1– 6.1	10, 11
Mugilidae	*Mugil cephalus cephalus*				6.94	E	12.0–36.5	1–3, 10–12
Chaenopsidae	Chaenopsidae sp.				0.01	D	11.0	2
Carangidae	*Caranx sexfasciatus*				0.02	E	30.7–36.8	11
	Scomberoides lysan				0.01	E	32.4	10
Syngnathidae	*Hippichthys penicillus*				0.04	E	62.6–136.1	10
	H. spicifer				0.01	E	130.9	10
Gerreidae	*Gerres equulus*				0.02	E	9.2–11.6	10
	G. erythrourus				0.81	E	9.8–13.5	10
Lateolabracidae	*Lateolabrax japonicus*				0.87	D–E	9.2–28.5	1–3
	L. latus	0.24	D	8.3	0.72	D–E	9.7–31.2	1–3
Teraponidae	*Rhynchopelates oxyrhynchus*				0.25	E	14.9–44.1	10
	Terapon jarbua				0.08	E	12.3–27.9	10
Leiognathidae	*Nuchequula nuchalis*				0.82	E	19.9–47.6	1, 3, 10–12
Lutjanidae	*Lutjanus* sp.	4.16	B	2.1– 2.6				11
Gobiidae	*Acanthogobius flavimanus*				0.05	E	12.1–120.4	1, 3
	A. lactipes				0.64	D–E	8.0–93.4	1, 3, 10, 12
	Bathygobius cotticeps	0.24	D	6.7				11
	Chaenogobius sp.				0.02	E	12.6–12.9	3
	Favonigobius gymnauchen				0.43	E	9.9–24.5	1, 3, 12
	Glossogobius olivaceus				0.02	E	17.6–29.4	10
	Gymnogobius castaneus				6.52	C–E	7.4–24.8	1–3
	G. scrobiculatus				10.96	B–E	5.2–13.3	1–3
	G. sp.				0.01	E	21.5	1
	Leucopsarion petersii	0.49	B	4.6– 4.9	24.95	D–E	15.1–37.9	1–3, 10–12
	Luciogobius spp.	27.38	B–D	2.3– 7.9	0.11	D–E	6.5–45.4	1, 2, 10–12
	Pseudogobius masago				0.03	E	8.4–11.8	2, 10
	P. sp.				0.03	D–E	6.1– 6.9	10
	Redigobius bikolanus				0.31	E	6.0–20.6	3, 10
	Rhinogobius sp.				0.05	E	10.0–11.9	10
	Sicyopterus japonicus				0.02	E	27.3–28.8	3
	Gobiidae spp.	0.24	B	2.7	0.01	D	5.8	10
Microdesmidae	*Parioglossus dotui*				0.47	E	9.5–20.8	3, 11, 12
Scatophagidae	*Scatophagus argus*				0.01	E	16.8	10
Scorpaenidae	*Sebastiscus marmoratus*	18.09	B	2.5– 3.5	0.01	B	3.9	1, 2, 12
Cottidae	*Cottus kazika*				0.76	B–E	4.0–12.6	1–3
Sillaginidae	*Sillago japonica*				0.02	E	9.8–10.7	10
Sparidae	*Acanthopagrus latus*	1.22	E	9.9–10.6	4.31	E	8.3–13.5	2, 10–12
	A. schlegelii				0.02	E	9.3–10.6	3
	Rhabdosargus sarba				1.22	E	8.2–23.1	1–3, 12
	Sparidae type	0.24	A	2.4				2
Triacanthidae	*Triacanthus biaculeatus*				0.05	E	18.7–43.9	10

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In the center of the current.   A total of ca. 400 fishes of more than 13 species from 8 families were collected from October 2015 to February 2016 (Table 4). *Plecoglossus altivelis altivelis* was the most common, accounting for 35.2% of the total abundance.   *Luciogobius* spp. (27.4%) was ranked second, followed by *Sebastiscus marmoratus* (18.1%), *Engraulis japonica* (12.0%), *Lutjanus* sp. (4.2%), *Acanthopagrus latus* (1.2%) (Table 4).   The other species were less than 1% of the total abundance. Both the maximum density and number of species were the lowest in October (47 and 3, respectively) and highest in November (449 and 6, respectively) (Fig. 21).

Length frequency distributions for developmental stages of the 5 dominant species are shown in Fig. 23.   Their developmental stages ranged from preflexion with yolk to postfpexion larvae, being chiefly postflexion in *Engraulis japonica* and preflexion in the other dominant species.   The size and developmental stage ranges were relatively narrow in most of dominant species, except for wide ranges of size in *Engraulis japonica*.

In the bank waters.   A total of ca. 10,000 fishes of more than 49 species from 24 families were collected from October 2014 to March 2018 (Table 4).   *Plecoglossus altivelis altivelis* were the most common, accounting for 37.9% of the total abundance. *Leucopsarion petersii* (25.0%) was ranked second, followed by *Gymnogobius scrobiculatus* (11.0%), *Mugil cephalus cephalus* (6.9%), *Gymnogobius castaneus* (6.5%), *Acanthopagrus latus* (4.3%), *Rhabdosargus sarba* (1.2%).   The other species were less than 1% of the total abundance.   The mean of the number of fish per haul and number of species were seasonally fluctuated from 43 (December) to 149 (November) and 12 (October) to 25 (November), respectively (Fig. 22).

Fishes collected in the bank waters were mostly postflexion larvae and juveniles, with the exception of adults of some species belonging to Syngnathidae and Gobiidae (Table 4).   Length frequency distributions for developmental stages of the 10 dominant species are shown in Fig. 24.   Of them, length modes of *Leucopsarion petersii*, *Mugil cephalus cephalus* and *Nuchequula nuchalis* exceeded 20 mm, whereas those of the other species were from ca. 10 to 20 mm.   *Plecoglossus altivelis altivelis, Leucopsarion petersii, Gymnogobius scrobiculatus*, *G. castaneus* and *Lateolabrax japonicus* appeared at stages from larvae to juveniles, whereas the individuals of the other dominant species were juveniles.
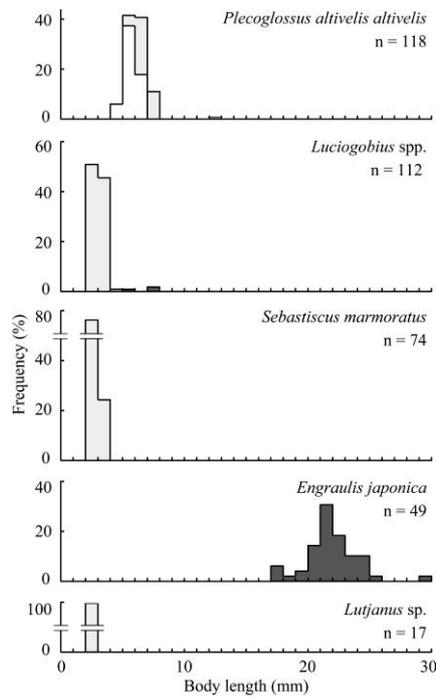
Fig. 23. Size frequency distributions for the developmental stages of the dominant species collected in the center of the current of the Shimanto estuary from October 2015 to February 2016. Otherwise same as Fig. 17.
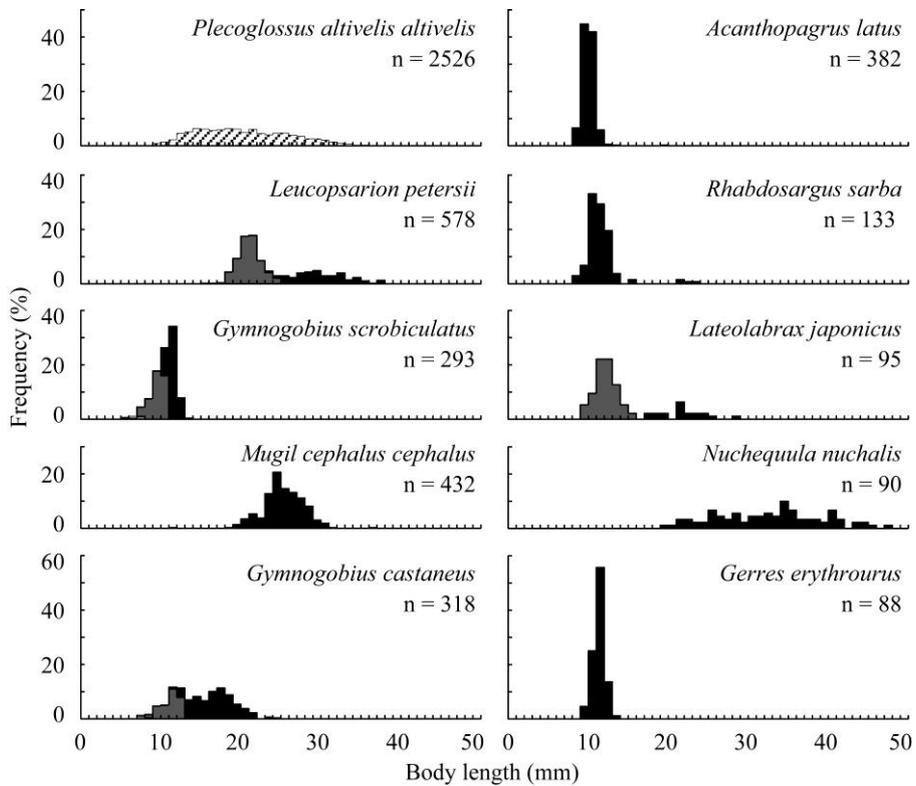

Fig. 24. Size frequency distributions for the developmental stages of the dominant species collected in the bank waters of Shimanto estuary from October 2014 to March 2018. No data for developmental stages of *Plecoglossus altivelis altivelis*. Otherwise same as Figs. 17 and 18.

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4.2. Discussion

The present study reveals that the larval and juvenile ichthyofauna of Vietnam estuary was resemble to Shimanto estuary rather than Yabe estuary of Ariake Bay.   The ichthyofauna differences may explain this result.   Accordingly, much difference of Ariake Bay estuary is due to the unique fauna of this bay, which has several endemic and restricted species distributed in the drastically turbid waters (Uchida and Tsukahara, 1995; Yagi et al., 2011).   On the other hand, although the northern Vietnamese estuary is located in tropical zone latitudinally, the ichthyofauna resembles rather a temperate's one, i.e., many species reach the southern limit of their range in temperate and subtropical waters, extending as far as the northern Vietnamese coasts, such as *Plecoglossus ativelis*, *Lateolabrax* sp*., Nuchequula nuchalis*, *Acanthopagrus latus* and *A. schlegelii*.   This distributional phenomenon is attributed to water temperature that was not so high in northern Vietnamese coasts, being like to be influenced by a cold current from the Yellow Sea (Sverdrup et al., 1961; Wyrtki, 1961; Endo, 1987; Tran et al., 2012).   Moreover, the ichthyofauna of the Shimanto estuary is temperate, but the Kuroshio Current transports early stages of several non-indigenous species such as *Stolephorus indicus* and *Gerres erythrourus* that spawn in the tropical and/or subtropical regions to the estuary (Fujita et al., 2002).

Despite the differentiation in species compositions among three study sites, the size and developmental stages ranges were significantly wider in the center of the current in Ariake Bay estuary (Fig. 20) than those in the Tien Yen (Fig. 17) and Shimanto (Fig. 23) estuaries.   This evident indicates the characteristic role of Ariake Bay environment in support a long pelagic period of fishes.

Although there were significantly latitudinal and seasonal variation in the occurrences of larvae and juveniles between Vietnamese and Japanese estuaries, the species richness was significantly greater in the bank waters than in the center of the current in both the regions.   This phenomenon is attributed to the settlement and immigration into the bank waters of estuaries of some species belonging to Mugilidae, Leiognathidae, Teraponidae and Sillaginidae, which were spawn and inhabited in the offshore during the pelagic larval period.

In spite of the certain differences between the center of the current and bank waters, the limited size and developmental stages of fishes in estuaries indicate that this

environment plays, in general, a characteristic function for fishes as transit biotopes rather resident ones. This phenomenon is due to the extreme variability in hydrographic environment occurs with tremendous influences on residents and trophic structures of estuaries, distinguishing the estuarine environment from other biotopes such as marine and freshwater.

The species compositions varied latitudinally across different sites; however, it was a tendency that Gobiidae was the most dominant in terms of both species diversity and abundance in the estuarine fish larval and juvenile communities (Table 5). The similar characteristic could be observed in other regions (e.g., Blaber and Milton, 1990; Ikejima et al., 2003), being considered one of the features that distinguish the estuary from the other biotopes in Indo-Pacific region.

Table 5. Family composition of larval and juvenile fishes collected in the Tien Yen (October 2014–April 2015), Yabe (February–April 2015) and Shimanto (October 2015–March 2016) estuaries

Family	Tien Yen estuary		Yabe estuary		Shimanto estuary	
	Rank	No. species	Rank	No. species	Rank	No. species
Gobiidae	1	≥20	1	≥6	1	≥14
Sparidae	2	4			3	3
Adrianichthyidae	3	1				
Gerreidae	4	2			10	2
Mugilidae	5	1	5	1	10	1
Clupeidae	6	3			13	2
Tetradontidae	7	1				
Cyprinidae	8	1	5	1		
Blennidae	9	1				
Plecoglossidae	10	1			2	1
Scorpaenidae	11	2			4	1
Ambassidae	12	1				
Atherinidae	13	1				
Eleotridae	14	1				
Zenarchopteridae	15	1				
Sillaginidae	15	1				
Engraulidae	17	1	3	1	5	1
Lateolabracidae	18	1	4	1	6	2
Soleidae	19	1				
Carangidae	20	1			17	1
Syngnathidae	20	1			14	2
Callionymidae	20	1				
Teraponidae	23	1			8	2
Leiognathidae	23	1			7	1
Platycephalidae	23	1				
Cottidae			2	1	10	1
Anguillidae			5	1		
Paralichthyidae			8	1		
Lutjanidae					9	1
Elopidae					14	1
Tricanthidae					14	1
Microdesmidae					17	1

Chapter 5.   Comparison of early life history of the Asian seaperches (*Lateolabrax*)

5.1.   Results

5.1.1.   Two types of *Lateolabrax* larvae in the estuaries of northern Vietnam

Morphology

General morphology.   Larvae and juveniles collected in the Tien Yen and Kalong estuaries are as type-T and type-K, respectively (Figs. 25–29).   The size ranges of specimens on which the descriptions were based were: preflexion with yolk in type-T (3.1–3.4 mm BL, n = 3), postflexion in type-T (10.3–14.4 mm, n = 6) and type-K (10.9–14.4 mm, n = 10), and juveniles in type-T (15.9–25.8 mm, n = 18) and type-K (15.0–28.4 mm, n = 10).
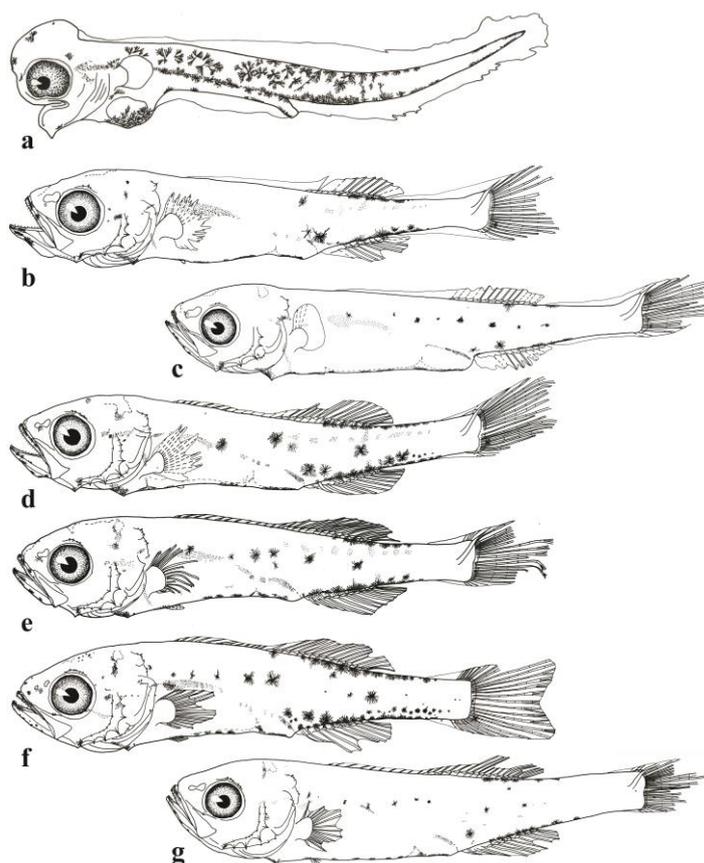
Fig. 25.   Larvae of *Lateolabrax* sp. from the two estuaries in northern Vietnam.   **a** 3.4 mm BL (type-T, UKU-332001007); **b** 10.3 mm BL (type-T, UKU-332001001); **c** 10.9 mm BL (type-K, UKU-332001005); **d** 11.5 mm BL (type-T, UKU-332001002); **e** 12.5 mm BL (type-T, UKU-332001003); **f** 14.4 mm BL (type-T, UKU-332001004); **g** 14.4 mm BL (type-K, UKU-332001006).

Larvae are laterally compressed in both the types. The guts are tightly coiled and relatively long and snout-anus distances are 53–56% BL in the preflexion with yolk larvae of type-T, increasing to 61–67% BL in the smaller postflexion larvae, being not so change until the juvenile stage in both the types. The upper jaw length and eye diameter are ca. 14–17% and 9–12% BL in type-T, and 11–13% and 8–11% in type-K, respectively, and these ratios appear stable throughout larva–juvenile stages. Reversely, the head length, snout length, body depth and caudal peduncle length change proportionally with their growth in both the types. The heads are moderate as ca. 20% and 25% BL in the smallest larvae, increasing gradually to ca. 40% and 37% in the juveniles in type-T and type-K, respectively. Snout length increases from ca. 2 to 9% BL with the growth of larvae of type-T, however, this ratio appears stable throughout postflexion larva–juvenile stages, being 9–11% and 6–8% BL in type-T and type-K, respectively. Larvae are initially elongate (ca. 15% BL in type-T; ca. 16% in type-K), but both are gradually moderate, being finally ca. 29% BL in both the types. The caudal peduncle lengths in the smallest postflexion larvae are ca. 23% and 26% BL, decreasing gradually to ca. 20% BL in the juvenile stages both the types.

There can be significant mean differentiation in five parts (the upper jaw, snout, head and caudal peduncle lengths and eye diameter) between the two types (Fig. 26). Furthermore, when each part on the head is proportionally compared as ratios to head length, the upper jaw and snout lengths and eye diameter are also significantly larger in type-T than in type-K (Fig. 27).
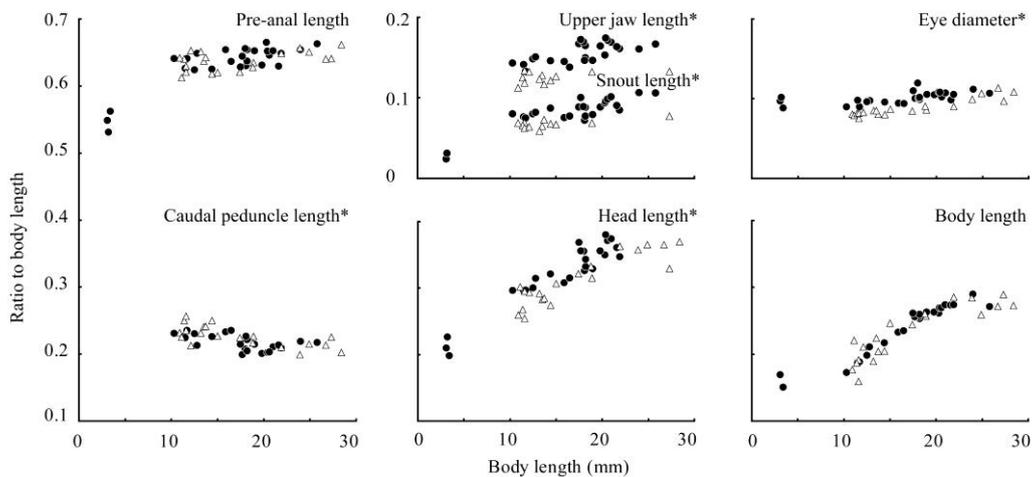
Fig. 26. Sequence of changes in the ratio of each measured part to the body length of the Vietnamese *Lateolabrax*. *Solid dots* and *open triangles* indicate the Tien Yen and Kalong specimens, respectively. * significance at <0.01 between two estuaries.
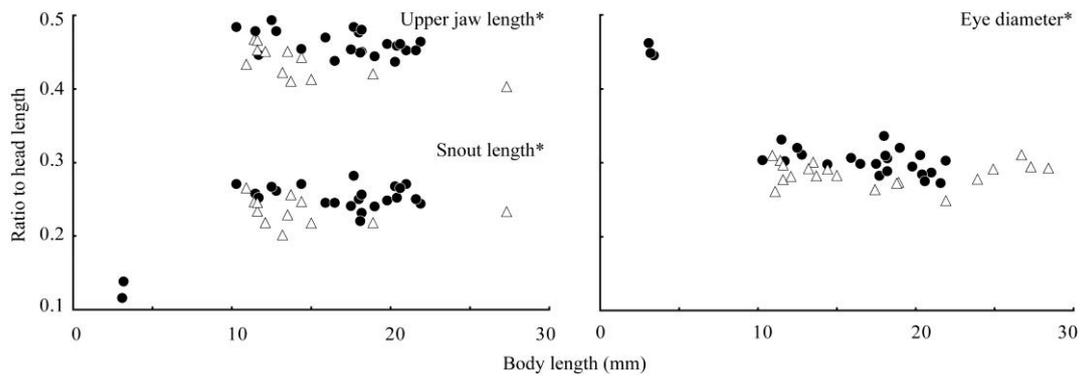
Fig. 27. Sequence of changes in the ratio of three measured parts to the head length of the Vietnamese *Lateolabrax*.   Otherwise same as Fig. 26.

Head spination.   There are no head spines in reflexion larvae of type-T (Fig. 25a).   Spines appeared initially on the supraocular, preopercle, opercle, interopercle and posttemporal, increasing in number with larval growth in both the types. Supracleithrum and lachrymal begin to bear spines in ca. 11 and 13 mm BL larvae, respectively, in both the types.   The subopercle spine occurs in the juvenile stage of ca. 18 mm BL in type-T and ca. 25 mm in type-K.   Therefore, between the two types, there is not much difference in head spination (Table 6), of which, however, the lachrymal bears distinctively fewer spines in type-K (primarily one) than type-T (primarily three).

Table 6. Head spine numbers of larvae and juveniles of *Lateolabrax* species in the Tien Yen (Ti) and Kalong (Ka) estuaries of northern Vietnam, and Rokkaku (Ro), Hayatsue (Ha) and Yabe (Ya) estuaries, and Miike (Mi) sand beach in Ariake Bay and Shimanto (Sh) estuary of southern Japan

Sites	No. of fish	Range of BL (mm)	Count of spines								
			La	SOc	IP	OP	O	IO	SOp	PT	SC
Ti	24	10.3–25.8	0–3	3– 7	4– 7	5–14	1	2–7	0–2	2–11	0–3
Ka	14	10.9–28.4	0–2	2– 7	2– 8	4–16	1	1–6	0–2	1–11	0–3
Ro	19	12.7–29.4	0–4	4–11	7–10	5–11	1	2–7	0–3	3–10	1–3
Ha	10	13.6–18.5	0–3	4– 9	6–10	5– 8	1	1–6	0–1	3– 7	1–3
Ya	50	10.9–19.9	0–4	2–11	5–14	3–11	1	1–6	0–3	2– 8	0–4
Mi	37	11.6–21.7	0–5	4–10	5–11	5–10	1	1–5	0–3	2– 9	1–4
Sh	42	9.3–25.0	0–3	2– 9	3–10	1–12	0–1	1–5	0–3	1– 8	0–3

IO interopercle, *IP* inner preopercle, *La* lachrymal, *O* opercle, *OP* outer preopercle, *PT* posttemporal, *SC* supracleithrum, *SOc* supraocular, *SOp* subopercle.

Meristic characters.   Total myomere counts range from 35 to 37 (mean: 35.9 in type-T and 35.6 in type-K).   Notochord flexion was been completed by ca. 10 mm BL in type-T and ca. 11 mm in type-K.   All cleared and stained specimens in postflexion larva and juvenile stages had developed complete numbers of vertebrae, dorsal and anal pterygiophores.   There were no significant differences in the count of vertebrae between the two types, with the ranges of 34–35 in type-T and 34–36 in type-K.   The mean numbers of both dorsal and anal pterygiophores were larger in type-T ($\bar{D}$ = 25.45±0.60 (SE) and $\bar{A}$ = 9.35±0.59) than type-K ($\bar{D}$ = 25.05±0.54 and $\bar{A}$ = 8.93±0.77) (Table 7).   The pelvic bud occurred in the smallest postflexion larvae in both the types. Type-T and type-K attain the juvenile stage, with a full complement of fins, by ca. 16 and 15 mm SL, respectively.

Table 7.   Frequency distributions of the number of vertebrae, and dorsal and anal pterygiophores in larvae and juveniles of *Lateolabrax* species from Vietnam and Japan (site abbreviations are given in Table 6)

| Sites | No. of vertebrae | | | | | No. of pterygiophores | | | | | | | | |
| | | | | | | Dorsal | | | | | Anal | | | |
	34	35	36	37	Mean±SD	24	25	26	27	Mean±SD	8	9	10	Mean±SD
Ti	3	17			34.85±0.37	1	9	10		25.45±0.60	1	11	8	9.35±0.59
Ka	3	14	1		34.89±0.47	2	13	3		25.05±0.54	5	7	4	8.93±0.77
Ro	1	11	7		35.32±0.58	2	12	5		25.16±0.60	1	15	3	9.11±0.46
Ha		4	6		35.60±0.52		6	4		25.40±0.52		8	2	9.20±0.42
Ya		17	33		35.66±0.48	2	26	21		25.39±0.57	4	35	10	9.12±0.53
Mi		9	25	3	35.84±0.55	4	18	15		25.30±0.66	3	24	10	9.19±0.57
Sh		2	47	1	35.98±0.25	1	5	39	1	25.87±0.45	2	32	15	9.27±0.53

Pigmentation.   Melanophores are evidently distributed more densely in larvae from the Tien Yen than Kalong estuaries (Fig. 25).   In preflexion with yolk larvae of type-T (Fig. 25a), melanophores are found on the angle of the lower jaw, under the chin, throat, ventral margin of the trunk, both the dorsal and ventral margins of the tail. Relatively large and branched melanophores had been distributed around the lateral midline and some small ones dorsally on the head.   Internally, melanophores form a line from the snout through ventral side of the skull to the dorsal end of the gut.

In postflexion larvae and juveniles (Fig. 25b–g), melanophores were present on the angle of the lower jaw, along the margins of jaws, and the dorsal and ventral margins of the tail in both the types.   Melanophores of the dorsal and ventral margins of the tail extend to posterior part in type-T against one-thirds of the caudal peduncle in type-K, being heavier in the type-T than type-K.   A row of melanophores had appeared ventrally from the chin to the hindgut in both the types.   On the side of body, relatively large (in type-T) and small (in type-K) branched melanophores had been distributed around the lateral midline, thereafter gradually being denser with growth in type-T. Internally, a pair of rows of melanophores sandwiches the vertebrae, being denser and extended more posteriorly in type-T than type-K.   A melanophore series is distributed along the dorsolateral surface of the gut and gas bladder in both the types.

Development of the skeleton.   The osteological development of *Lateolabrax* sp. larvae and juveniles of the two types is presented in Figs. 28 and 29.   The counts of noticeable changes in osteological development, for example, the initial appearance of cartilage, the full complement of cartilage, the beginning of ossification and the full complement of ossified structures for respective elements, were summarized.   This treatment is useful for total understanding of the osteological development as an aggregation of qualitative changes.
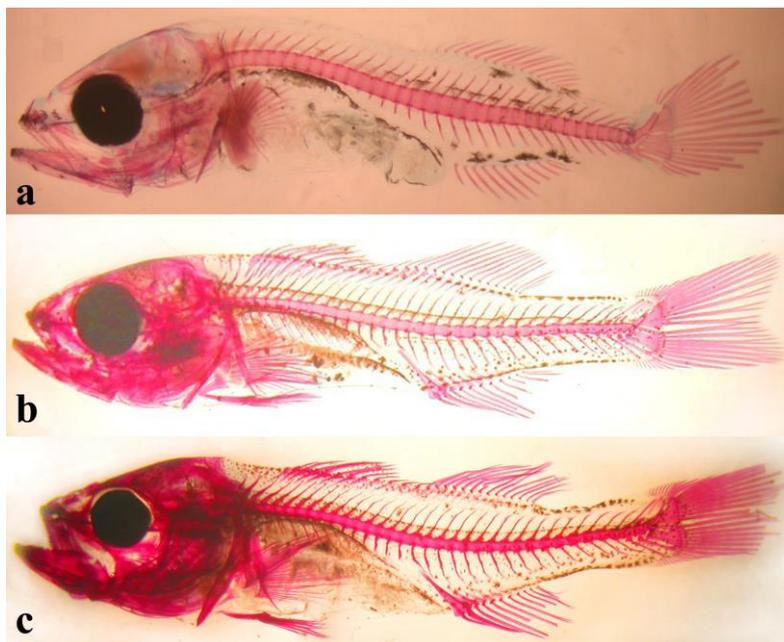
Fig. 28.   Development of the skeleton in *Lateolabrax* sp. collected from two estuaries in northern Vietnam.   **a** 11.1 mm BL (type-K); **b** 17.7 mm BL (type-T); **c** 18.9 mm BL (type-K).

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Fig. 29 shows the cumulative percentage of the counts of progressed changes against body length for vertebral column and fin-supports in larvae and juveniles of *Lateolabrax* sp. collected in the two estuaries.   From ca. 11 mm BL specimens, the cartilaginous formation of vertebral column and fin-supports was completed, but the ossification of the vertebral column was still in process of development by ca. 15 mm BL in both the types and those of fin-supports, except for distal radials, by ca. 18 and 19 mm in type-T and type-K, respectively (Figs. 28, 29).   There was no significant differentiation in the developmental process of the skeletal tissues in *Lateolabrax* larvae and juveniles between the two types (Fig. 29).
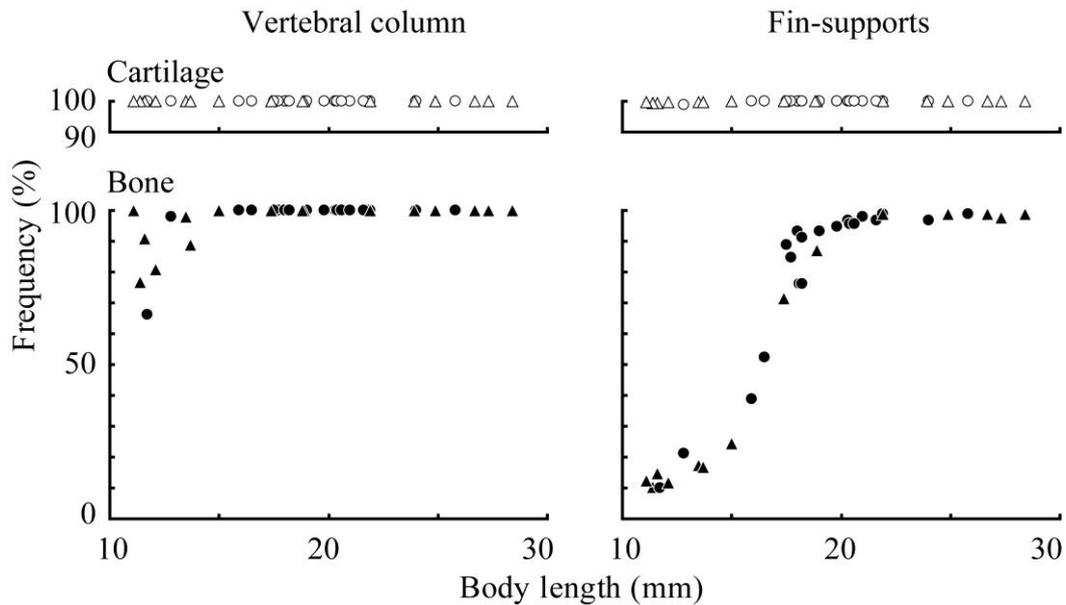
Fig. 29.   Relationship between counts of osteological changes (cumulative percentage) and body length in the Vietnamese *Lateolabrax*.   *Dots* and *triangles* indicate the Tien Yen and Kalong specimens, respectively.

Distribution

Tien Yen estuary.   A total of 31 postflexion larvae and juveniles occurred in the bank waters (Figs. 30, 31) and none in the center of the current of the estuary from March 2013 to September 2015.   From March 2013 to February 2014, they occurred in the period of December to March with a peak abundance in February (Fig. 31) and their body length ranged from 9.4 to 25.8 mm, with a mode at 17.1–18.0 mm (Fig. 30). From October 2014 to September 2015, *Lateolabrax* sp. were collected in January and February (Fig. 31), with size ranging from 10.3 to 21.0 mm BL (Fig. 30).
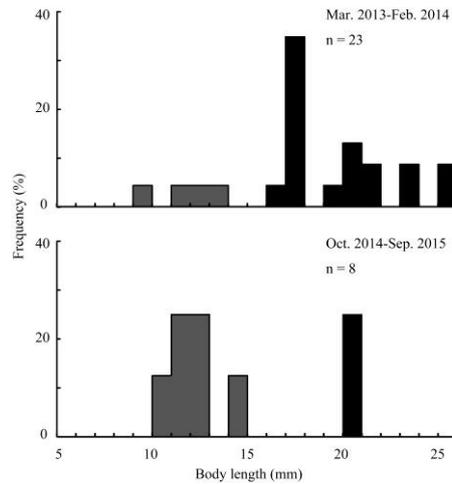
Fig. 30.   Annual change in size frequency distributions of *Lateolabrax* sp. collected in the Tien Yen estuary from March 2013 to September 2015.   Otherwise same as Fig. 18.
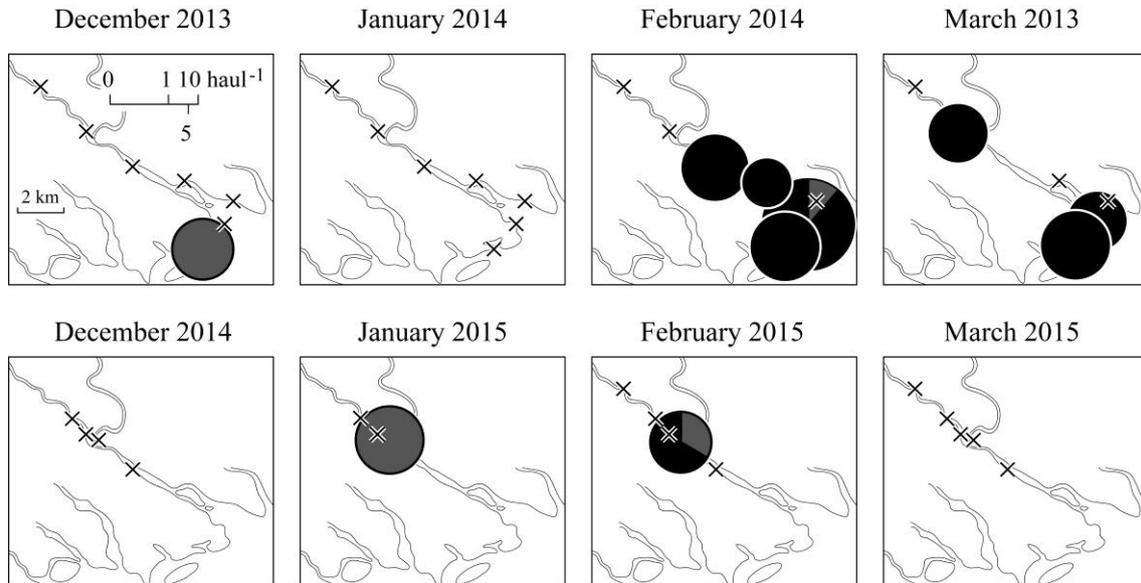
Fig. 31.   Seasonal changes of horizontal distribution of *Lateolabrax* sp. collected in the bank waters by a seine net in the Tien Yen estuary from March 2013 to September 2015.   No seaperches were collected during the period of April to November.   The diameter of each *circle* is drawn in proportion to the cube root of CPUE [*n haul⁻¹* (ca. 50 m)].   *Crosses* represent no *Lateolabrax*. Otherwise same as Fig. 18.

Seasonally, the modal sizes gradually increased from December to March (Fig. 32).   Horizontally, the larvae and juveniles occurred from Stn. TS8 to Stn. TS15, being more abundant in the stations around the mouth of the estuary (Stns. TS8 and TS10, Figs. 31, 33).

The temperatures, salinities and turbidities of the waters where the specimens were collected ranged from 17.3 to 24.8°C, 4.5–27.3 and 0–55 NTU, respectively.
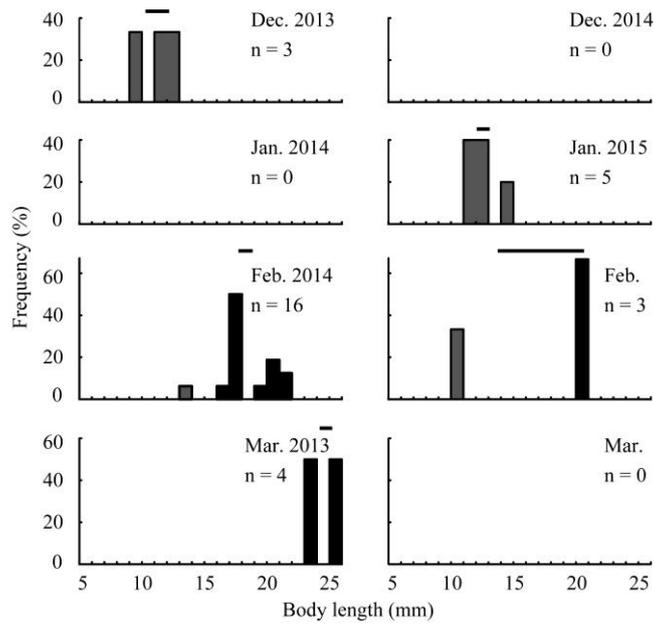
Fig. 32. Seasonal changes in size frequency distribution of *Lateolabrax* sp. collected in the bank waters of the Tien Yen estuary. *Thick lines* on *bars* denote mean values (±SE) of body length. Otherwise same as Fig. 18.
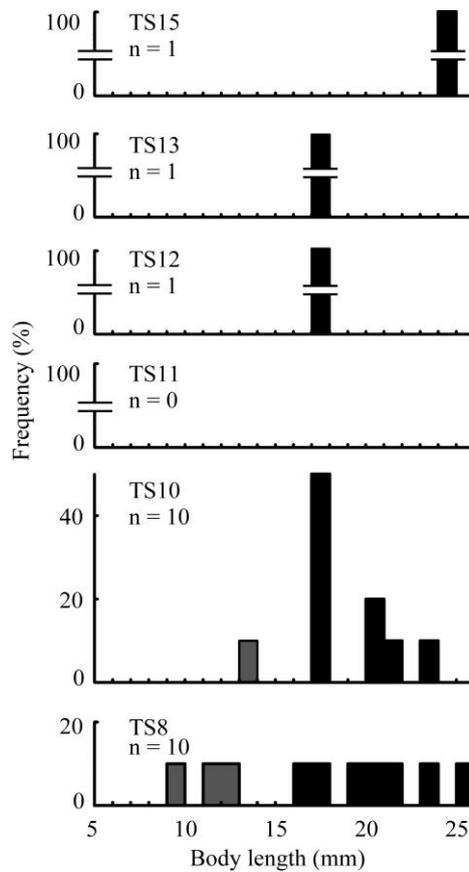
Fig. 33. Spatial changes in size frequency distribution of *Lateolabrax* sp. collected in the bank waters of Tien Yen estuary. Otherwise same as Fig. 18.

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Kalong estuary.   *Lateolabrax* sp. occurred in both center of the current and the bank waters of Kalong estuary from December 2014 to April 2015 (Figs. 34, 35).
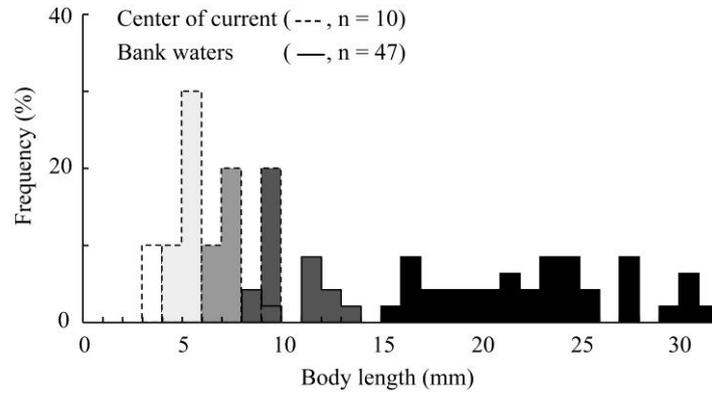
Fig. 34.   Size frequency distributions of *Lateolabrax* sp. collected in Kalong estuary from December 2014 to April 2015.   Otherwise same as Figs. 17 and 18.
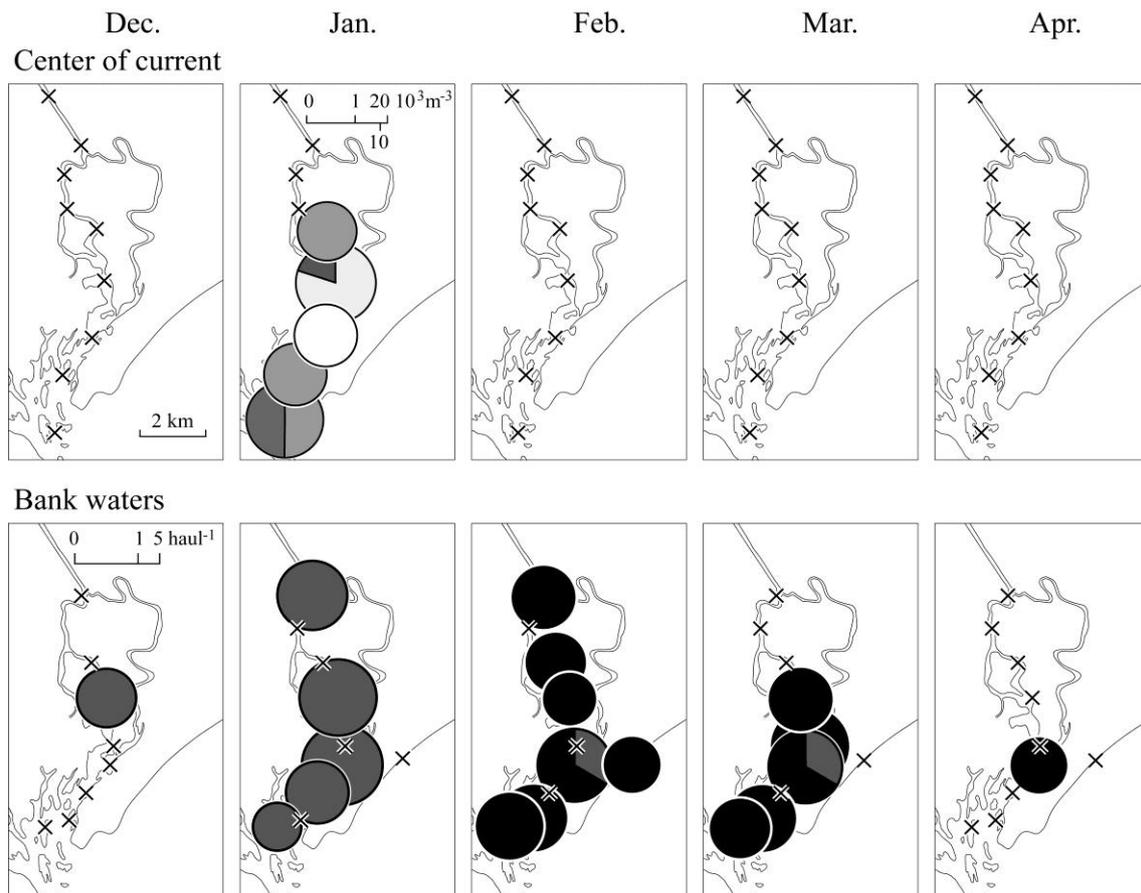
Fig. 35.   Seasonal changes of horizontal distribution of *Lateolabrax* sp. collected in the center of the current by a larva net and the bank waters by a seine net in the Kalong estuary from December 2014 to April 2015.   The diameter of each *circle* is drawn in proportion to the cube root of density (*n 10³m⁻³*) in the upper and CPUE [*n haul⁻¹* (ca. 50 m)] in the lower.   Otherwise same as Figs. 17, 18 and 31.

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In the center of the current, a total of 10 larvae were collected in January (chiefly preflexion), ranging from 3.4 to 9.2 mm in BL (Figs. 34, 35). They occurred from the outer to middle parts of the estuary (Stns. KL1–KL5, Fig. 35), where temperatures, salinities and turbidities ranged from 17.1 to 17.5°C, 21.0–30.0 and 2–57 NTU, respectively. Preflexion larvae were collected in the middle stations of the estuary (Stns. KL3 and KL4, Fig. 35).
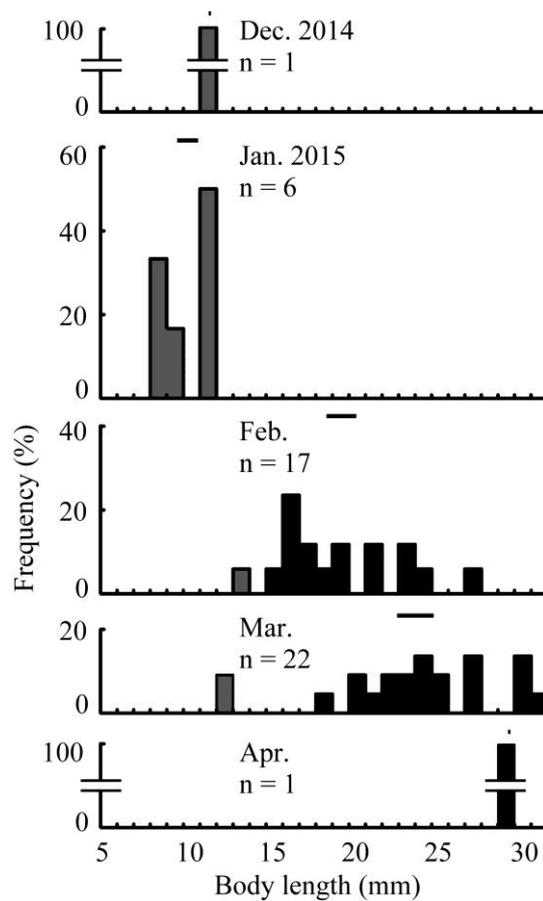
Fig. 36. Seasonal changes in size frequency distribution of *Lateolabrax* sp. collected in the bank waters of the Kalong estuary from December 2014 to April 2015. Otherwise same as Figs. 18 and 32.

In the bank waters, a total of 48 fishes were collected in the estuary and one in the surf zone (Fig. 35). They were composed of postflexion and juveniles stages (mostly juvenile), ranging from 8.4 to 32.0 mm with no significant modal size (Fig. 34). *Lateolabrax* sp. occurred from December to April, being most abundant in March (Fig. 35). Size ranges widened in February and March, and narrow in the other months, with modal sizes seasonally increased from December and January to April (Fig. 36).

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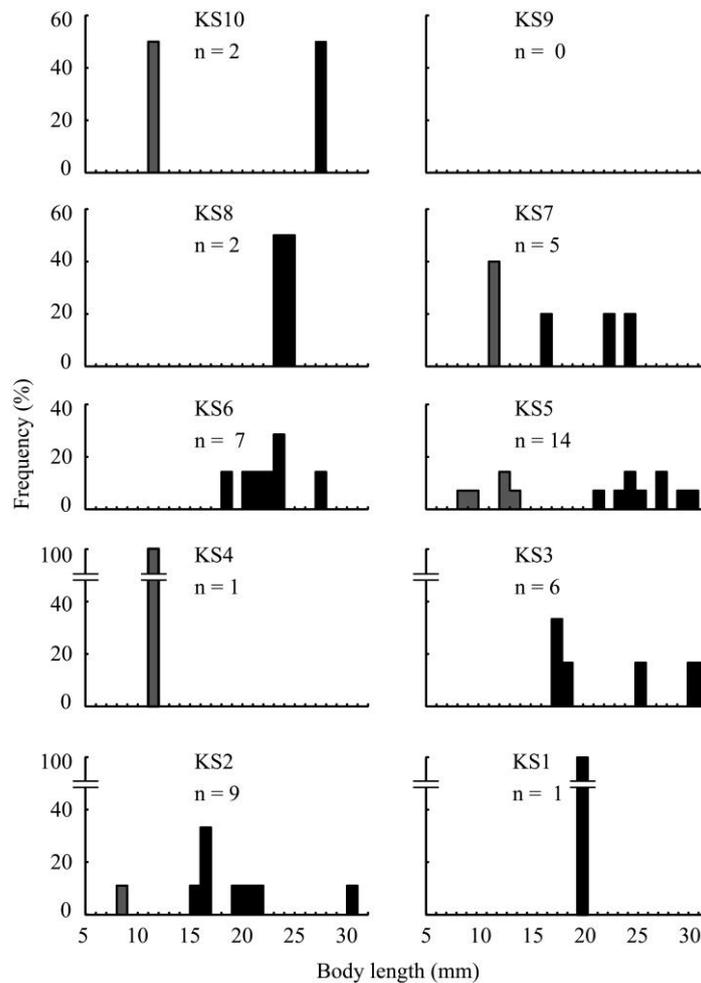
Fig. 37. Spatial changes in size frequency distribution of *Lateolabrax* sp. collected in the bank waters of the Kalong estuary from December 2014 to April 2015. Otherwise same as Fig. 18.

Horizontally, the fishes were dispersed from Stn. KS2 to Stn. KS10 of the estuary, being more abundant in the middle and outer (Stns. KS2–KS7) than the inner stations (Stns. KS8–KS10), with the sizes changed irregularly with stations (Fig. 37). A juvenile was present at the surf zone station (Stn. KS1, Fig. 35). The temperatures, salinities and turbidities of bank waters where the specimens were collected ranged from 15.9 to 28.3°C, 1.8–31.8 and 0-76 NTU, respectively.

Growth

The sagittae and lapilli were removed from a total 42 larva (13.8 mm, n = 1) and juveniles (14.9–26.5 mm, n = 41) of *Lateolabrax* sp. collected in the bank waters of the Kalong estuary on 11–12 March 2017 (Table 8). Daily increments on lapilli could be counted in all given specimen sizes, while rings on sagittae could be counted in

specimens less than 19 mm BL.　　Hatching dates of juveniles ranged from 7 January to February and peaked during the period of 11–20 January (Table 8; Fig. 38).　　The birthdates were, in general, concentrated to days around the new moon (Fig. 38).

The age-BL relationships of *Lateolabrax* sp. juveniles ranging from 14.9 to 25.8 mm BL (n = 40) are presented in Fig. 39.　　The linear regression formula of BL (y; mm) on estimated age (x; day) was expressed as y = 0.406x + 0.704 (r = 0.931).

The BL-otolith radius relationships of *Lateolabrax* sp. larva and juveniles ranging from 13.8 to 25.8 mm BL (n = 42) are presented in Fig. 40.　　The linear regression formula of otolith radius (y; μm) on BL (x; mm) was expressed as y = 33.585x - 211.610 (r = 0.960) and y = 12.136x - 50.190 (r = 0.972) for sagittal radius-BL and lapillar radius-BL relationships, respectively.

Table 8.　Examination records of the estimated age and hatching dates of larvae and juveniles of *Lateolabrax* species from Vietnam and Japan (site abbreviations are given in Table 6)

| Site	Collection date			No. fish	Body length (mm)		Age (day)		Estimated birthdate
					Range	Mean	Range	Mean	
Ka	11, 12	Mar.	2012	42	13.8–26.5	20.5	33–65	49	Jan. 7–Feb.7
Ro	27, 29	Mar.	2017	10	12.7–18.1	15.3	44–81	58	Jan. 7–Feb. 11
	26	Apr.	2017	9	17.3–29.4	23.6	63–87	75	Jan. 29–Feb. 22
Ha	29	Mar.	2017	10	13.6–18.5	15.9	41–80	64	Jan. 8–Feb. 16
Ya	28	Mar.	2017	50	10.9–19.9	15.8	37–80	58	Jan. 7–Feb. 19
Mi	28	Mar.	2017	37	11.6–21.7	15.6	39–88	57	Dec. 30–Feb. 17
	Total			116	10.9–29.4	16.3	37–88	59	Dec. 30–Feb. 22
Sh	19	Jan.	2015	1		10.7		28	Dec. 22
	20	Feb.	2015	24	10.8–15.2	13.1	25–45	37	Jan. 6–26
	20	Mar.	2015	1		18.6		ND	ND
	22	Jan.	2016	2	9.3– 9.4	9.4	24–28	26	Dec. 25–29
	23	Mar.	2016	7	11.6–25.0	19.3	37–83	59	Dec. 31–Feb.15
	30	Jan.	2017	1		10.4		23	Jan. 7
	24	Feb.	2017	4	10.8–12.9	11.7	25–30	27	Jan. 25–30
	15	Mar.	2018	10	18.8–28.2	22.4	54–73	64	Jan. 2–20
	Total			50	9.3–28.2	15.6	24–83	45	Dec. 22–Feb. 15

ND No data
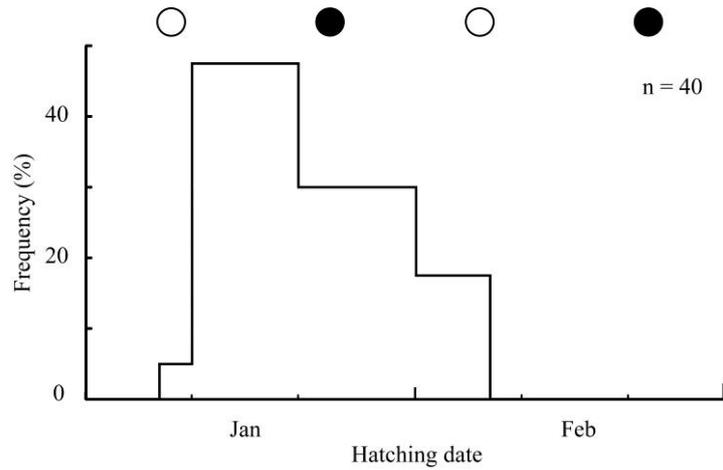
Fig. 38. Frequency distributions of the hatching dates of *Lateolabrax* sp. collected in March 2012 in the Kalong estuary. *Solid* and *open dots* indicate the new and full moon, respectively.
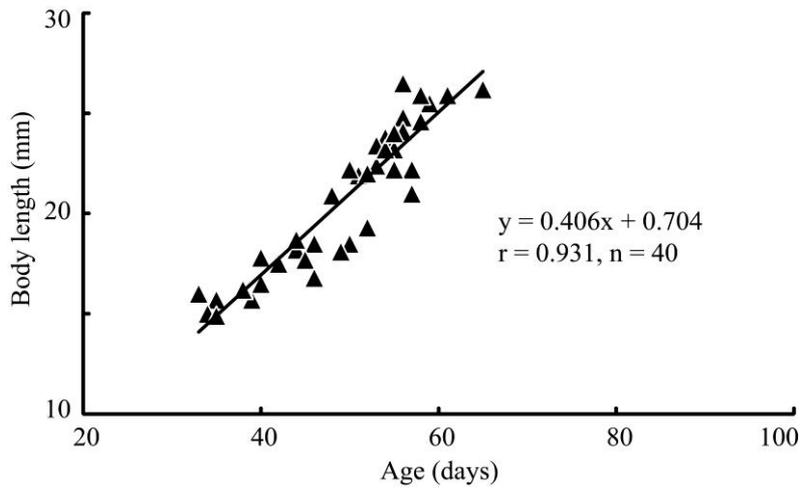

Fig. 39. Relationship between age and body length of *Lateolabrax* sp. collected in March 2012 in the Kalong estuary.
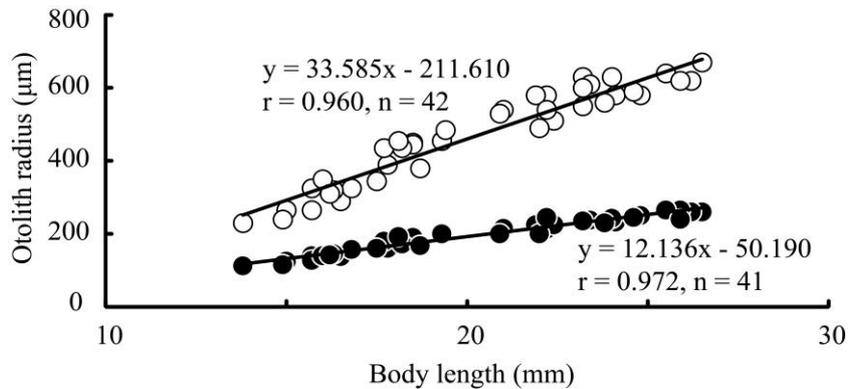

Fig. 40. Relationship between body length and otolith radius of sagitta (*open dots*) and lapillus (*solid dots*) of *Lateolabrax* sp. collected in March 2012 in Kalong estuary.

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Food habit

Numerical percentage of food items in the stomachs of *Lateolabrax* larvae and juveniles from the Tien Yen and Kalong estuaries are shown in Fig. 41.   Although their food habit changed with growth, both larvae and juveniles largely fed on copepods of Calanoida in both the estuaries.   Harpacticoid copepods were ranked second in numerical percentage in fishes from both the estuaries, however, with growth, their number increased in the specimens from Tien Yen estuary, but decreased in those from Kalong estuary.   The larvae of *Lateolabrax* sp. were found as the prey items of 27.3 mm BL specimen in the Kalong estuary.   Cladocerans were found in the stomachs of larvae and juveniles from the Kalong estuary but absent in the Tien Yen specimens. Conversely, some Mollusca, Gammaridae larvae and Tricladida being of benthic habit were present in the stomachs of specimens in Tien Yen but absent from those in the Kalong estuary.   There was a tendency that the larger fishes consumed a variety of prey items in both the estuaries.   The feeding incidences were usually over 75% in the two estuaries, and the number of food items per fish fluctuated irrespective of location. Both the given values increased with developmental stages in the two estuaries.
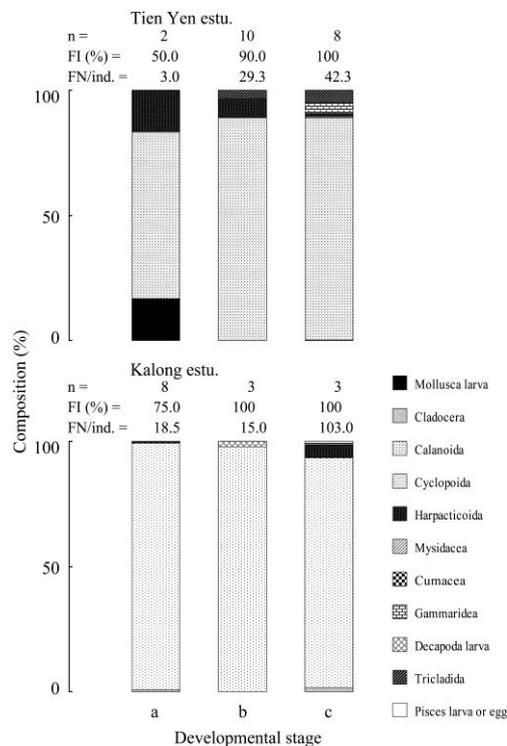
Fig. 41.   Change in stomach contents with the developmental stage of the Vietnamese *Lateolabrax*. *a* larvae, *b* ≤20 mm BL juveniles, *c* >20 mm BL juveniles, *FI* feeding incidence (no. of individuals with food/no. of individuals examined), *FN* food number.

5.1.2. *Lateolabrax japonicus* in Ariake Bay

Morphology

General morphology. Larvae and juveniles from the 3 estuaries and Miike beach were chosen to describe. They are laterally compressed with moderate head and eyes. The larvae are initially elongate (ca. 19% BL), but become gradually moderate and finally ca. 30% BL in juveniles. Pre-anal, head, upper jaw and snout length, and eye diameter gradually increase from ca. 60 to 68%, 29–39, 13–17, 7–11 , and 8–12% BL, respectively, while caudal peduncle length decreases from ca. 26 to 19% with growth in less than ca. 21 mm BL specimens, after that, these ratios seem to be constant as size increase. Of the 3 estuaries and one surf zone, the ratios of head length and body depth to body length tended to be larger in the specimens from Rokkaku estuary (Fig. 42).
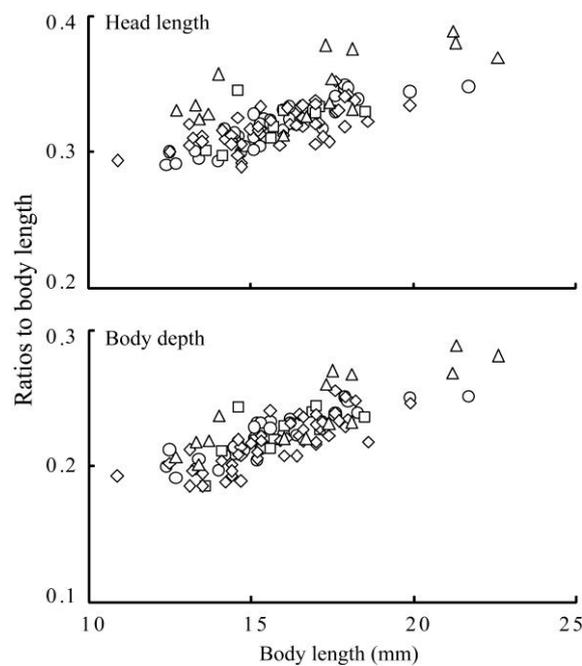
Fig. 42. Comparisons of the proportional measurements of head length and body depth, shown as percentages of body length of *Lateolabrax japonicus* larvae and juveniles among the neighboring habitats in Ariake Bay. *Triangles*, *squares*, *diamonds* and *dots* indicate the Rokkaku, Hayatsue, Yabe and Miike specimens, respectively.

Head spination. Spines appeared initially on the supraocular, preopercle, opercle, interopercle and posttemporal regions. Supracleithrum, lachrymal and subopercle begin to bear spines in ca. 11, 12 and 14 mm BL, respectively. The number of head spines is shown in Table 6. There is not much difference in head spination among the neighboring habitats in Ariake Bay.

Meristic characters. The frequency distribution of meristic character counts in larvae and juveniles from Ariake Bay is shown in Table 7. There are no significant differences in the counts of vertebrae, and dorsal and anal pterygiophores with the ranges of 34–37, 24–26 and 8–10, respectively, among the 3 estuaries and one surf zone.

Development of the skeleton. The osteological development of *Lateolabrax japonicus* larvae and juveniles from the neighboring habitats in Ariake Bay are presented in Figs. 43 and 44. In the developmental process of cartilage, the formation of vertebral column was completed from the smallest larvae, but that of fin-supports was still in the process of development by ca. 15 mm BL. The ossification of osteological structures of vertebral column was accomplished before the fishes reached ca. 14 mm in Rokkaku estuary and Miike beach, 15 mm in Hayatsue estuary and 17 mm in Yabe estuary, and that of fin-supports, except for distal radials, was completed by ca. 18 mm approximately in Rokkaku and Miike, but was still in process of development in the largest juveniles in Hayatsue (18.5 mm BL) and Yabe (19.9 mm) estuaries (Fig. 43).

Variation in osteological development was evident among neighboring habitats in Ariake Bay. The fin-supports developed faster in specimens from Rokkaku and Hayatsue Rivers and surf zone of Miike beach than in those from Yabe River (Fig. 44).
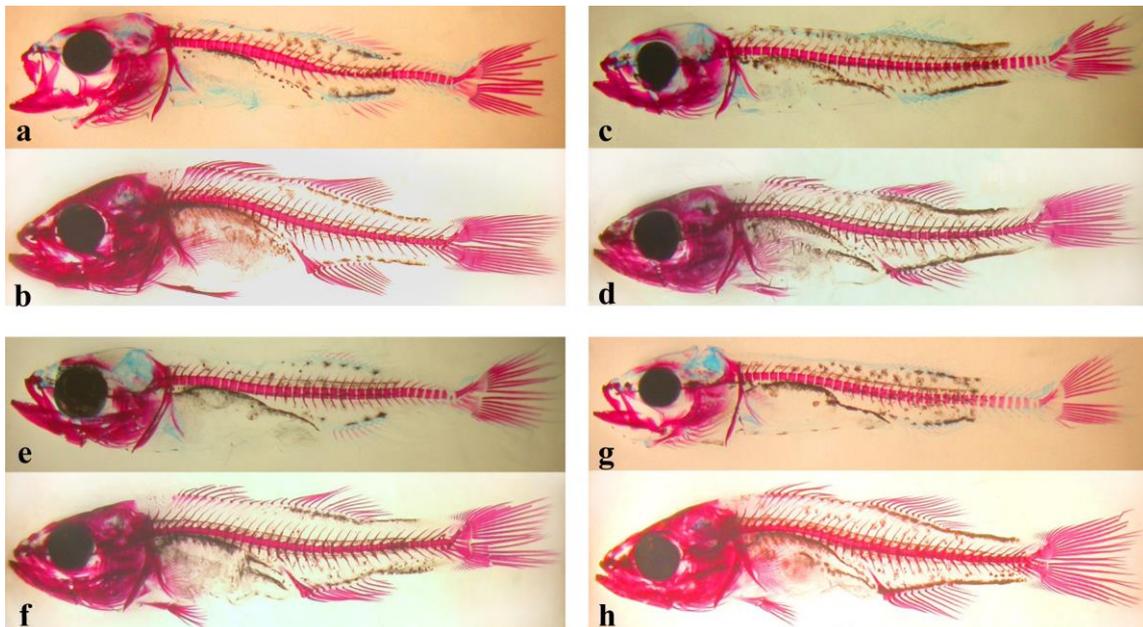
Fig. 43. Development of the skeleton in *Lateolabrax japonicus* larvae and juveniles collected from the neighboring habitats in Ariake Bay. **a** 12.7 mm and **b** 18.1 mm BL from Rokkaku estuary; **c** 13.6 mm and **d** 18.5 mm from Hayatsue estuary; **e** 12.5 mm and **f** 19.9 mm from Yabe estuary; **g** 12.4 mm and **h** 17.9 mm from Miike beach.
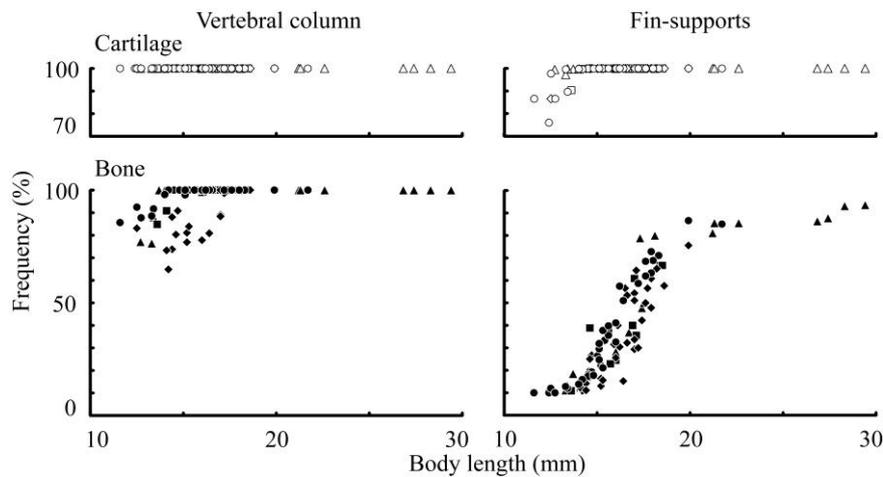
Fig. 44. Comparisons of relationship between counts of osteological changes (cumulative percentage) and body length of *Lateolabrax japonicus* larvae and juveniles among the neighboring habitats in Ariake Bay.   Otherwise same as Fig. 42.

Distribution

Lateolabrax japonicus occurred in the center of the currents in the three estuaries and bank waters of Miike beach at the same developmental stage and almost similar sizes, ranging from 10.9 to 29.4 mm BL with a mode at 16.1–17.0 (Figs. 45–47).
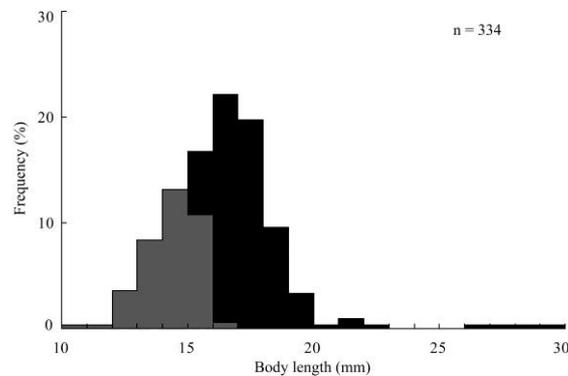
Fig. 45. Size frequency distributions of *Lateolabrax japonicus* collected in March and April 2017 from Ariake Bay.   Otherwise same as Fig. 18.

Of the three estuaries, larvae and juveniles were the most abundant in the Yabe estuary (Fig. 46).   They were horizontally dispersed from outer to inner stations in Yabe and Hayatsue estuaries, except for Stn. 37 where no specimens were collected (Fig. 47).   In Rokkaku estuary, the fishes were collected by a larva net in outer stations (Stns. 6 and 7, Fig. 47).   The temperatures, salinities and turbidities of the waters where the specimens were collected ranged from 11.6 to 12.8°C, 1.5–31.9 and 4–1917 NTU, respectively, in March 2017.

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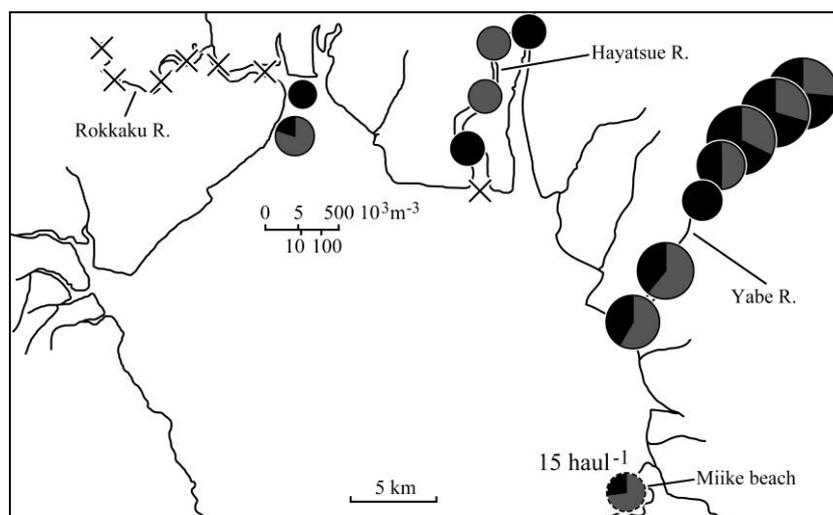
Fig. 46.   Horizontal distribution of *Lateolabrax japonicus* collected in March 2017 from Ariake Bay. The diameter of each *circle* is drawn in proportion to the cube root of density (*n 10³m⁻³*) of the fishes collected in the center of the currents of the three neighboring estuaries by larva nets (*solid lines*) and CPUE [*n haul⁻¹* (ca. 50 m)] in the bank waters of Miike sand beach by a seine net (*broken lines*).   Otherwise same as Figs. 18 and 31.
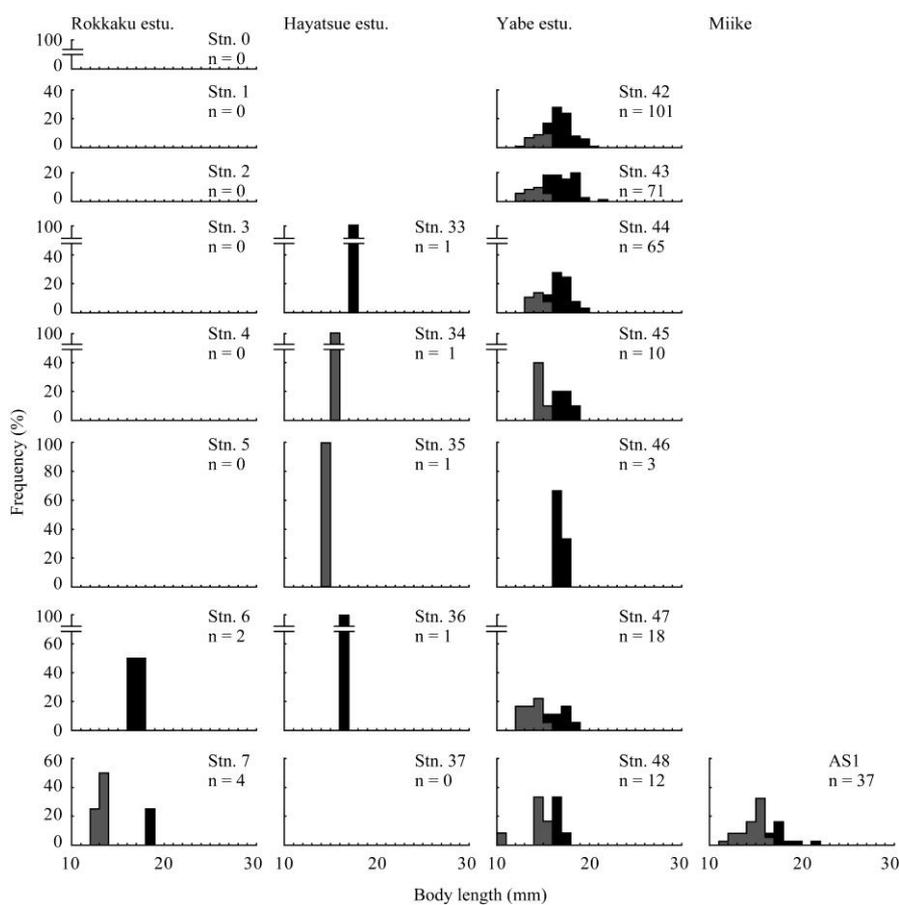

Fig. 47.   Spatial changes in size frequency distribution of *Lateolabrax japonicus* collected in the center of the 3 neighboring estuaries by larva nets and in the bank waters of Miike beach with a seine net in March 2017 from Ariake Bay.   Otherwise same as Fig. 18.

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Growth

The hatching dates of *Lateolabrax japonicus* larvae and juveniles (10.9–26.8 mm BL, n = 112) collected on 27–29 March and 26 April 2017 in three estuaries and Miike beach of Ariake ranged from 30 December 2016 to 22 February 2017 and peaked during the period of 21–31 January (Table 8; Fig. 48).   The birthdates were, in general, concentrated to days around the new moon (Fig. 48).
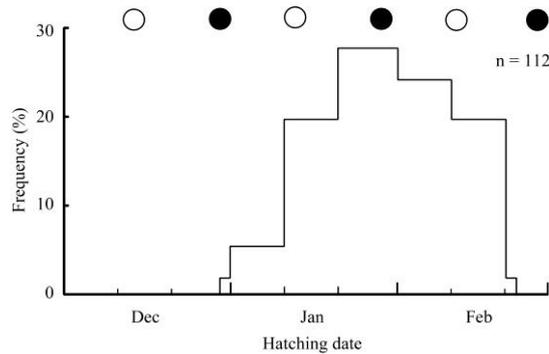
Fig. 48.   Frequency distributions of hatching date of *Lateolabrax japonicus* collected in March and April 2017 from Ariake Bay.   *Solid* and *open dots* indicate the new and full moon, respectively.

The age-BL relationships of the given specimens are presented in Fig. 49.   The linear regression formula of BL (y; mm) on estimated age (x; day) was expressed as y = 0.157x + 6.697 (r = 0.874).   Of the 3 estuaries and a surf zone, there were no significant differences in the growth of fishes in Hayatsue and Yabe estuaries and Miike beach; however, at the same age, the larvae tended to be smaller, conversely, the juveniles were larger in size of specimens from Rokkaku estuary than those from the other sites.
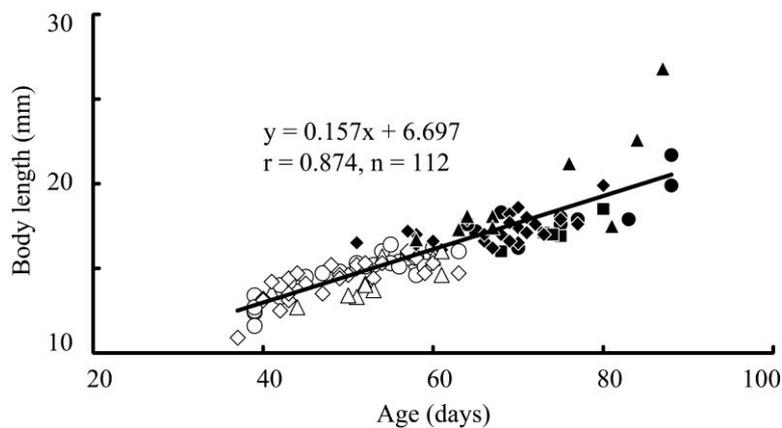
Fig. 49. Comparisons of relationship between age and body length of *Lateolabrax japonicus* among the neighboring habitats in Ariake Bay.   *Open* and *solid symbols* indicate larvae and juveniles, respectively.   Otherwise same as Fig. 42.

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The BL-otolith radius relationships of *Lateolabrax* larva and juveniles ranging from 10.9 to 29.4 mm BL (n = 116, Table 8) are presented in Fig. 50.   The linear regression formula of otolith radius (y; μm) on BL (x; mm) was expressed as y = 43.269x - 388.900 (r = 0.967) and y = 15.489x - 112.590 (r = 0.953) for sagittal radius-BL and lapillar radius-BL relationships, respectively.   There were no significant differences in otolith radius among three estuaries and the surf zone (Fig. 50).
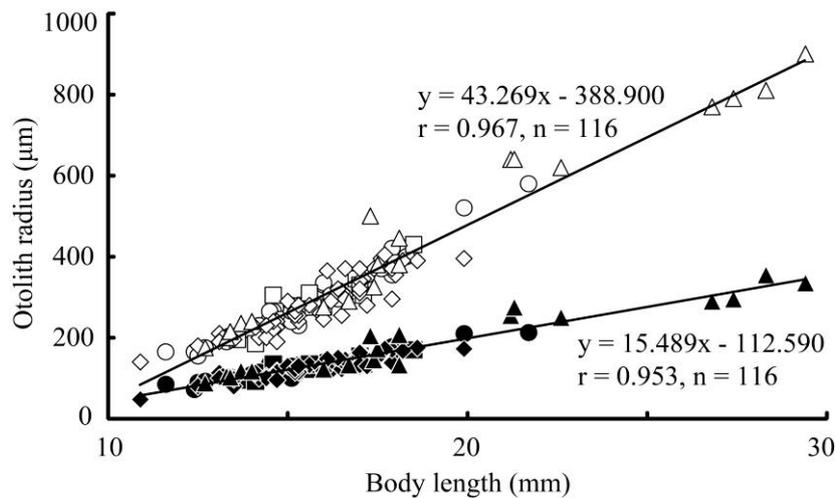

Fig. 50.   Relationship between body length and the otolith radius of sagitta (*open symbols*) and lapillus (*solid symbols*) of *Lateolabrax japonicus* larvae and juveniles collected in Ariake Bay. Otherwise same as Fig. 42.

Food habit

Food compositions of the stomachs of *L. japonicus* larvae and juveniles collected in three estuaries and Miike beach are shown in Fig. 51.   Their food changed with growth.   Calanoid copepods were the most important prey item for all stages and cyclopoid copepods were ranked second and both increased in numerical percentage with growth in the 4 locations in Ariake Bay.   The latter copepods tended to be more abundant in the food compositions in fishes from Rokkaku estuary than those from the other sites.   Harpacticoid copepods were found in larvae and juveniles from Yabe estuary, but only in over 20 mm BL juveniles from Rokkaku estuary and absent from those in the other sites.   The food prey items were more diverse in the Rokkaku specimens than in the other sites.   The feeding incidences and the number of feeding events per individual increased with development in all the sites, except for a 21.7 mm BL juvenile from Miike beach.

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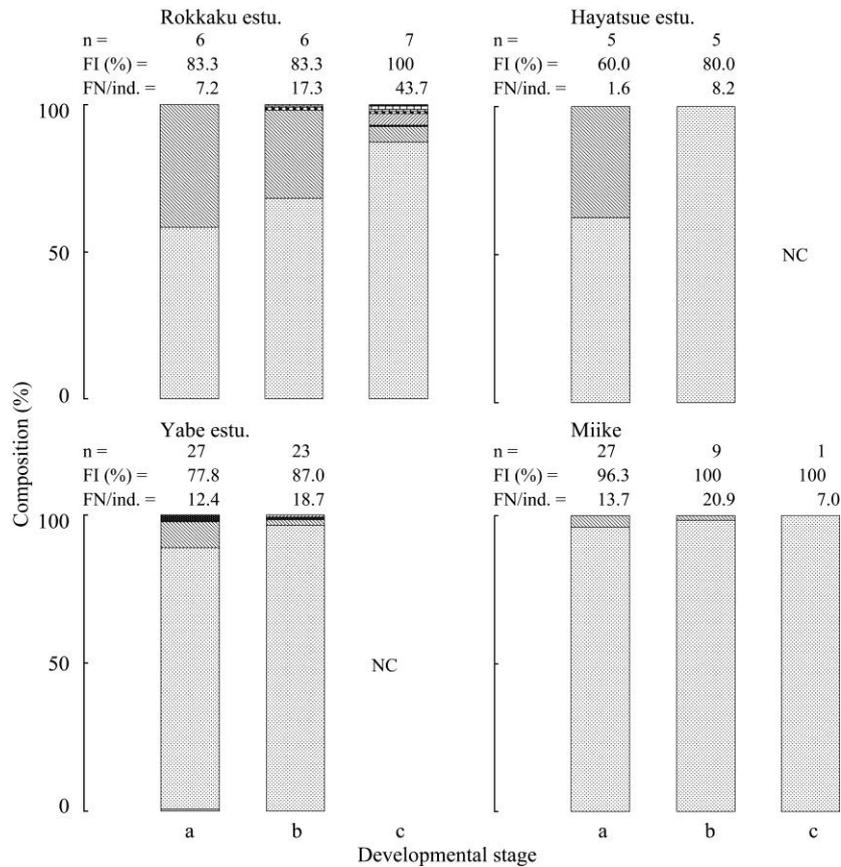
Fig. 51. Comparisons of the change in stomach contents with developmental stage of *Lateolabrax japonicus* among the neighboring habitats in Ariake Bay. *NC* not collected. Otherwise same as Fig. 41.

5.1.3. *Lateolabrax japonicus* in the Shimanto estuary

Morphology

General morphology. Larvae and juveniles (9.3–28.2 mm) are laterally compressed with moderate head and eyes. The pre-anal, head, upper jaw and snout length, body depth, eye diameter and caudal peduncle length are ca. 60–69, 28–39, 14–18, 7–11, 17–27, 8–12 and 19–24% BL, respectively. The ratios of the six former parts to body length gradually increase, while that of the latter decreases with growth of smaller than ca. 19 mm BL specimens, after that these ratios tended to be constant as size increase.

Head spination. The numbers of head spines are shown in Table 6. Spines appeared initially on the supraocular, preopercle, interopercle and posttemporal regions. Spines occur initially in ca. 10 mm BL on opercle and 11 mm on supracleithrum, lachrymal and subopercle.

Meristic characters.   The frequency distribution of meristic character counts in the larvae and juveniles from Shimanto estuary is shown in Table 7.   The counts of vertebrae and dorsal and anal pterygiophores range from 35 to 37, 24–27 and 8–10, respectively.

Development of the skeleton.   The osteological development of *Lateolabrax japonicus* larvae and juveniles (9.3–28.5 mm BL) collected in the bank waters of the Shimanto estuary is presented in Figs. 52 and 53.   The cartilaginous formation of vertebral column was completed from the smallest larvae, while ossification was still in the process of development before the fishes reached ca. 14 mm BL in size.   The cartilaginous formation and ossification of fin-supports were completed by ca. 14 and 19 mm BL, respectively, except for the ossification of distal radials.
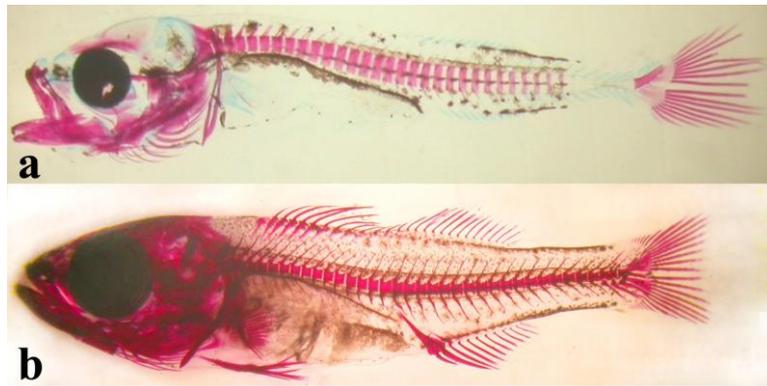
Fig. 52.   Development of the skeleton in *Lateolabrax japonicus* collected from the Shimanto estuary.   **a** 9.3 mm BL larva; **b** 18.6 mm juvenile.
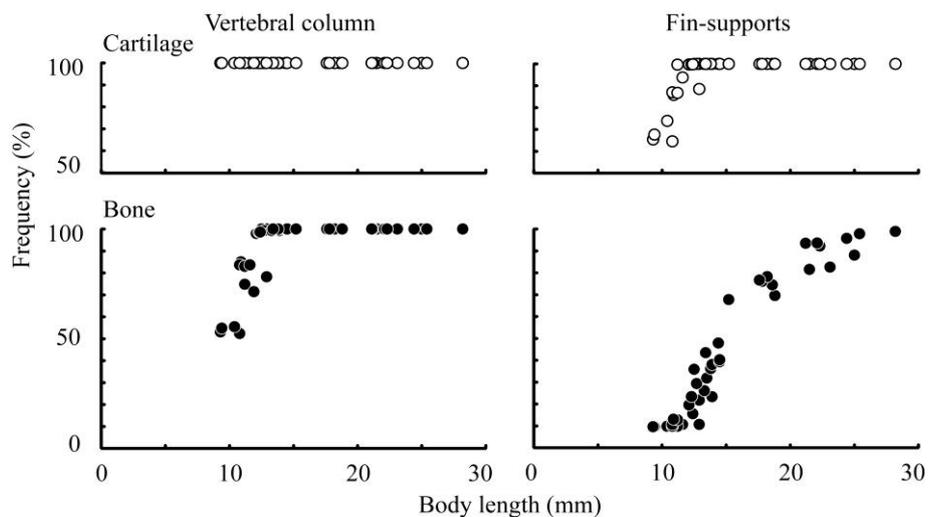
Fig. 53.   Relationship between counts of osteological changes (cumulative percentage) and body length in *Lateolabrax japonicus* collected in the Shimanto estuary.

Distribution

A total of 95 *L. japonicus* were collected from January to March of 4 years (26 in 2015, 10 in 2016, 5 in 2017 and 54 in 2018). They were composed of postflexion larvae and juveniles (mostly postflexion), ranging from 5.2 to 28.5 mm BL (Fig. 54).
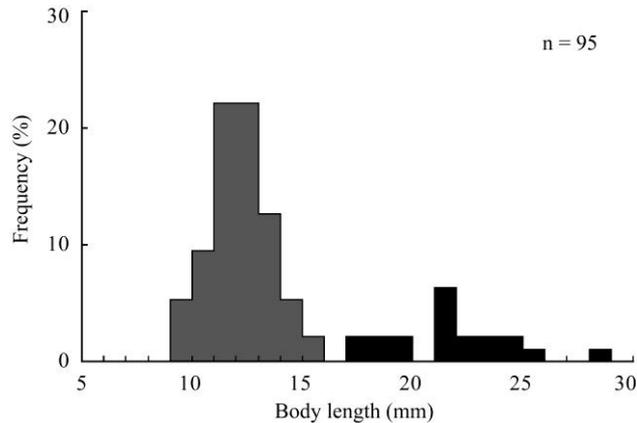

Fig. 54. Size frequency distributions of *Lateolabrax japonicus* collected in the bank waters of the Shimanto estuary from January 2015 to March 2018. Otherwise same as Fig. 18.

Seasonally, the CPUE and fish size gradually increased from January to March (Figs. 55, 56). Horizontally, the fishes were more abundant in the inner (Stns. B6', B8 and B12') than outer parts of the estuary (Fig. 55). No seaperches were collected in the Stn. B1 (Fig. 55). The size ranges usually widen in Stn. B6' and relatively narrow in the other stations (Fig. 57). The temperatures and salinities of the waters where the specimens were collected ranged from 10.4 to 19.7°C, 3.2–30.2, respectively.
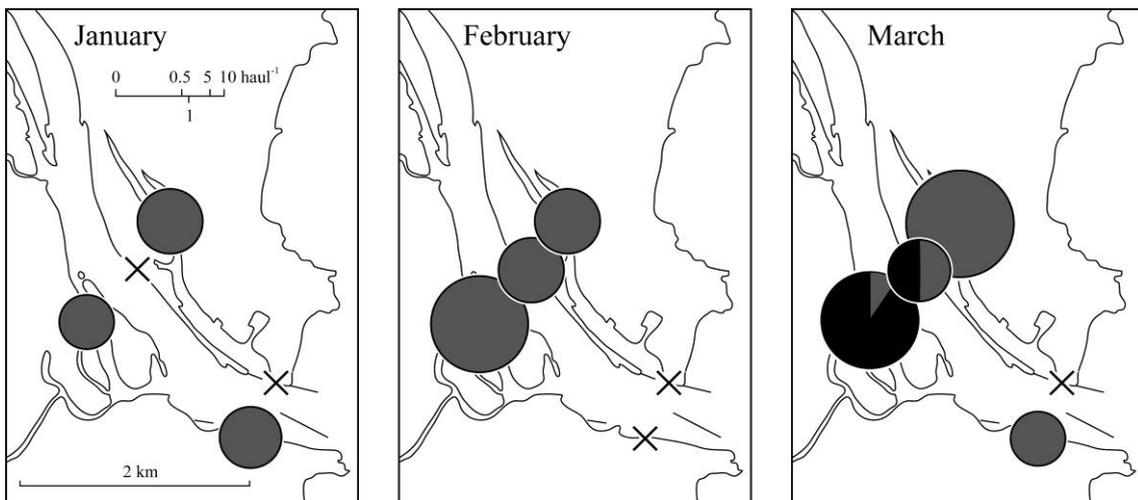
Fig. 55. Seasonal changes of horizontal distribution of *Lateolabrax japonicus* collected in the bank waters of the Shimanto estuary from October 2014 to March 2018. No seaperches were collected during the period of October to December. Otherwise same as Figs. 18 and 31.
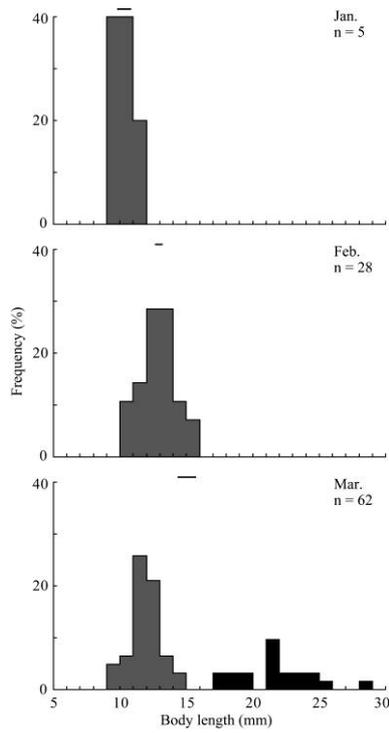
Fig. 56.　Seasonal changes in size frequency distribution of *Lateolabrax japonicus* collected in the bank waters of the Shimanto estuary from January 2015 to March 2018.　 Otherwise same as Figs. 18 and 32.
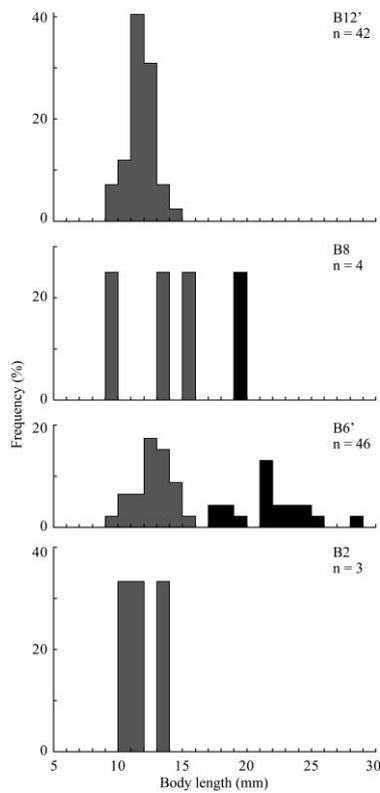

Fig. 57.　Spatial changes in size frequency distribution of *Lateolabrax japonicus* collected in the bank waters of the Shimanto estuary from January 2015 to March 2018.　 No seaperches were collected in Stn. B1.　 Otherwise same as Fig. 18.

Growth

The hatching dates of *L. japonicus* larvae and juveniles (9.3–28.2 mm BL, n = 43) collected from January to March of the four years (19 in 2015, 9 in 2016, 5 in 2017 and 10 in 2018) were estimated to extend from late December to middle February and peaked in January, except for a peak in December 2016 (Table 8; Fig. 58). The birthdates were, in general, concentrated to days around the new moon (Fig. 58).
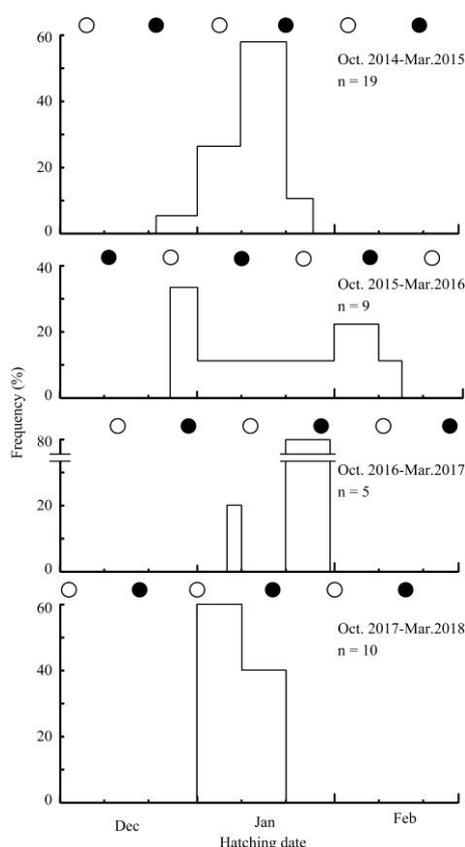

Fig. 58. Annual change in frequency distributions of the hatching date of *Lateolabrax japonicus* in the Shimanto estuary. *Solid* and *open dots* indicate the new and full moon, respectively.

The age-BL relationships of the given specimens are presented in Fig. 59. The linear regression formula of BL (y; mm) on estimated age (x; day) was expressed as y = 0.289x + 2.852 (r = 0.965).

The BL-otolith radius relationships of *Lateolabrax* larvae and juveniles ranging from 9.3 to 28.2 mm BL (n = 50, Table 8) are presented in Fig. 60. The linear regression formula of otolith radius (y; μm) on BL (x; mm) were expressed as y = 41.127x - 264.160 (r = 0.989) and y = 14.296x - 62.193 (r = 0.986) for sagittal radius-BL and lapillar radius-BL relationships, respectively.
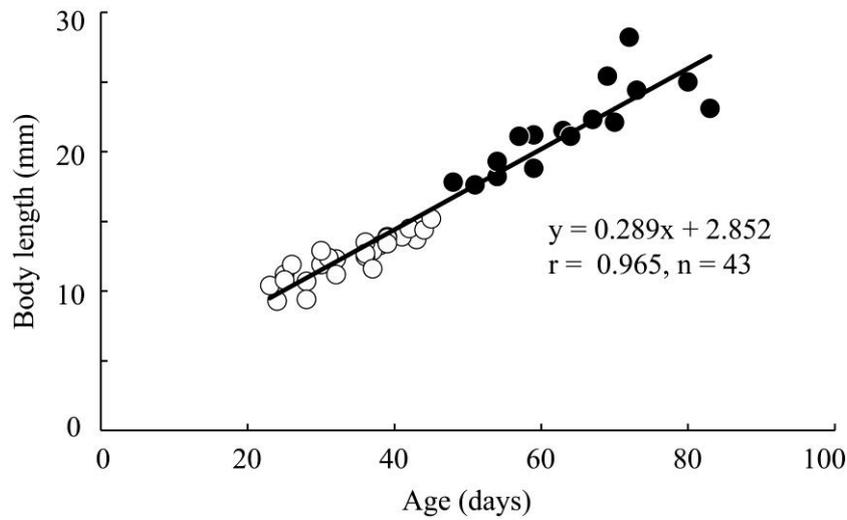
Fig. 59.   Relationship between age and body length of *Lateolabrax japonicus* collected in the bank waters of the Shimanto estuary.   *Open* and *solid dots* indicate larvae and juveniles, respectively.
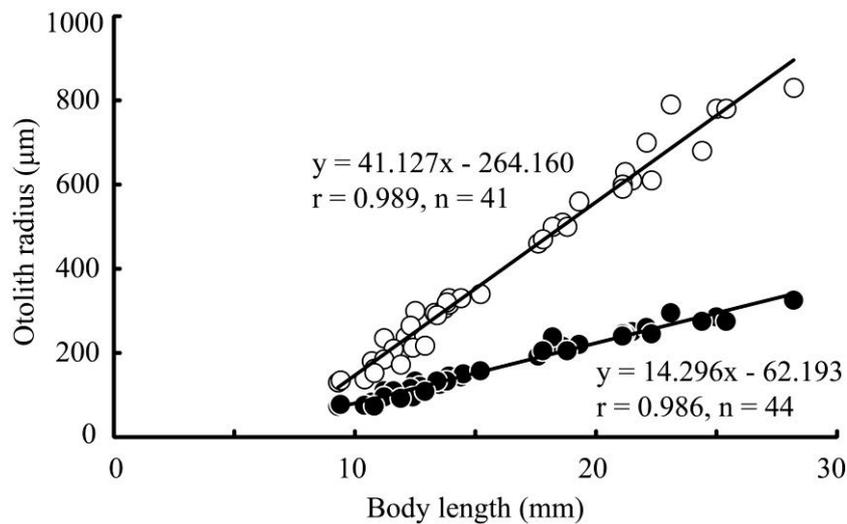

Fig. 60.   Relationship between body length and the otolith radius of sagitta (*open dots*) and lapillus (*solid dots*) of *Lateolabrax japonicus* collected in the bank waters of the Shimanto estuary.

Food habit

Food compositions of the stomachs of *L. japonicus* larvae and juveniles from the Shimanto estuary are shown in Fig. 61.   Their food changed with growth.   Larvae fed chiefly on harpacticoid and calanoid copopeds, and cladocerans, while juveniles fed largely on Calanoida.   Thus, harpacticoida and cladocerans decreased, and conversely, calanoida increased with growth in numerical percentage.   The feeding incidences were high (over 90% at all stages), and the number of feeding events per individual were higher in the fishes >20 mm BL than the smaller ones.

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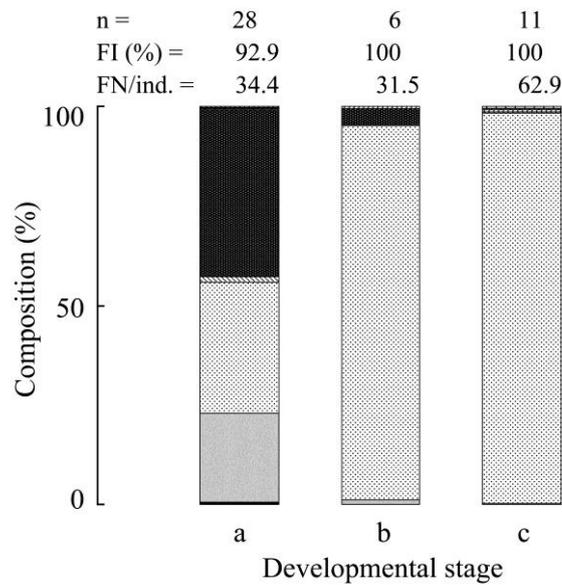
Fig. 61. Change in stomach contents with developmental stage of *Lateolabrax japonicus* collected in the bank waters of the Shimanto estuary. Otherwise same as Fig. 41.

5.2. Discussion

Occurrence of two types of larvae of the Asian seaperch (Lateolabrax) in the estuaries in northern Vietnam

The three species of *Lateolabrax* of the family Lateolabracidae (Yokogawa and Seki, 1995; Nelson et al., 2016) are recorded along the coast in western Pacific. Of them, *Lateolabrax japonicus* and the Chinese form of *Lateolabrax* sp. are much closely related species; however, the genetic morphological and ontogenetic studies suggest that they are two distinct species (Yokogawa and Seki, 1995; Nakayama et al., 1996; Sashida and Kinoshita, 2014). It is known that the former species is found along coasts from Kyushu to Hokkaido in Japan; the latter is distributed along coasts from the Yellow to South China Seas (Katayama, 1984; Yamada et al., 2007), of which the northern Vietnamese coasts is probably the most southern distribution locality for this genus (Nguyen, 1991; Nguyen and Nguyen, 2005). Vietnamese *Lateolabrax* was identified as *L. japonicus* by Nguyen (1991) and Nguyen and Nguyen (2005), though continental succession would suggest the population should be more closely related to the Chinese form. However, Vietnamese and Japanese *Lateolabrax* are possibly same species, because there is a case of little differentiation of larval morphology in *Plecoglossus altivelis* between Vietnam and Japan (Tran et al., 2012). Distinguishing larvae of species of *Lateolabrax* relies on the pigmentation pattern (Wu et al., 1984;

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Kinoshita and Fujita, 1988; Wan and Chen, 1988; Kinoshita et al., 1995; Nakayama et al., 1996; Tran, 2013; Sashida and Kinoshita, 2014).   Ontogenetic studies of the larvae of Chinese *Lateolabrax* have been conducted by Wu et al. (1984), Wan and Chen (1988), Nakayama et al. (1996) and Sashida and Kinoshita (2014).   The first two studies were problematic because of their insufficient drawings, the third was described the larvae and juveniles based on reared specimens, and the last identified wild larvae of *Lateolabrax*, as the Chinese species likely originating from aquaculture cages in southern Japan.   A distinctive character common among the above all four works identify a broken line melanophore row as an important feature for the Japanese *Lateolabrax* (*L. japonicus* and *L. latus*) (Mito, 1957, 1963, 1966; Kinoshita and Fujita, 1988; Kinoshita et al., 1995; Nakayama et al., 1996), but is not present in the Chinese *Lateolabrax*.   Our specimens never formed melanophores along the lateral middle into a broken line, and thus resemble the Chinese larvae from this point of view. Furthermore, the mean numbers of vertebrae and dorsal and anal pterygiophores of the Vietnamese *Lateolabrax* tend to be closer to those of the Chinese *Lateolabrax* than *L. japonicus* (Kinoshita et al., 1995; Yokogawa and Seki, 1995; Nakayama et al., 1996; Zhao et al., 2005; this study) suggesting the Vietnamese *Lateolabrax* is a population of the Asian continental *Lateolabrax*.

The interpretation of meristic and morphometric differences is often clouded by the impossibility to distinguish between genotypic and phenotypic variation.   The Japanese *L. japonicus* larvae tend to be more sparsely pigmented from turbid estuaries (>2000 NTU) of Ariake Bay than from common estuaries of other sites (Kinoshita and Fujita, 1988; Kinoshita et al., 1995).   There is only a distance of ca. 60 km between the Tien Yen and Kalong estuaries, but differences in morphometric and meristic characters were statistically apparent between the larvae from the two estuaries.   Physical parameters of the two Vietnamese estuaries were not much difference suggesting that differences in larval pigmentation between the two estuaries are due to their genotypic variation and that *Lateolabrax* of these Vietnamese estuaries do not interbreed due to isolating mechanisms, i.e. each stock could to spawn in each estuary.   In Japan and China, usually *Lateolabrax* spawn in the sea (Watanabe, 1965; Jiang et al., 1988; Horiki, 1993; Ohmi, 2002; Hibino et al., 2007), however in the Shimanto estuary of southern Japan eggs of *Lateolabrax* were collected with a larva net in the brackish water of the

estuary (Fujita, 2005).   If *Lateolabrax* spawns in the estuaries or rivers of Vietnam, this important genus of fish may have a higher genetic diversity in the east Asia than currently thought.   Molecular study examining the two types of larvae from these nearby estuaries should be conducted to clarify this question.

The potential biodiversity of Suzuki, as evidenced by differences in its ontogeny among the neighboring rivers in Ariake Bay

When the larvae and juveniles were compared among the neighboring nurseries, in Ariake Bay, their biodiversity was revealed.   First, the difference in proportional morphology appeared between the fishes from Rokkaku estuary and from the other sites. Second, according to the osteological study, differences in the process of osteological changes appeared among the fishes in the neighboring habitats.   Between the fishes in the center of the current of Yabe estuary and a surf zone of Miike beach, the vertebral column and fin-supports tended to develop faster in the latter than the former.   Such difference is probably due to the settlement of larvae into the banks of the surf zone, while they keep to be buoyed themselves, use a stream of estuary for the nurseries. When the fishes were compared among the 3 estuaries, the vertebral column and fin-supports tended to develop faster in Rokkaku and Hayatsue than in Yabe specimens. Sfakianakis et al. (2004) reviewed that morphological ontogeny and function are closely related and that all fish species in order to overcome all those environmental changes threatening their lives has developed similar patterns of ontogeny and as ontogeny proceed, the formation of the fins make fish able to faster and more complication (Matsuoka, 1987; Balart, 1995).   Accordingly, differentiation in the process of osteological development in fishes among the estuaries seemed to be related to their adaptation to the current speed in each river, which is extremely higher in Rokkaku and Hayatsue than Yabe river estuaries.   The similar difference is also observed in *Coilia nasus* between Rokkaku river estuary and the Isahaya retention basin in Ariake Bay (Simunjuntak, 2015).   The little difference in osteological process between Rokkaku and Miike specimens shows the balance of relationships between the osteological development of fishes and the adaption to the current speed, and the settlement.

Third, the differentiation in the growth of larvae and juveniles appeared between Rokkaku estuary and the other habitats.   There seem to be three possibilities to explain this: (1) the growth may be different partly in each developmental stage, which means

that the Rokkaku than the other site specimens the growth rates were lower in the larval stage, but higher in juveniles; (2) *L. japonicus* in Ariake Bay may be divided at least into two cohorts by spawning dates.   Of them, in one cohort which was spawn earlier, the growth rates were higher in the fishes recruited into the Rokkaku estuary than those in the other nurseries, and an opposite tendency in growth occurs in the late cohort; (3) differences in growth may be due to the food habit differentiation, e.g., the number of cyclopoid copepods in the stomach contents is much proportionally higher in the fishes from Rokkaku estuary than those from the other habitats.

The larvae and juveniles of *L. japonicus* commonly use surf zones and estuaries as their nursery grounds around Japan (Fujita et al., 1988; Kinoshita et al., 1995). Nevertheless, only Ariake Bay yields the larvae and juveniles, keeping to be buoyed themselves, use a stream of estuary for the nurseries (Yagi et al., 2011).   Previously they had been spawned near the mouth of the bay, subsequently transported toward inner parts by anticlockwise current, being hatched (Hibino et al., 2007), and the larvae seem to recruit passively and randomly to various neighboring river estuaries and the surf zone outside estuary as their nurseries.   There are much environmental differentiations among these habitats, where various salinities, turbidities and/or tidal velocities were topographically observed (Fig. 7).   According to the above comparison, recruits into the most symbolized estuarine rivers flowing into Ariake Bay, showed significantly more difference in proportional morphology, growth and osteological development.   This differentiation can demonstrate indeed a plasticity to make any cohort stocks survive to sustain the unique Ariake population.

Comparison of early life history of the Asian seaperches in the estuaries between Vietnam and Japan

Morphology.   When the morphology of larvae and juveniles was compared among the Vietnamese, Ariake and Shimanto *Lateolabrax* (Fig. 62), some differences were found: (1) the differences in morphometric and meristic characters were statistically apparent between *Lateolabrax* sp. in Vietnam and *L. japonicus* in both Ariake and Shimanto populations. This phenomenon is likely a reflection of species-specific differences. (2) The Ariake specimens showed a range between the Vietnamese and Shimanto specimens in some of meristic counts and body proportions.
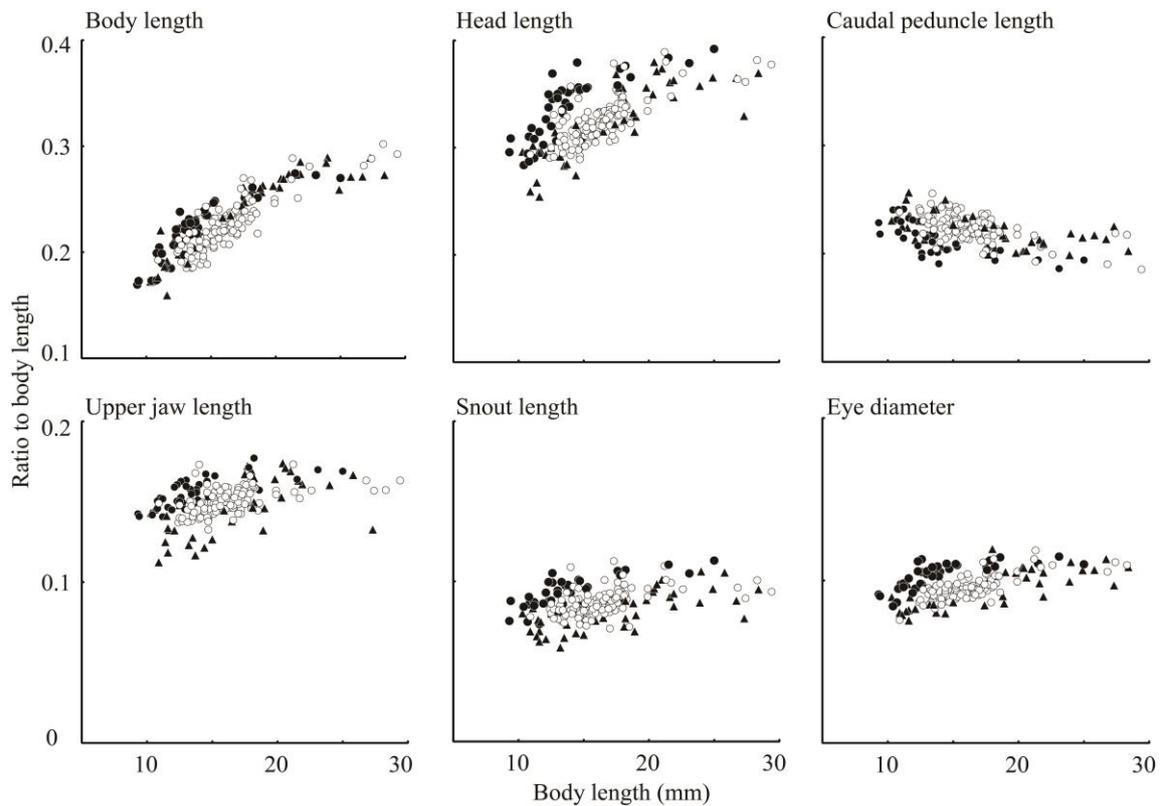
Fig. 62.   Comparisons of the proportional measurements of *Lateolabrax* larvae and juveniles among the Vietnamese (*solid triangles*), Ariake Bay (*open dots*) and Shimanto (*solid dots*) populations.

The interpretation of meristic and morphometric differences is often clouded by the impossibility to distinguish between genotypic and phenotypic variation.   The water environmental conditions of the Vietnamese and Shimanto estuaries are quite similar, being much different from those of Ariake Bay.   The results suggest that the observed pattern in morphology of Ariake Bay population is due to genotypic variation and that supports the hypotheses of previous studies that the Ariake Bay *L. japonicus* population is either a relict population from the Asian continent or has speciated independently, adapting to an environment similar to that of the Asian continent coast (Kinoshita et al., 1995) or *L. japonicus* on Ariake Bay is the endemic population of hybrid origin between *Lateolabrax* sp. and *L. japonicus* (Nakayama, 2002).

Growth and food habits.   According to the linear approximations of body length to age, the significant differences in the growth of larvae and juveniles appeared among the three sites, i.e., the fish growth was the fastest in Kalong estuary of Vietnam, followed by Shimanto estuary and Ariake Bay.   Higher temperature leads to higher growth rates of early stage of seaperch under natural condition (Shoji and Tanaka, 2007).

Accordingly, the significant colder waters of Ariake Bay could be the reason that growth rate of specimens from this bay was the lowest; however, it seems that water temperature differences are not possible to explain the differences in growth of fishes between Kalong and Shimanto estuaries because the water temperatures were not so higher in the former than the latter, even lower in some cases (Tran et al., 2014), during the periods of occurrences of *Lateolabrax* larvae and juveniles. These seem to be two possibilities to explain this: (1) that this differentiation in growth may be due to the species-specific differentiation. To clarify this hypothesis, the comparison of fish growth between the two species should be examined under the same condition in the laboratory. (2) The specific potentiality may be a reason for this growth difference. Although the variations in food habit were observed among the three populations, the differences of food composition fluctuated irrespective of location and developmental stages and do not match with the tendency in the growth differences.

Hatching dates of *Lateolabrax* were concentrated to days around the new moon in both Vietnam and Japan. Kinoshita et al. (1999) observed the similar phenomenon in *Cottus kazika*, suggesting a hypothesis that the embryos hatch selectively on the moonless nights to avoid predation or survival rates are the highest in embryos hatched on moonless night due to easy avoidance of predators (Kinoshita et al., 1999).

Distribution. The distribution of larvae and juveniles of *Lateolabrax* species could show characteristic phenomena by different oceanography. In *Lateolabrax* sp., the early larvae from preflexion with yolk to postflexion could be found in the center of the current, extending to the middle reach of Kalong estuary. Furthermore, larvae were dispersed from lower to upper reaches of estuary, but absent in the surf zone outside the estuary. This evidence suggests that *Lateolabrax* larvae seem to settle into the banks of the estuary but not in the surf zone. An opposite distributional tendency was presented in the *Lateolabrax* from the Tien Yen estuary. Both larvae and juveniles did not occur in the center of the current of the estuary, but were abundant in around the mouth of the estuary and adjacent surf zones. Furthermore, some preflexion with yolk were collected outside the mouth of the estuary (Stns. TL1–TL4). It seems that the larvae settled around the mouth of estuary and/or the surf zone outside the estuary, after that they extended their distribution along the bank waters. The differentiation in distribution of early stages, especially preflexion with yolk larvae supports the above

hypothesis that *Lateolabrax* in the Vietnamese estuaries do not interbreeding, and partly affect the difference in morphology between the fishes in the two regions.

Fujita et al. (1988) reported on the distribution of larvae and juveniles of two *Lateolabrax* species in the Shimanto estuary, suggesting that *L. japonicus* prefers the lower salinity due to the interspecific coaction between the two closely related species as the same seasonal occurrence. This conclusion is confirmed in the present study, that the fishes are the most abundant in the upper stations, being lower salinities. This phenomenon shows the characteristic difference of *L. japonicus* in the Shimanto estuary from those in the other sites.

Although the *Lateolabrax* shows the characteristic phenomena by different locations, the size and developmental stage compositions are common to both Vietnam and Japan, which are composed of larval to juvenile stages, suggesting that the estuaries provide worldwide a nursery ground for the transformation stage for seaperch. Therefore, distribution of *Lateolabrax* larvae and juveniles could show characteristic but common phenomena by different oceanography.

In this chapter, despite distribution across different water environments, *Lateolabrax* fishes could lead their early life history from the cool temperate to tropical regions, and for adaptation to each local environment, they have remarkable variation in life history traits, indicating the potential biodiversity of this fish genus in the world.

Chapter 6.　Comparison of early juveniles of porgies (*Acanthopagrus*)

6.1.　Results

6.1.1.　Early juveniles of *Acanthopagrus* species in the estuary of northern Vietnam

Morphology

Identification of juveniles.　A total of 1,524 juveniles of three species belonging to *Acanthopagrus* were collected during period of the present study.　Of them, 1,348 *A. latus* (9.0–26.0 mm BL), 173 *A. schlegelii* (8.0–18.0 mm BL) and three *A. pacificus* (9.0–9.8 mm BL) were identifiable according to Syojima (1958) and Kinoshita and Oka (2014).　First, *A. pacificus* was distinguishable from other two species by the supracleithral and posttemporal spines, proportionally higher body depth, larger head and larger eye (Fig. 63a).　Since *A. pacificus* were rare in our samples what follows will be limited to results that describe *A. latus* and *A. schlegelii*.
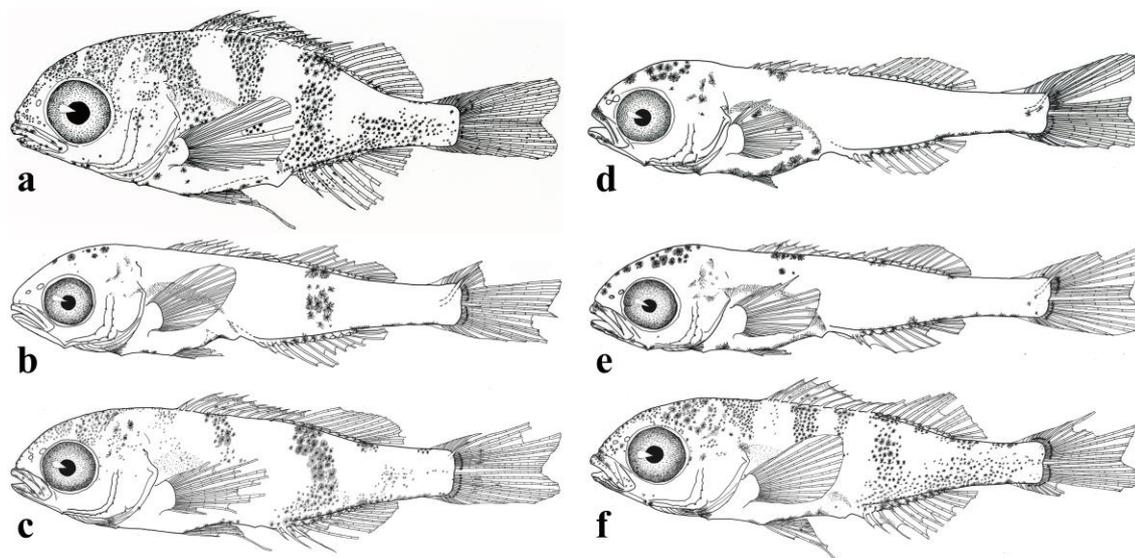
Fig. 63.　Early juveniles of *Acanthopagrus* collected in the Tien Yen estuary, northern Vietnam, from December 2014 to April 2015.　**a** *A. pacificus* 9.4 mm BL (UKU-371001); **b** *A. latus* 9.0 mm BL (UKU-371002); **c** ditto 12.5 mm BL (UKU-371003); **d** *A. schlegelii* 8.1 mm BL (UKU-371004); **e** ditto 9.2 mm BL (UKU-371005); **f** ditto 12.3 mm BL (UKU-371006).

Acanthopagrus latus (Fig. 63b, c) and *A. schlegelii* (Fig. 63d–f) could be distinguished by the assemblage of transverse bands assembling melanophores on the body and a stellate pigmentation on the lower jaw angle.　The band formed initially on the tail and trunk in the former and latter, respectively, developing during each juvenile

period.   A distinctive melanophore was observed on the lower jaw angle in *A. schlegelii*, but not in *A. latus*.   Furthermore, over 14 and 16 mm, number of scale rows differentiating between dorsal 5th-spine base and lateral line in *A. latus* and *A. schlegelii* differ, $3^1/_2$ and $5^1/_2$, respectively.   The latter count is unique within Vietnamese *Acanthopagrus* (Iwatsuki, 2013).

Spines were present on the inner and outer margins of the preopercle but absent on the supracleithral and posttemporal regions in both the species.   One or two spines are visible on the posterior margin of the interopercle near its junction with the subopercle in juveniles smaller than 14 mm BL of both the species.   There are little differences in proportions of most of the body parts (see materials and methods section) to standard length between the two species, however, the dorsal and anal spines tended to be significantly longer in *A. latus* than in *A. schlegelii* (Fig. 64).
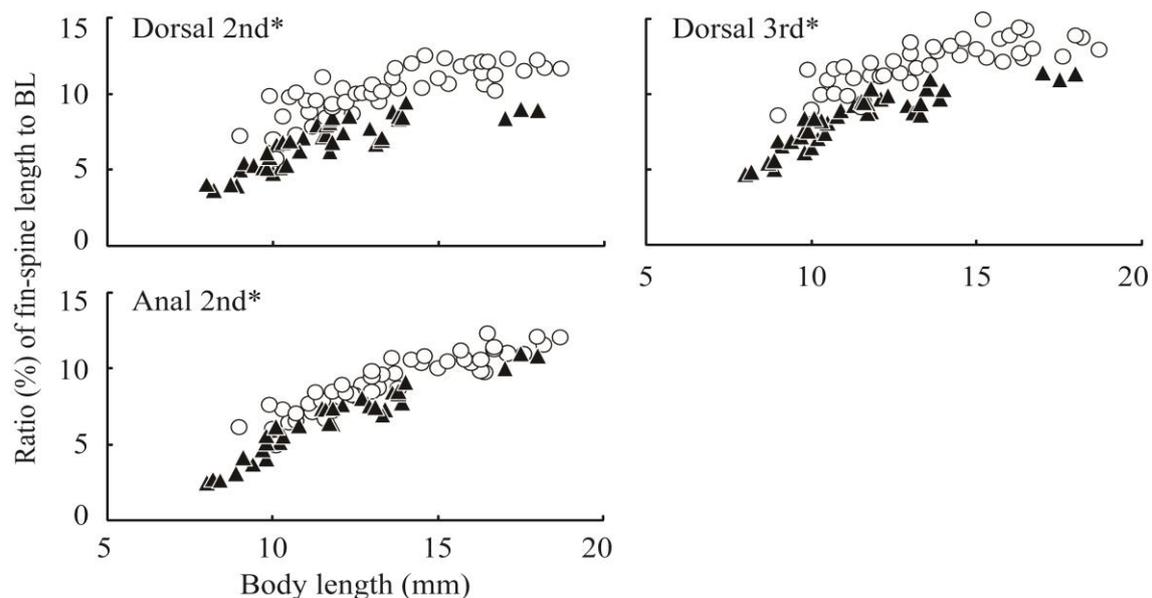
Fig. 64.   Comparisons of the proportional measurements of fin-spines, shown as percentages of body length, between *Acanthopagrus latus* (*open dots*, *n* = 50) and *A. schlegelii* (*solid triangles*, *n* = 50) juveniles.   *Significant difference p<0.001 between the two species.

Development of the skeleton.   The cumulative percentages of the counts of the progressed changes against body length for the vertebral column and fin-supports in early juveniles of the *Acanthopagrus* (*A. latus*: 9.9–18.0 mm BL, n = 50, Fig. 65a, b; *A. schlegelii*: 8.2–18.0 mm, n = 44, Fig. 65c, d) are shown in Fig. 66.   From the smallest specimens (Fig. 65a, b), the cartilaginous formation of the vertebral column and fin-supports was completed, but the ossification was still in the process of development

in both the species (Fig. 66).   The ossification of osteological structures of the vertebral column were accomplished before the juveniles reached ca. 10 and 14 mm in *A. schlegelii* and *A. latus*, respectively, while that of the fin-supports, except for distal radials, was completed before ca. 13 mm in the former species and 15 mm approximately in the latter (Figs. 65, 66).   Therefore, based on the ossification, the osteological development proceeded at smaller size in *A. schlegelii* than *A. latus*.
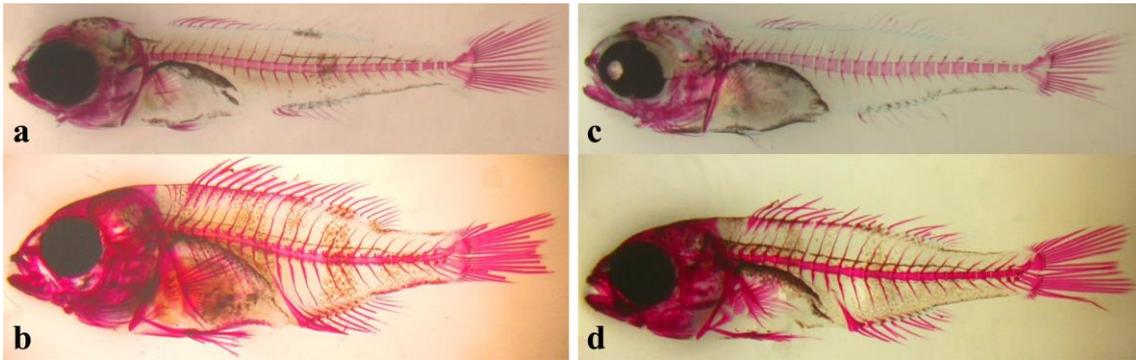

Fig. 65.   Development of the skeleton in *Acanthopagrus* juveniles collected in the Tien Yen estuary, from December 2014 to April 2015.   **a** *A. latus* 9.9 mm BL; **b** ditto 14.6 mm; **c** *A. schlegelii* 8.2 mm; **d** ditto 13.1 mm.
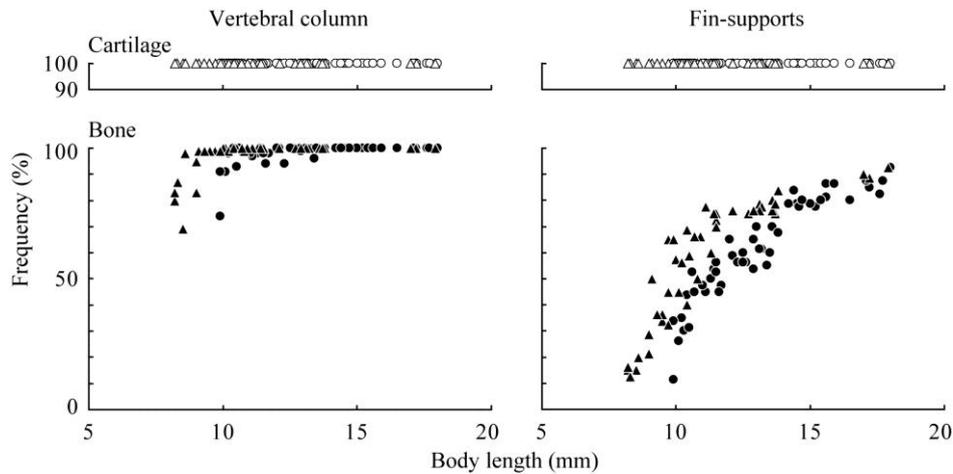
Fig. 66.   Comparison of relationship between counts of osteological changes (cumulative percentage) and body length between the two *Acanthopagrus* species in the Tien Yen estuary. *Dots* and *triangles* represent *A. latus* (n = 50) and *A. schlegelii* (n = 50), respectively.

Distribution

Seasonal distribution.   *Acanthopagrus latus* outnumbered and were larger in size than *A. schlegelii* (Figs. 67, 68).   *A. latus* and *A. schlegelii* occurred from early December to April and from late December to March, being most abundant in late December and late January (Fig. 68), when temperatures ranged from 16.0 to 24.7°C and

from 17.3 to 24.6°C, respectively.   The size compositions were seasonally little different, but only March yielded separated compositions with smaller and larger than December to February in both the species (Fig. 69).
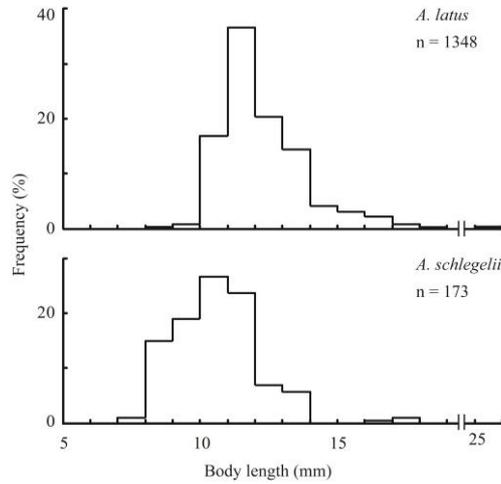

Fig. 67.   Comparison of the size-frequency distributions of early juvenile *Acanthopagrus latus* and *A. schlegelii* collected in the Tien Yen estuary.
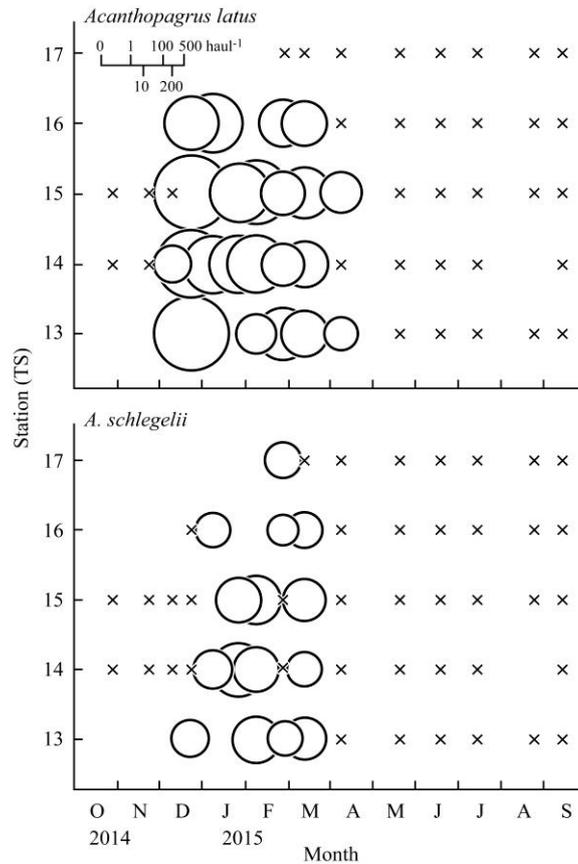

Fig. 68.   Seasonal and spatial distributions of *Acanthopagrus* early juveniles in the Tien Yen estuary. The diameter of each *circle* is drawn in proportion to the cube root of CPUE [n haul^{-1} (ca. 50 m distance)] of juveniles.   *Crosses* represent no *Acanthopagrus* juveniles.

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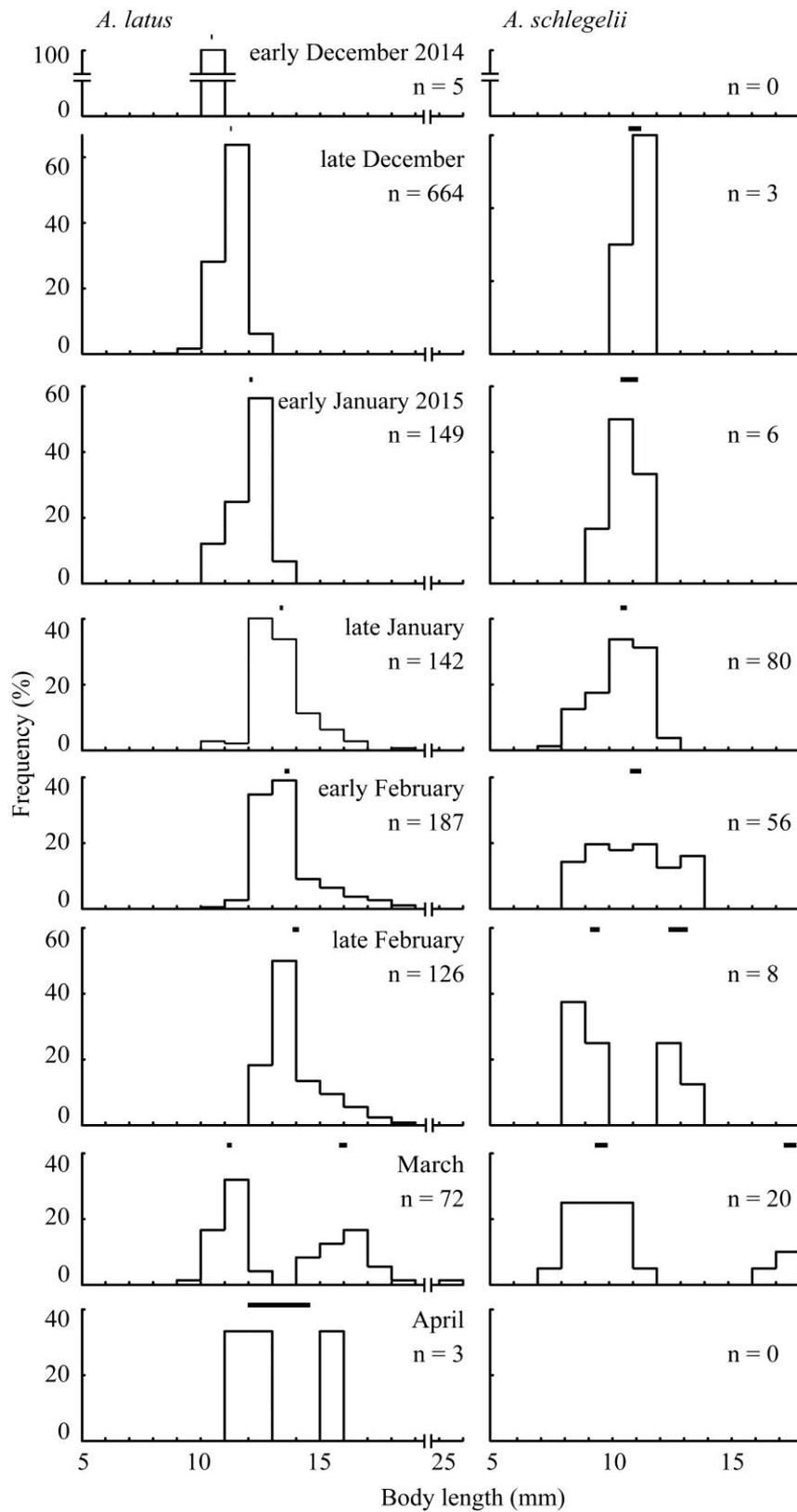
Fig. 69.   Seasonal changes of the size-frequency distributions of early juvenile *Acanthopagrus latus* and *A. schlegelii* in the bank waters of the Tien Yen estuary.   *Thick lines* on *bars* denote mean values (±SE) of body length.

Spatial distribution. Both the species were dispersed from Stn. TS13 to Stn. TS16 where salinities ranged from 2.3 to 19.5, and little was present at Stn. TS17 being salinities of 0.8 to 4.3 (Fig. 68). Horizontally, there were little differentiations in size compositions from lower to upper reaches in the two *Acanthopagrus* (Fig. 70).
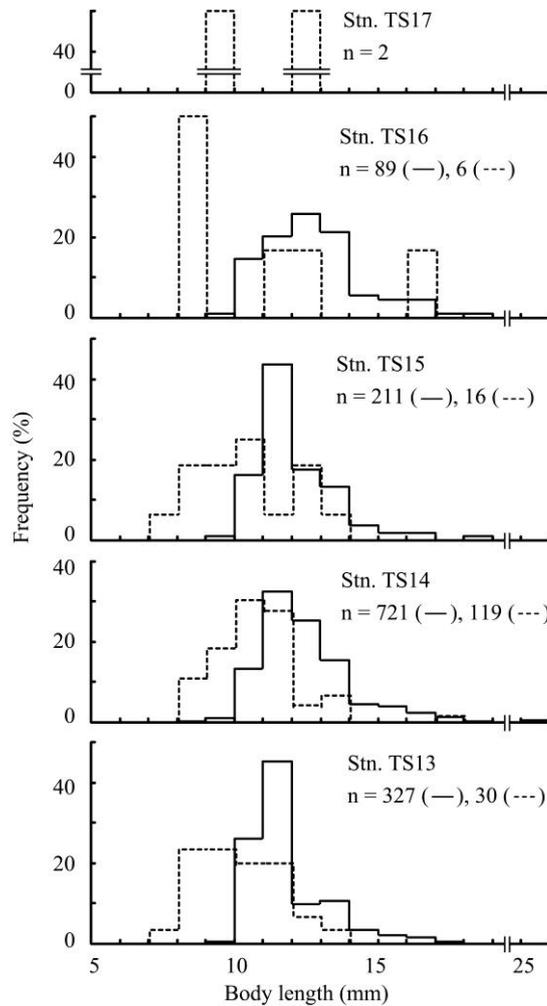
Fig. 70. Spatial comparison of the size-frequency distributions of early juvenile *Acanthopagrus latus* (*solid bars*) and *A. schlegelii* (*dashed bars*) in Tien Yen estuary.

Growth

Sagittae and lapilli were removed from juveniles of *A. latus* (9.9–17.7 mm) and *A. schlegelii* (8.2–18.0 mm) collected from December 2014 to March 2015 (Table 9). Hatching dates ranged from 8 November to 22 February and 20 November to 7 February (Table 9), and peaked during the period of 21–30 November and 1–10 January in *A. latus* and *A. schlegelii*, respectively, being concentrated to the days around the spring tide (Fig. 71).
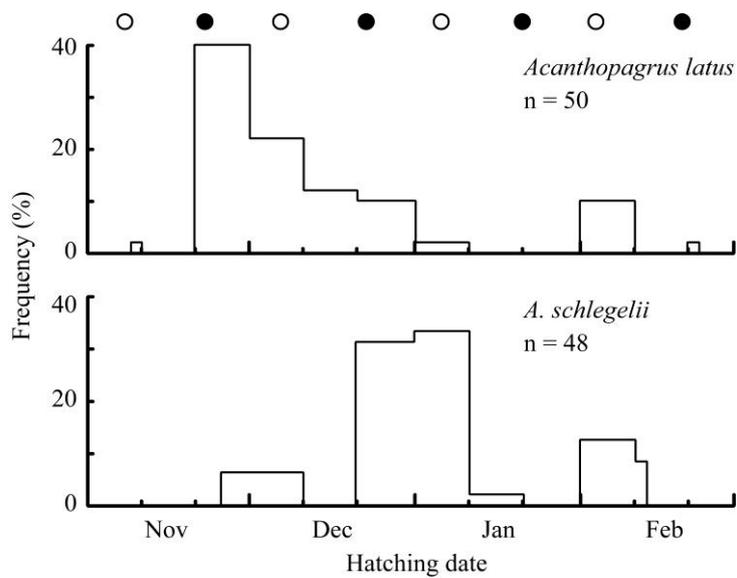
Fig. 71. Hatching date frequency distributions for the two *Acanthopagrus* species collected in the Tien Yen estuary from December 2014 to April 2015. *Solid* and *open dots* indicate the new and full moon, respectively.

The age-BL relationships of the two *Acanthopagrus* species are presented in Fig. 72. The linear regression formulae of BL (y, mm) on age (x; day) were expressed as y = 0.165x + 5.557 (r = 0.942) and y = 0.227x + 2.717 (r = 0.841) for *A. latus* and *A. schlegelii*, respectively. In the less than ca. 40 day juveniles, *A. latus* tended to be larger than *A. schlegelii*. There were similarity in the body size of juveniles from ca. 40 to 50 days between the two species.
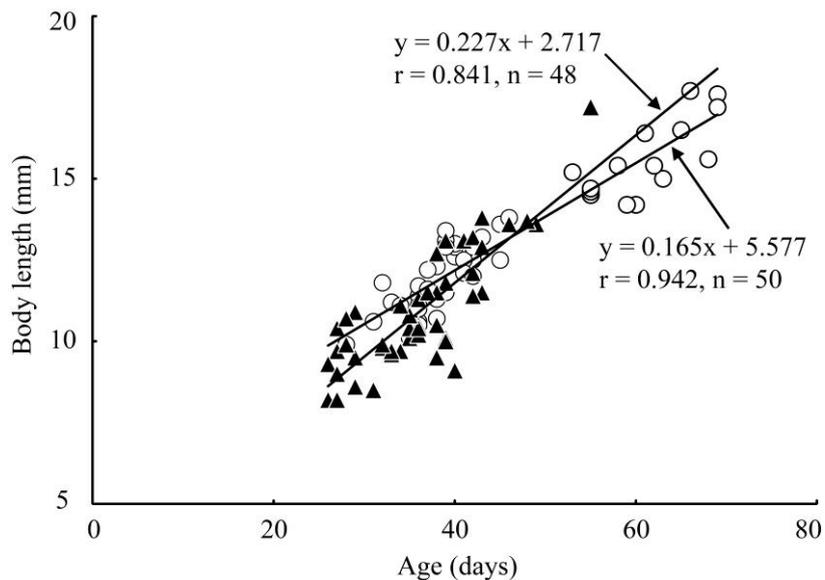
Fig. 72. Comparison of relationships between age and body length between the two *Acanthopagrus* species in Tien Yen estuary. *Dots* and *triangles* represent *A. latus* and *A. schlegelii*, respectively.

The BL-otolith radius relationships of the two *Acanthopagrus* species are presented in Fig. 73. Linear regression formulae of otolith radius (y; μm) on BL (x; mm) were expressed as y = 49.774x - 309.720 (r = 0.971) and y = 40.982x - 193.910 (r = 0.944) for sagittal radius-BL relationships and y = 23.876x - 117.550 (r = 0.956) and y = 19.811x - 69.796 (r = 0.957) for lapillar radius-BL relationships in *A. latus* and *A. schlegelii*, respectively. These linear approximates indicate that there were not much difference in otolith radius between the two species.
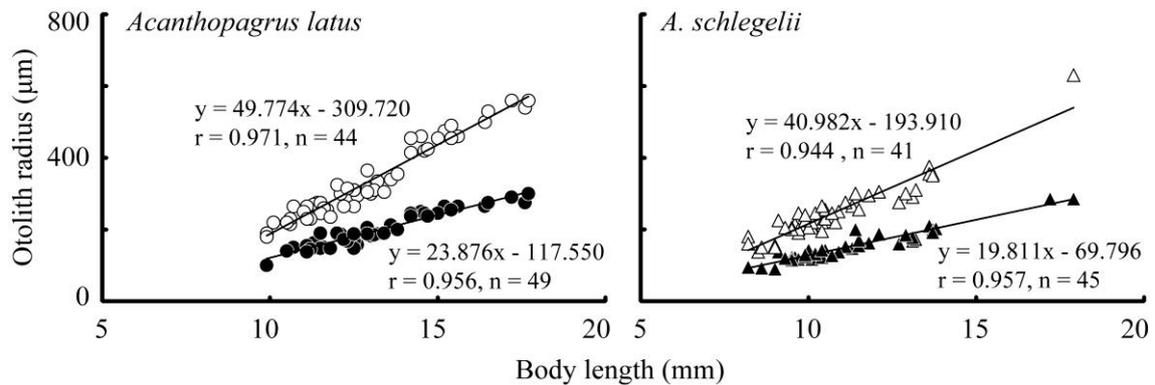
Fig. 73. Comparison of relationships between body length and otolith radius of sagitta (*open symbols*) and lapillus (*solid symbols*) between two *Acanthopagrus* species in Tien Yen estuary.

Food habit

The prey compositions of the stomachs in juveniles of the two *Acanthopagrus* species were shown in Fig. 74. There was not much difference in food compositions between the two species.

Acanthopagrus latus: there were almost similar in food composition among different sizes. The juveniles fed mainly in cyclopoid, followed by harpacticoid and calanoid copepods. There was a tendency that the larger fishes consumed a variety of prey items. The feeding incidence was 100% at all sizes. Although the number feeding events per individual fluctuated irrespective of size, this value was significantly higher in the over 12 mm BL specimens.

Acanthopagrus schlegelii: food habit changed with growth of juveniles. Initially, cyclopoid was the most important prey for fishes, followed by calanoid and harpacticoid copepods; however, as size increased, the number percentage of the former decreased whereas that of the two latter increased, consequently, the larger than 16 mm

juveniles fed chiefly on harpacticoid, followed by cyclopoid copepods.   The feeding incidence was 100% at all sizes, and the number feeding events per individual increased with the growth.
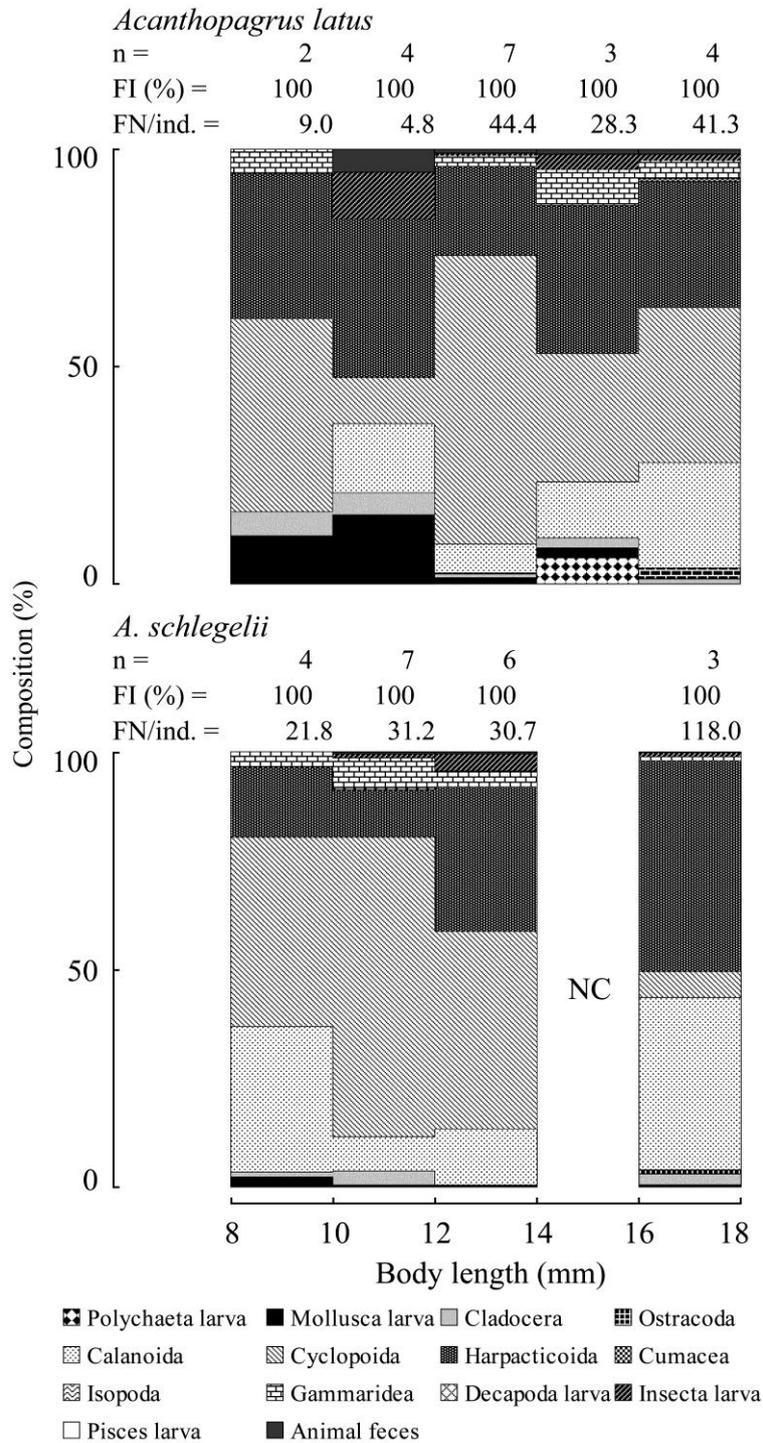

Fig. 74.   Comparison of the change in stomach contents with growth of early juveniles between the two *Acanthopagrus* species in the Tien Yen estuary.

6.1.2. Early juveniles of *Acanthopagrus latus* in the Shimanto estuary

Morphology

Development of the skeleton. The cumulative percentages of the counts of the progressed changes against body length for the vertebral column and fin-supports in early juveniles (8.8–13.5 mm, n = 22, Fig. 75) of the *A. latus* are shown in Fig. 76. In the vertebral column, the cartilaginous formation and ossification were completed from the smallest juveniles (Fig. 75a), except for a 9.6 mm BL specimen (Fig. 76). In the fin-supports, the cartilaginous formation was completed from the smallest specimens, while ossification, except for distal radials, was still in the process of development by 11 mm approximately (Figs. 75, 76).
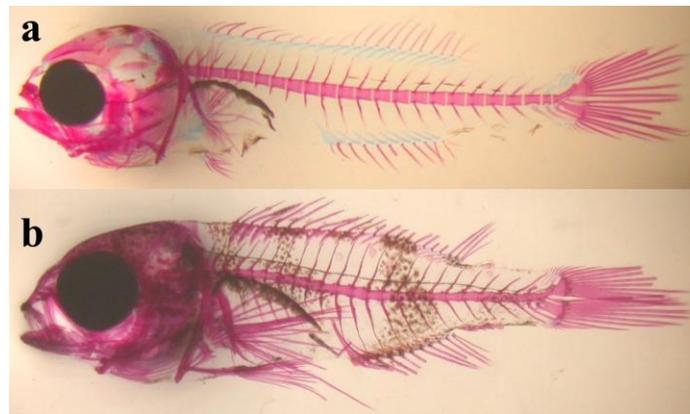
Fig. 75. Development of the skeleton in *Acanthopagrus latus* juveniles collected in the Shimanto estuary. **a** 8.8 mm; **b** 11.4 mm BL.
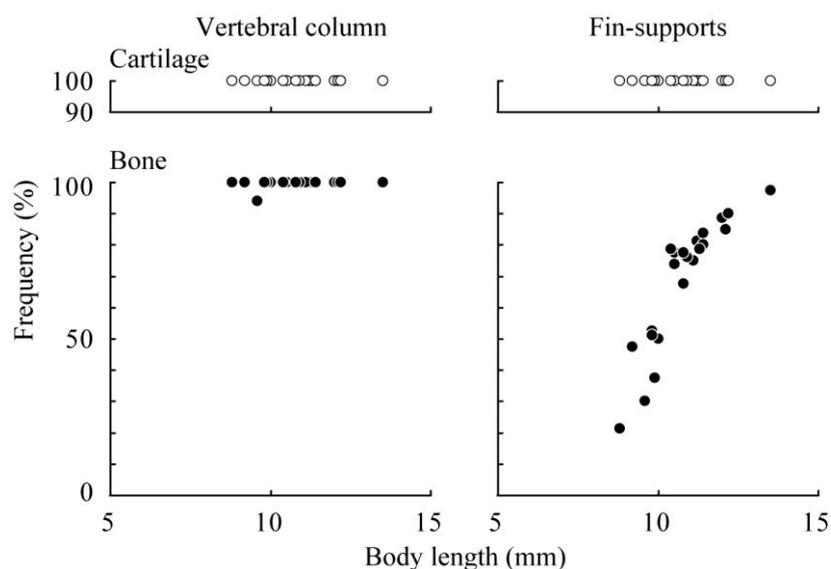

Fig. 76. Relationship between counts of osteological changes (cumulative percentage) and body length in early juveniles of *Acanthopagrus latus* in the Shimanto estuary.

Distribution

Seasonal distribution. *Acanthopagrus latus* early juveniles were occurred during the periods of October to December from 2014 to 2018, and a juvenile was collected in February (Fig. 77), when the temperatures ranged from 8.2 to 25.8°C. The size compositions were annually little differentiation with a mode at 9.1–10.0 mm (Fig. 78), and the larger than 12 mm BL juveniles were occasionally occurred. The mean size increased from November to February, but little differentiation was seen between October and November (Fig. 79).

Spatial distribution. The juveniles dispersed from Stn. B1 to Stn. B12' (Fig. 80), where salinities ranged from 0.6 to 31.3. Horizontally, there was little differentiation in size compositions from lower to upper reaches (Fig. 80).
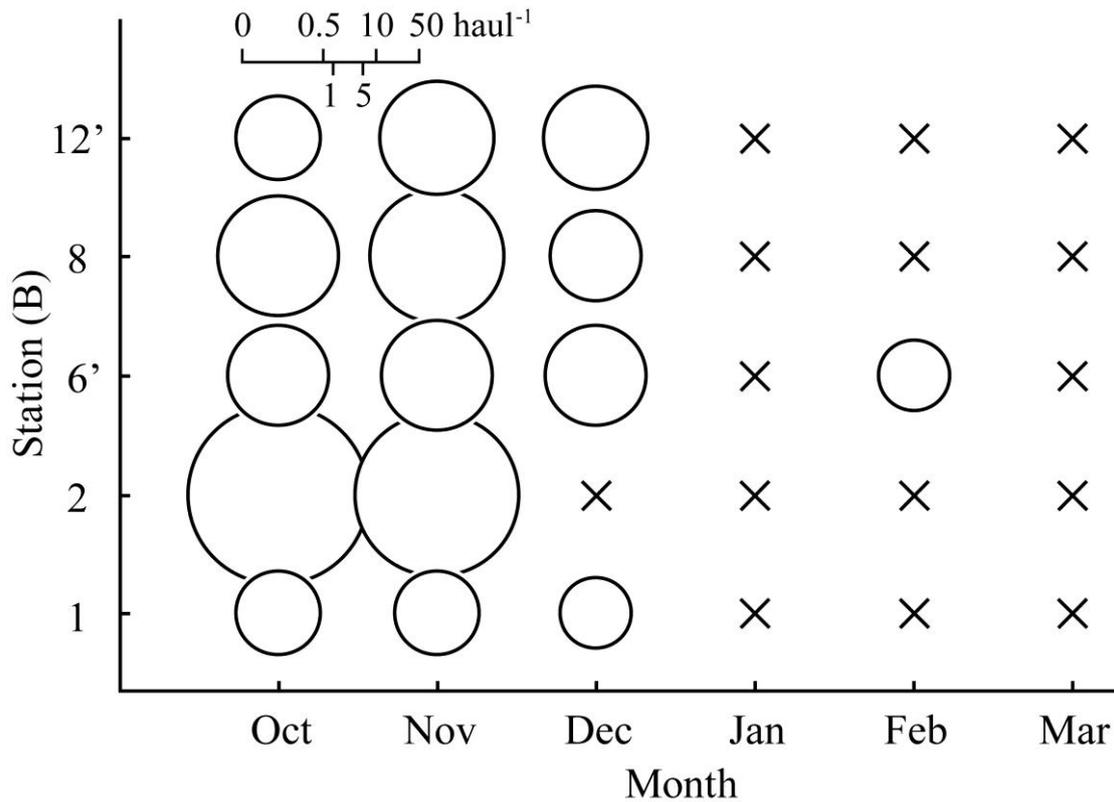

Fig. 77. Seasonal and spatial distributions of early juvenile *Acanthopagrus latus* in the Shimanto estuary from October 2014 to March 2018. Otherwise same as Fig. 68.
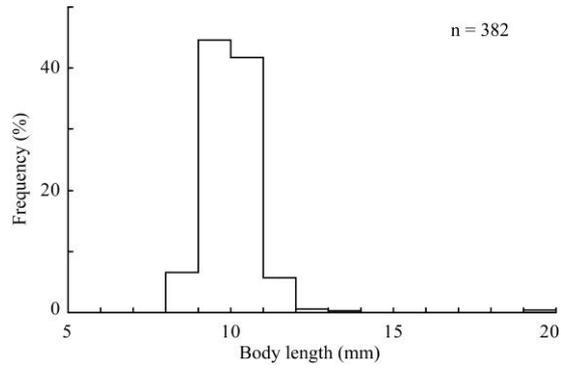
Fig. 78. Size-frequency distributions of early juvenile *Acanthopagrus latus* collected in Shimanto estuary from October 2014 to March 2018.
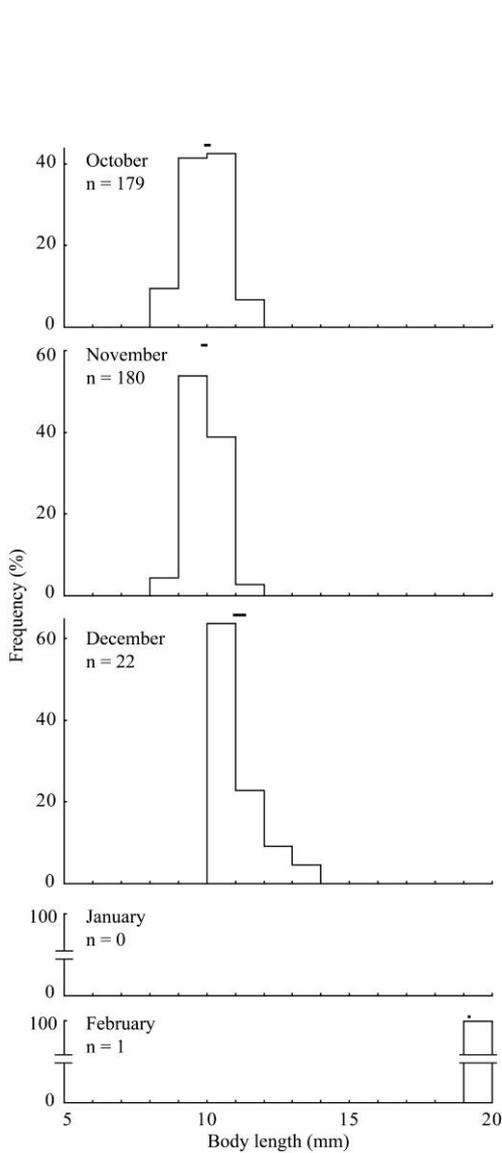

Fig. 79. Seasonal changes of size-frequency distributions of early juvenile *Acanthopagrus latus* in the bank waters of the Shimanto estuary during the period of October 2014 to March 2018. Otherwise same as Fig. 69.
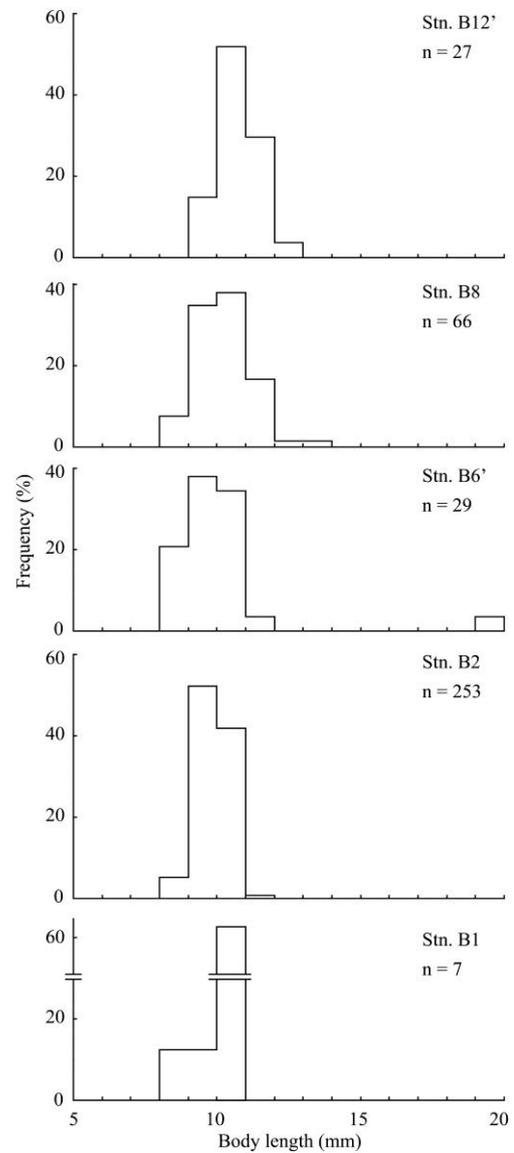

Fig. 80. Spatial changes of size-frequency distributions of early juvenile *Acanthopagrus latus* in the Shimanto estuary during the period of October 2014 to March 2018.

Growth

The hatching dates of *A. latus* juveniles (8.5–11.4 mm, n = 47) collected from October to December 2016 were estimated to extend from 5 October to 18 November and peaked during the period of 1st to 10th November (Table 9; Fig. 81).

The age-BL relationship of the juveniles ranging from 8.5 to 13.5 mm BL (n = 49) is presented in Fig. 82. Linear regression formula of BL (y, mm) on age (x; day) was expressed as y = 0.160x + 6.167 (r = 0.910).

The BL-otolith radius relationships of juveniles ranging from 8.5 to 13.5 mm BL presented in Fig. 83. Linear regression formulae of otolith radius (y; μm) on BL (x; mm) were expressed as y = 59.753x - 407.870 (r = 0.924) and y = 33.300x - 216.520 (r = 0.921) for sagittal radius-BL and lapillar radius-BL relationships, respectively.

Table 9. Examination records of the estimated age and hatching dates of early juveniles of *Acanthopagrus* species collected in the bank waters of Tien Yen (Ti) and Shimanto (Sh) estuaries

| Site	Species name	Collection date			No. fish	Body length (mm)		Age (day)		Estimated birthdate
						Range	Mean	Range	Mean	
Ti	*Acanthopagrus*	9	Dec.	2014	1		10.6		36	Nov. 8
	latus	5	Jan.	2015	22	9.9–13.6	11.7	33–50	43	Nov. 21–Dec. 8
		8	Feb.	2015	21	12.3–17.7	14.8	43–74	60	Dec. 1–Jan. 1
		10	Mar.	2015	5	9.9–12.2	11.2	33–42	38	Feb. 1–10
		8	Apr.	2015	1		12.5		50	Feb. 22
		Total			50	9.9–17.7	13.0	33–74	50	Nov. 8–Feb. 22
	A. schlegelii	22	Dec.	2014	1		10.4		32	Nov. 25
		5	Jan.	2015	5	9.8–11.8	10.5	37–44	40	Nov. 27–Jan. 4
		8	Feb.	2015	31	8.2–13.8	11.2	31–54	44	Dec. 21–Jan. 13
		10	Mar.	2015	13	8.2–18.0	11.0	31–60	36	Jan. 4–Feb. 12
		Total			50	8.2–18.0	11.1	31–60	41	Nov. 25–Feb. 12
Sh	*A. latus*	26	Oct.	2015	11	8.5– 9.9	9.2	18–21	20	Oct. 5–8
		27	Nov.	2015	31	8.8–12.0	10.3	21–36	26	Oct. 22–Nov. 6
		24	Dec.	2015	5	10.5–11.4	10.9	27–32	30	Nov. 22–27
		26	Dec.	2016	3	12.1–13.5	12.6	38–44	41	Nov. 12–18
		Total			50	8.5–13.5	10.3	18–44	26	Oct. 5–Nov. 27
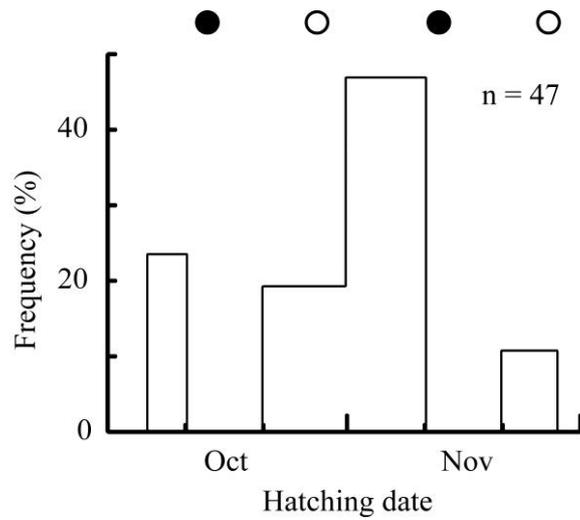
Fig. 81.   Hatching date frequency distributions for *Acanthopagrus latus* in the Shimanto estuary from October to December 2015.   Otherwise same as Fig. 71.
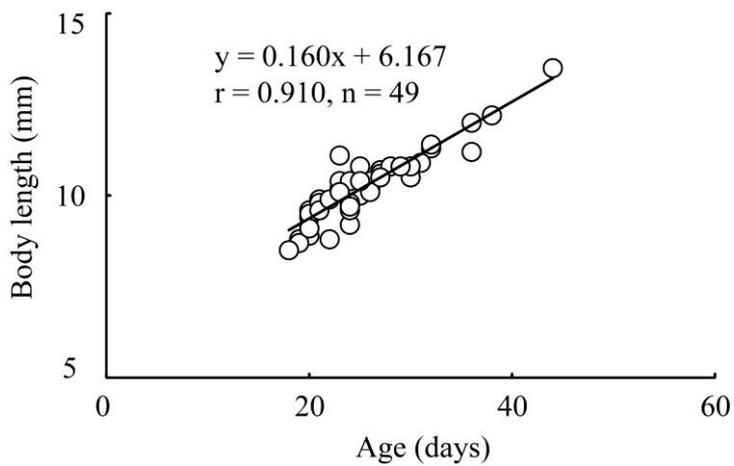

Fig. 82.   Relationship between age and body length of juvenile *Acanthopagrus latus* collected in the Shimanto estuary.
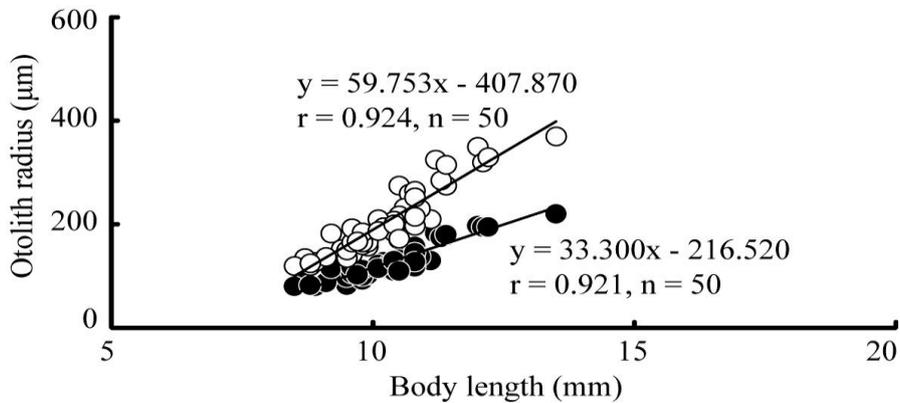

Fig. 83.   Relationship between body length and otolith radius of sagitta (*open dots*) and lapillus (*solid dots*) in *Acanthopagrus latus* juveniles collected in the Shimanto estuary.

Food habit

Stomach contents of juveniles ranging from 8.8 to 13.5 mm BL were examined (Fig. 84). Their food habit changed with the growth. Initially, the calanoid copepods was the most important prey for fishes, followed by cyclopoid and harpacticoid copepods; however, as size increase, the number percentage of the two former decreased whereas that of the last increased, consequently, the larger than 12 mm juveniles fed largely on harpacticoid copepods. The feeding incidence increased from 60 to 100% with the growth, and the number of feeding events per individual was the highest in 10.1–12.0 mm specimens.
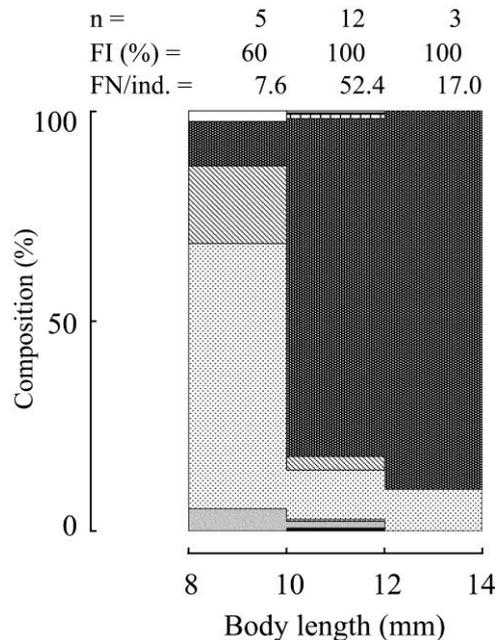

Fig. 84. Change in stomach contents with growth of *Acanthopagrus latus* juveniles collected in Shimanto estuary. Otherwise same as Fig. 74.

6.2. Discussion

Simultaneous and sympatric occurrence of early juveniles of Acanthopaprus latus and A. schlegelii in the estuary of northern Vietnam

Early juveniles *Acanthopagrus latus* and *A. schlegelii* can be distinguished based on the location of the initial band of pigmentation that transverses body and whether a marked pigmentation is present or not on the angle of lower jaw. In Japanese wild specimens, the latter pigmentation was drawn in the larvae of neither *A. latus* nor *A. schlegelii*, but was described in the juveniles of *A. schlegelii* (Syojima, 1958; Mito, 1966; Kinoshita, 1988). Kinoshita (1988) used this character to differentiate the two *Acanthopagrus* juveniles in Japan, but this character is not useful to classify early larvae which in Japan can be distinguished by the seasonal difference in their appearance in coastal waters. Also in Vietnamese *A. schlegelii*, the larvae probably bear no pigmentation on this position, so that dividing two *Acanthopagrus* larvae could be problematic as the two species share the same spawning season in northern Vietnam. Significant proportional differentiations of dorsal and anal spine lengths are probably useful to distinguish between the two species during late larval period.

Acanthopagrus latus and *A. schlegelii* occurred as the same developmental stage (early juvenile), in the bank waters of northern Vietnam. *A. latus* was significantly larger than *A. schlegelii* at a given stage of development as has been found for these two *Acanthopagrus* species from Japan (Senta and Kinoshita, 1985; Senta et al., 1988; Kinoshita, 1993; Fujita et al., 2002). Hence, their development than growth were more regular in the inhabitation such as bank waters, and tend to be more stimulated in higher temperatures (Seikai et al., 1986; Kinoshita, 1993). Nevertheless, the two species juveniles occurred during the same season in Vietnam, and although opposite occurring season, when it was almost same temperature ranging from ca. 16 to 25°C in Japan (Kinoshita, 1993; Fujita et al., 2002). Therefore, the differentiation between the two *Acanthopagrus* species seems to be attributed to specific potential distinction. This temperature range of ca. 16 to 25°C was observed once a year in northern Vietnam, against twice in estuaries or surf zones facing Tosa Bay of Japan (Kinoshita, 1993; Fujita et al., 2002). Thus, a thermoperiodicity is common to early juveniles of the two *Acanthopagrus*, which is demonstrated also in Japan, being latitudinally away ca. 15° north from Vietnam.

Speciation seems to be frequently caused by differentiation of an early life history (Cohen, 1984). Kinoshita (1993) speculated that speciation of *A. latus* and *A. schlegelii* from a common ancestor occurred due to development of a seasonal difference in spawning period. The cooccurrence of early juveniles of the two *Acanthopagrus* species in Vietnam demonstrates that a seasonal difference in spawning period is not necessary to prevent interbreeding and suggests speciation occurred or is maintained due to existence of distinct spawning grounds or behaviors.

Early juveniles of the two *Acanthopagrus* that colonized the shallows along the banks of the estuary extended to near freshwater habitat. There was little variation among stations in developmental stage and size for both the two species. This can suggest that their larvae settle dispersedly into banks, not migrating with growth, following a spring tidal current.

Although the vertical distribution of juveniles of the two *Acanthopagrus* species was not investigated in this study, benthic foods such as Gammaridae were found from the smallest juveniles of both the species suggesting that juveniles of the two

Acanthopagrus transform to demersal habit from the first size that settled into the bank waters of estuary.

Similarity and differentiation in early juveniles of Acanthopagrus latus between Vietnam and Japan

When the juveniles of *A. latus* were compared between Tien Yen and Shimanto estuaries, some morphological and ecological differentiations were found.   There are significant mean differentiations in body parts of the specimens larger than ca. 11 mm BL between the two areas (Fig. 85).   Furthermore, according to osteological (Figs. 66, 76) and otolith (Figs. 72, 82) studies, the growth and development were significantly faster in *A. latus* juveniles from Japan than those from Vietnam.   The interpretation of ontogenetic differences is often clouded by inability to distinguish between genotypic and phenotypic variation.   Kinoshita (1993) revealed that there were seasonal differences on development sequence of ossification, being due to seasonal differences in water temperatures in a black sparid, *Rhabdosargus sarba*.   Sfakianakis et al. (2004) suggested that as temperatures rises the ontogeny in respect to total length accelerates in a sparid fish, *Pagellus erythrinus*.   The relationship between morphology and water environmental difference was evident in early stage of other fishes, such as *Lateolabrax japonicus* (Kinoshita and Fujita, 1988; Kinoshita et al., 1995) and *Paralichthys olivaceus* (Seikai et al., 1986).   The water physical parameters when the juveniles were collected were not much different between Vietnam and Japan.   Iwatsuki (2013) indicated that there were the variations in morphology and genetic of *A. latus* in the Indo-West Pacific regions.   Therefore, these ontogenetic differences in early juveniles between Vietnam and Japan seem to reflect genetic, not phenotypic modification.

There was a tendency that the faster osteological development was associated with smaller body size ranges of *A. latus* juveniles in the bank waters in Japan than in Vietnam.   There was a similar phenomenon between two *Acanthopagrus* in Vietnam. These results imply the relationship between the developmental process of the skeletal tissues and characteristic habitat use by this fish genus in the life cycle.

The present study showed that early juveniles of *Acanthopagrus* are usual components of the estuarine ichthyofauna.   Furthermore, it is the same spatial distribution tendency of early stages of this genus for both tropical and temperate

regions that their larvae settle dispersedly into banks, not migrating with growth, following a spring tidal current.   It seems utilization of estuary in early stages of life history by this fish genus is a worldwide phenomenon.
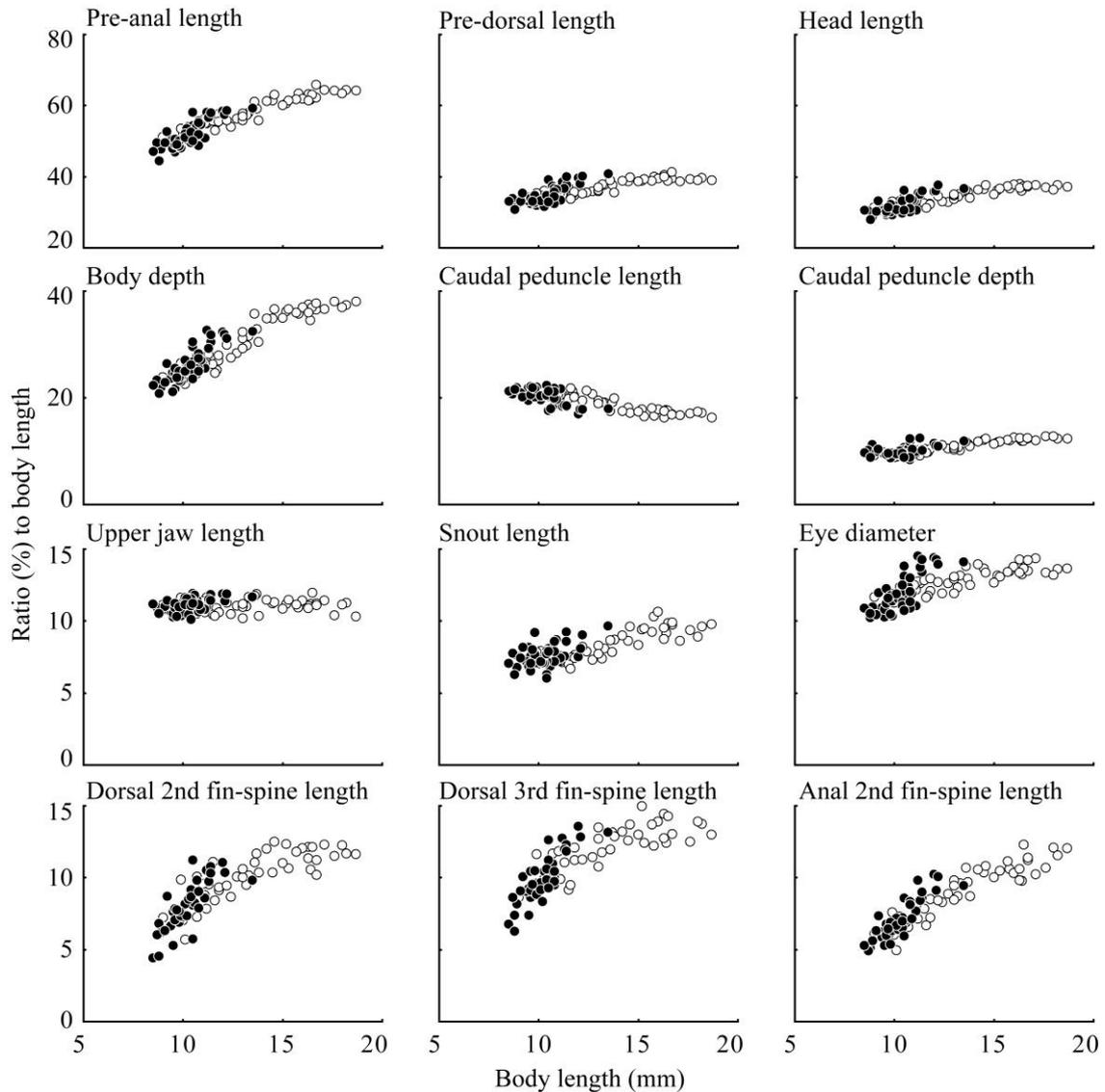

Fig. 85.   Comparison of the proportional measurements of *Acanthopagrus latus* juveniles between the Tien Yen (*open dots*) and Shimanto (*solid dots*) estuaries.

Like *Lateolabrax*, despite distribution across different water environments, *Acanthopagrus* fishes could lead their early life history from cool temperate to tropical regions, and for adaptation to each local environment, they have remarkable variation in life history traits, indicating the potential biodiversity of this genus in the world.

Chapter 7.   General discussion

Some geographical variations in ontogeny and pattern of estuarine use by early stages of euryhaline fishes were well documented in the present study.   Considering these findings, I herein further discuss the latitudinal variations of biotope functions of estuaries for early life history of the euryhaline fishes by different oceanography.

The water temperature is likely to be the most important factor controlling distribution of fishes among climatic zones.   Timing of larvae and juveniles of both *Lateolabrax* and *Acanthopagrus* species varies with latitude, but a thermoperiodicity is common to them, which is demonstrated also in Japan.   The distribution of a coastal fish may be limited by a lack of tolerance of one or more early life history stages to one or more water conditions (Sheaves, 2006).   Although northern Vietnam is located in the tropical zone latitudinally, the sea temperatures of the coast facing northern Gulf of Tonkin so cold.   Therefore, this area is suitable habitat not only for adult but also for the early stages of many species that are commonly distributed in temperate and subtropical waters, being the southernmost locality for those species distributions (chapter 4).   Hence, the coastal ichthyofauna of northern Vietnam seems to display transitional biodiversity from tropical to temperate waters.

This study indicates that the growth of larvae and juveniles of both seaperches and porgies varied with different latitudinal regions.   The two common factors were examined to understand these variations, i.e., the food habits and water temperatures.   Some obvious trends in the growth variations are common due to changing food habits; however, the relationship between food habits and the difference in growth among the different geographical populations of both *Lateolabrax* and *Acanthopagrus* species could not be significantly shown in this study.   It seems that the geographical diversity in food habits of euryhaline fishes implies the adaptation to each local environment rather than the feeding preference.   If food habits are not a limiting factor, then water temperatures are likely to be the most important factor controlling growth (e.g., Seikai et al., 1986; Kinoshita, 1993; Sfakianakis et al., 2004).   The relationship between water-environmental temperatures and fish growth could be evident in *L. japonicus* between Ariake Bay and Shimanto estuary (chapter 5); however, in the other cases of the present study this relationship could not be completely understood because of other

heterogeneous factors that may affect growth of early stages.   Therefore, to approach the problem, further laboratory experiments must be made among latitudinal samples.

The seaperches and porgies are well known to be typical euryhaline fishes; however, that term is commonly applied for young or adult stages.   These fishes usually spawn in the sea, but the stage when adaptation to wide-salinity waters begins in the ontogeny has never been mentioned.   The present study indicates that these euryhaline fishes recruited to the estuarine habitats in early stage, such as larvae, being a significant worldwide phenomenon.

In conclusion, this study reveals that euryhaline fishes, especially seaperches and porgies, could experience their early developmental stages from the cool temperate to tropical regions, and show characteristic but common phenomena by different oceanography, thus it should be biodiversity.

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