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Diet shift with settlement in the yellowfin goby *Acanthogobius flavimanus* on a tidal mudflat

Kouki KANOU[*,†], Mitsuhiko SANO [*], and Hiroshi KOHNO[**]

Abstract : To ascertain the diet shift from pelagic larval to benthic juvenile phases in the yellowfin goby, *Acanthogobius flavimanus*, the gut contents of 287 specimens (9.7-15.9 mm in standard length), collected on a tidal mudflat in the Tama River estuary, central Japan, were examined. Major food components changed rapidly from planktonic animals (e.g., polyphemoids, and calanoid and cyclopoid copepods) to benthic or epiphytic crustaceans (e.g., harpacticoid copepods), with a decrease in prey size, as juveniles settled to their benthic habitat. Settled juveniles had lower gut fullness index values than recorded for small pelagic larvae and juveniles.

Keywords : *Acanthogobius flavimanus, settlement, diet shift, tidal mudflat*

1. Introduction

The yellowfin goby, *Acanthogobius flavimanus*, is one of the most common fishes in Japanese estuarine and coastal waters and has enjoyed some popularity as a game fish (SHIMIZU, 1984). The early life history has been studied comprehensively (e.g., DOTSU and MITO, 1955; SUZUKI *et al.*, 1989; KANOU, 2003), the habitat shift being summarized as follows; spawning occurs mainly at a depth of 5-10 m in sheltered bay waters, newly-hatched and early pelagic larvae being distributed around the spawning ground (Tokyo Metropolitan Fisheries Experimental Station, 1985); late pelagic larvae and juveniles migrate to shallow water, such as estuarine tidal mudflats, subsequently settling to a demersal habitat (KANOU *et al.*, 2000, 2004a).

Although the feeding ecology of benthic juvenile yellowfin goby has been reported by many

authors (e.g., KIKUCHI and YAMASHITA, 1992; TAKIZAWA *et al.*, 1994; SAKAI *et al.*, 2000), that of the transitional phase from late pelagic larvae to newly-settled juveniles, which may play an important role in the survival of marine fishes under natural conditions (THORISSON, 1994; MINAMI, 1995), has not been studied well. The present study describes ontogenetic changes in the food habit of yellowfin goby during the transitional phase, on the basis of specimens collected on a tidal mudflat.

2. Materials and Methods

Sampling was conducted on a tidal mudflat in the Tama River estuary (35° 32′ N, 139° 46′ E), central Japan, on 12 April 2001. To collect larval and juvenile *Acanthogobius flavimanus*, a small seine net (1×1 mm square mesh, 10 m wide and 1 m deep) was towed at a depth of 1 m three hours after low tide in daytime, following the methods described in KANOU *et al.* (2004b). During the sampling period, the water was turbid, the salinity and temperature in surface water being 21.0‰ and 18.4°C, respectively. All samples were fixed in 5% formalin in the field and later preserved in 70% ethanol in the laboratory.

Based on morphological changes, the yellowfin goby postflexion larvae and juveniles

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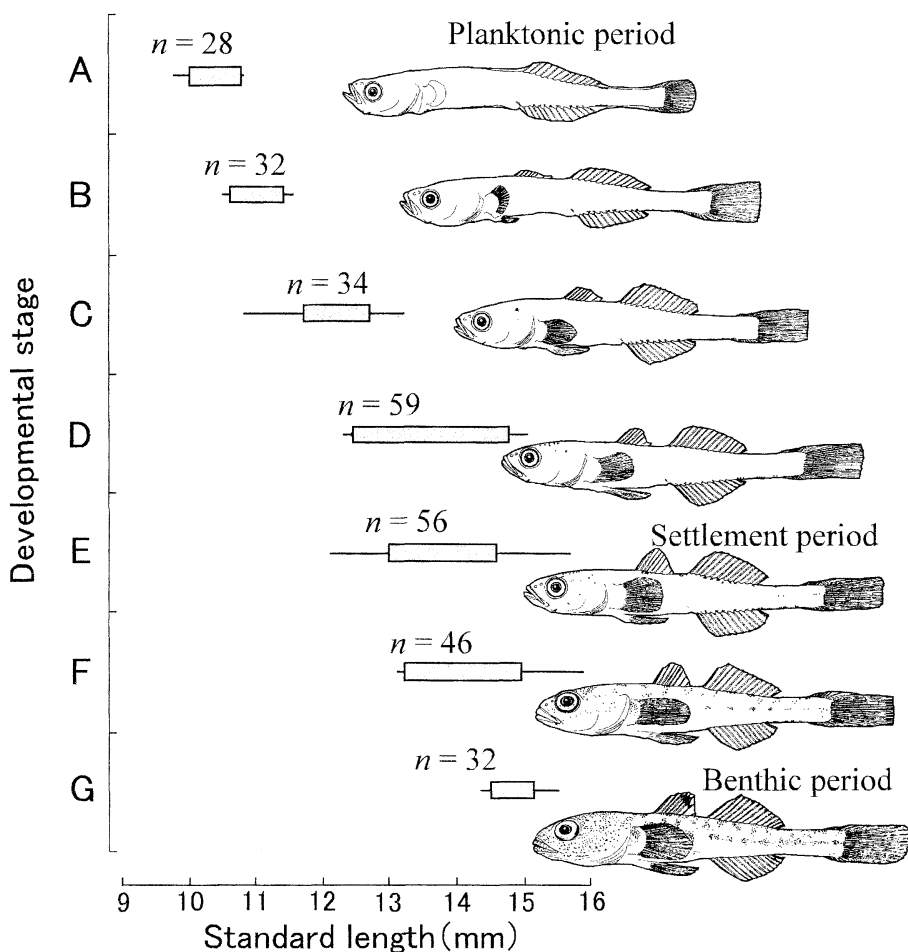† Present address: Japan Wildlife Research Center, 3-10-10 Shitaya, Taito-ku, Tokyo 110-8676, Japan

Fig. 1.   Number of specimens and standard length in each developmental stage (A–G) of *Acanthogobius flavimanus* examined in this study. Narrow and broad horizontal bars indicate range and standard deviation of standard length, respectively. A–D, planktonic period ; E and F, settlement period ; G, benthic period.

were divided into seven stages (A–G) (KANOU et al., 2004c). In addition, following observations of swimming behavior under rearing conditions, the life mode of each stage was categorized into planktonic (stages A–D), settlement (stages E and F) and benthic periods (stage G) (KANOU et al., 2004c). For gut content analyses, 287 specimens representing all seven stages [9.7–15.9 mm in standard length (SL)] were selected from the above samples, the number of specimens and body size of each stage examined being shown in Fig. 1.

Mouth width and SL of each specimen were measured to the nearest 0.01 mm with a micrometer attached to a binocular microscope, following YOUNG and DAVIS (1990). The entire alimentary canal (from mouth to anus) then was removed. The gut was straight at stage A, folding beginning in stages B and C. A deep "N" shape gut (adult condition) was evident by stage F (KANOU et al., 2004c). Because of the differences in gut shape, we examined the contents in the anterior part of the gut in specimens with a straight gut and up to the first bend of the gut in larger specimens. Food items in the gut contents of each fish were sorted in

major taxonomic categories. The number and body width of items in each gut were counted and measured, respectively. Carapace width in crustaceans and the deepest width against the longest axis in the other organisms were measured. The percentage volume of each food item in the diet was visually determined as follows: gut contents were squashed on a 1×1 mm grid slide to a uniform depth of 0.2 to 1.0 mm and the volume occupied by each item measured. The latter was then divided by the total volume of the gut contents to calculate the percentage volume of that item in the diet. Food resource use was expressed as mean percentage composition of each item by volume (%V), which was calculated by dividing the sum total of the individual volumetric percentage for the item by the number of specimens examined (SANO et al., 1984; HORINOUCHI and SANO, 2000). Specimens with empty guts were excluded from the analysis.

The gut fullness index (GFI) was used to measure the degree of feeding intensity of each fish as follows:

$$GFI = (GCV / SL^3) \times 1000$$

where GCV is the volume of the contents in the anterior part of the gut in specimens with a straight gut and up to the first bend of the gut in larger specimens. Specimens with empty guts were included in the comparison of mean GFI among the different developmental stages. In addition, the vacuity index (VI) was calculated as follows:

$$VI = (\text{number of specimens with empty guts} / \text{the total number of specimens}) \times 100.$$

Non-parametric Kruskal-Wallis analysis was employed to test if %V, GFI, mouth width of fish, and number and body width of prey differed among fish developmental stages. If the differences were significant ($P < 0.05$), they were compared between all possible pairs of developmental stages using Tukey's Q test.

3. Results

Of the 287 specimens examined, 224 individuals contained food items and 63 were empty (VI = 22.0). VI values for each developmental
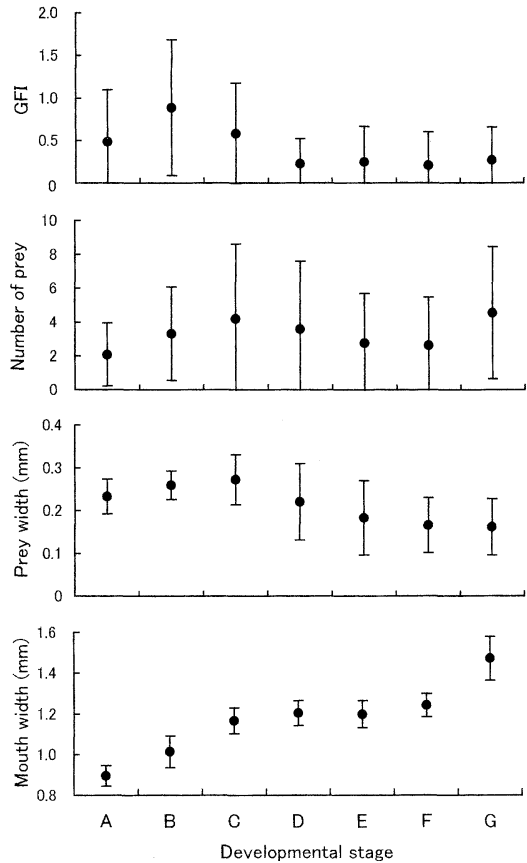

Fig. 2. Ontogenetic changes in mean gut fullness index (GFI), number and width of prey, and mouth width in *Acanthogobius flavimanus*. Bars indicate standard deviation.

stage were low, ranging from 12.5 to 26.1 (Table 1), with mean overall GFI being 0.41. The GFI values differed significantly among the developmental stages (Fig. 2, Kruskal-Wallis test, $H = 49.5$, $P < 0.001$), with higher values in stages B and C than in the subsequent stages (Tukey's Q test, $P < 0.05$).

The major food items overall were planktonic animals, including polyphemoids, and calanoid and cyclopoid copepods, and small benthic or epiphytic crustaceans, such as harpacticoid copepods, these categories accounting for 89.5% of the gut contents by volume. The %V of major food items (planktonic animals and small benthic or epiphytic crustaceans) differed significantly among the developmental stages

Table 1　Percentage volume of food items in the diet of each developmental stage of *Acanthogobius flavimanus*

Food item	Developmental stage							Total
	A	B	C	D	E	F	G	
Planktonic animals								
Calanoid and cyclopoid copepods	54.7	46.6	42.8	55.6	33.6	7.9	9.5	36.0
Polyphemoids	29.0	45.1	34.1	15.1	9.9	2.5	0	17.3
Barnacle larvae	13.6	2.8	8.9	5.7	4.8	0	0	4.8
Shrimp larvae	0	0	0	0	0.2	0	0	+
Crab zoeae	0	0	0	0	1.7	0	0	0.3
Small benthic or epiphytic crustaceans								
Harpacticoid copepods	0	3.4	5.7	11.6	38.2	51.0	43.4	23.9
Poechilostomid copepods	0	0	0	0.4	0.7	4.5	1.9	1.1
Podocopid ostracods	0	0	0.8	2.9	4.3	0	0.5	1.6
Gammaridean amphipods	0	0	7.6	3.4	0.9	5.6	0	2.7
Cumaceans	0	0	0	1.2	0	7.1	4.0	1.8
Polychaetes								
Errant polychaetes	0	0	0	3.6	2.9	10.5	21.7	5.6
Sedentary polychaetes	0	0	0	0	0	6.8	4.8	1.6
Molluscs								
Gastropods	0	0	0	0	0.4	0	0	0.1
Bivalves	0	0	0	0	0	0.4	0	0.1
Nematodes	0	0	0	0	0.2	0.4	1.7	0.3
Invertebrate eggs	2.7	2.1	0	0	0	0	0	0.5
Detritus	0	0	0	0.4	2.0	3.4	12.7	2.6
Number of fish with food examined	21	25	27	47	42	34	28	224
Vacuity index	25.0	21.9	20.6	20.3	25.0	26.1	12.5	22.0

+<0.1.

(Table 1, Kruskal-Wallis test, planktonic animals, $H = 122.3$, $P < 0.001$; small benthic or epiphytic crustaceans, $H = 90.5$, $P < 0.001$). The %V of planktonic animals was greater in stages A–D than in stages E–G (Tukey's Q test, $P < 0.05$), the opposite being found for small benthic or epiphytic crustaceans (Tukey's Q test, $P < 0.05$).

Prey numbers per gut ranged from 0 to 17 individuals, although the Kruskal-Wallis test revealed that the number did not differ significantly among the developmental stages (Fig. 2, $H = 10.6$, $P = 0.10$). Body width of prey in the gut contents ranged from 0.08 to 0.41 mm. The differences in prey width among fish developmental stages were statistically significant (Fig. 2, Kruskal-Wallis test, $H = 168.4$, $P < 0.001$), with greater widths in stages B and C than in stages E to G (Turkey's Q test, $P < 0.05$). Mouth width of fish increased during stages A to C, thereafter stabilizing at about 1.2 mm until stage F and increasing rapidly in

stage G (Fig. 2, Tukey's Q test, $P < 0.05$).

4. Discussion

The major food items of yellowfin goby changed rapidly from planktonic animals to benthic or epiphytic crustaceans, with fish settlement. Similar switching in food items coupled with settlement are known for various demersal fishes (see MINAMI, 1984; TANAKA et al., 1996; McCORMICK and MAKEY, 1997).

In general, marine fish larvae and juveniles select larger prey items with growth (e.g., LAST, 1978; PETERSON and AUSUBEL, 1984; YOUNG and DAVIS, 1990), which may be partly the result of morphological changes in feeding-related characters as follows: increasing mouth width (LAST, 1978; HUNTER, 1981), improvement of jaw structure (GOSLINE, 1971; KOHNO et al., 1997), and development of teeth and gill rakers (GOSLINE, 1971; WRIGHT et al., 1983). On the other hand, decreasing prey size from late larvae to juveniles has been reported for several

fishes (THORISSON, 1994), although the reason remains unclear. In the present study, such a decrease in prey size was observed in the yellowfin goby, with a change in food items at settlement. Because significant changes in feeding-related characters (e.g., mouth width, jaw structure and number of teeth) of the fish were not found at the same time (KANOU et al., 2004c, present study), the decreased prey size may be related to differences in prey composition between the pelagic and benthic habitats in the study area.

Cessation or difficulty in feeding from late larvae to juveniles, indicated by high VI values (VI > 50 in most cases), have been reported in a number of coastal fishes under natural conditions (e.g., THORISSON, 1994; TANAKA et al., 1996; KANOU and KOHNO, 2001). Such may be partly linked to starvation or vulnerability to predation (THORISSON, 1994; MINAMI, 1995; GWAK et al., 1999). In some flatfishes, the non-feeding span coincides with the settlement period (KEEFE and ABLE, 1993; TANAKA et al., 1996), which may be a result of the structural and functional reorganization of the digestive system during metamorphosis, delayed behavioral adaptation to the benthic habitat and a shortage of suitably-sized prey for newly-settled individuals(TANAKA et al., 1996;NOICHI, 2001). Although yellowfin goby did not have a non-feeding period as shown by low VI values from 13 to 26, GFI values decreased around settlement. These results suggest that the settlement period for this goby is characterized by poor nutritional condition, even though feeding was not ceased entirely. Because of a lack of data for prey abundance on the mudflat, however, we could not determine whether or not the poor nutritional condition is related to exogenous factors. Further experimental studies under field condition, including information for prey availability around settlement, will be required.

Acknowledgements

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A numerical experiment on the coastal and bottom topographic effects of the Tokara Strait on the Kuroshio flow

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Abstract : Coastal and bottom topographic effects of the Tokara Strait south of Kyushu on the Kuroshio flow are studied by use of a two layer numerical model. It is shown that a western region of the Tokara Strait is essentially considered as a separation region of the Kuroshio from the western boundary in the East China Sea and an anticyclonic eddy is formed in the separation region. It is also shown that the southwestward flow along the continental slope off Nansei Islands is formed in the lower layer by the topographic guiding effect along the isopleth of depth. The southwestward flow is also formed in a flat bottom model during the spin-down period of the cyclonic eddy. This southwestward flow is an opposite direction to the northeastward Ryukyu Current, which is not modeled in this study. As the Ryukyu Current is essentially formed as a barotropic response to the seasonal change in wind stress, the vertically homogeneous flow is expected. It is suggested that the Ryuku Current is blocked by this southwestward flow and the vertical velocity change (vertical velocity shear) is generated in the Ryukyu Current, which agrees with the observational evidence.

1. Introduction

It has been widely accepted that the Kuroshio has a bimodal path characteristics in the Shikoku Basin between a non-large meander path and a large meander path (e.g. TAFT, 1972; NITANI, 1975; ISHII et al., 1983). Recently, the difference in the horizontal velocity distribution of the Kuroshio through the Tokara Stait south of Kyushu was especially noticed as an important parameter of the selection of the bimodal path of the Kuroshio. AKITOMO et al. (1991, 1997) numerically showed that the northward shift of the main Kuroshio axis in southwest to Kyushu is formed during the large meander path. A similar tendency is also shown by observational data analyses (e.g., KAWABE, 1995; YAMASHIRO and KAWABE, 1996, 2002; OKA and KAWABE, 2003). As the simplified flat bottom is assumed in the numerical models of AKITOMO et al. (1991, 1997), more de-

tailed discussion on the coastal and bottom topographic effects of the Tokara Strait is needed to draw firm conclusion on this problem.

In the present study, a realistic topography of the Tokara Strait and Shikoku Basin south of Japan are modeled and the coastal and bottom topographic effects of the Tokara Strait on the velocity distribution of the Kuroshio is examined. ZHANG and SEKINE (1995ab) modeled realistic coastal and bottom topographies south of Japan and examined the path dynamics of the Kuroshio. However, since the inflow of the numerical model was given at the western region of the Tokara Strait, detailed coastal and bottom topographic effects of the Tokara Strait have not been examined. Therefore, the inflow of the numerical model is given at east of Taiwan in the present study and the topographic effects of Tokara Strait is examined.

Some numerical models with different model characteristics are performed in the present

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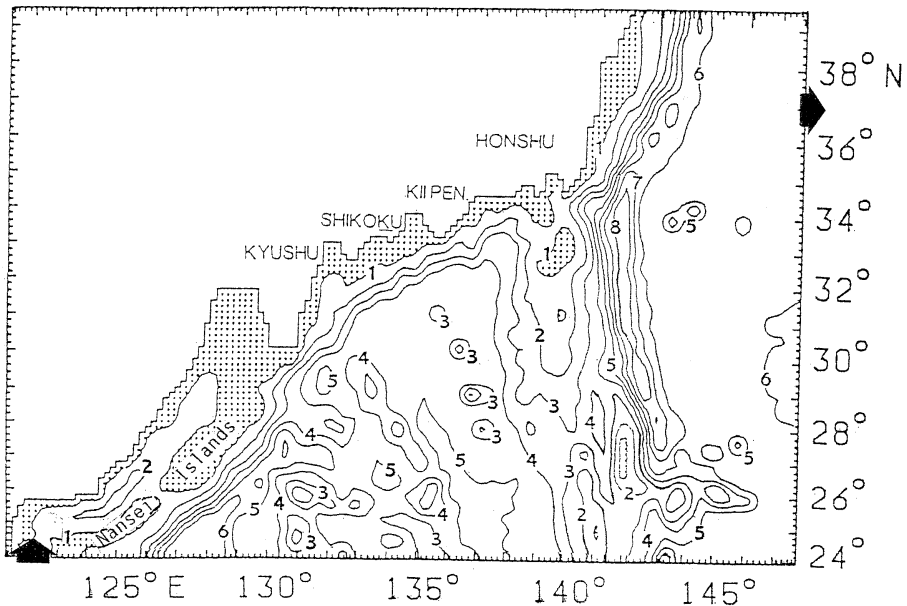
Fig. 1.   Schematic view of the model ocean shown by the isopleth of depth (in 1000 m). Two arrows show the region of the in-and outflow and regions shallower than 1000 m are stippled.

study and the coastal topographic and bottom topographic effects are examined independently. Namely, the coastal topographic effect is examined by the flat bottom model and the bottom topographic effect is examined by the realistic bottom model, depending on the intensity of the current velocity of in- and outflow. In the followings, the details of the numerical model and characteristics of each model are described in the next section. The results of the numerical experiments are mentioned in sections 3, summary and discussion are made in section 4.

2. Numerical model

A two layer ocean with bottom and coastal topographies shown in Fig. 1 is employed in this study. Here, an isopleth of the depth of 150 m is assumed as the coastal boundary in the East China Sea. The reduced gravity of the two layer model is assumed to be 2.87×10^{-2}msec^{-2}. The basic equations are the same as those of ZHANG and SEKINE (1995ab). The system is driven by stationary in- and outflow through the open boundary.

As for the initial state, the flow is given only

in the upper layer and the lower layer has no motion (Fig.2). Sinusoidal horizontal velocity distribution of in- and outflow is assumed and only northward (eastward) velocity component is given at the inflow (outflow) boundary. A viscous boundary condition is imposed on the northern coastal boundary and a slip boundary condition is imposed on the other open boundaries. In the numerical calculation, we adopt a rectangular grid with horizontal spacing of 18.7 Km along x - axis (eastward) and 15.8 Km along y - axis (northward).

In the present study, 8 cases of numerical experiments with different model character are performed. Firstly, a flat bottom with the coastal topography of Fig. 1 and with a constant depth of 3800 m is assumed and the coastal topographic effect is mainly examined. Here, the different in- and outflow volume transport of 30 Sv (1 Sv $= 10^6$m^3 sec^{-1}), 55 Sv, 70 Sv and 80 Sv is given and the effect of nonlinear effect (advection) is also examined. The four models with different in- and outflow are referred to as F30, F55, F70 and F80. The range of in- and outflow volume transport of the Kuroshio, 30 Sv to 80 Sv, is essentially based on
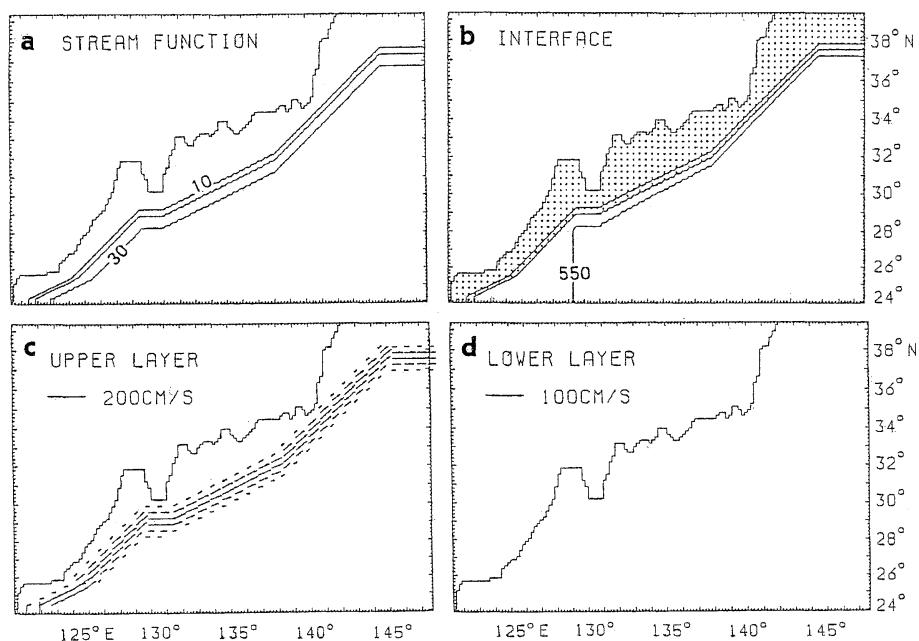
Fig. 2. Initial condition of F30. Spatial distribution of (a) volume transport function, (b) upper layer thickness, (c) velocity fields of upper layer and (d) those of lower layer. The contour intervals of the volume transport function and the upper layer thickness are 10 Sv and 50 m, respectively. Areas with negative volume transport function or thinner upper layer less than 500 m are stippled.

the observed geostrophic flow observations of 35 Sv–55 Sv (Isobe and IMAWAKI, 2002) and 30 Sv–65 Sv (IMAWAKI et al., 2001) and 40 Sv–90 Sv estimated from the sea level height TOPEX/POSEIDON (IMAWAKI et al., 2001).

Secondly, the realistic coastal and bottom topographies of Fig. 1 are employed and the bottom topographic effect of the continental slope is furthermore examined. Here, similar four models with different in- and outflow volume transport of 30 Sv, 55 Sv, 70 Sv and 80 Sv are carried out and they are referred to as T30, T55, T70 and T80, respectively. As for these four realistic bottom models, coefficient of horizontal eddy viscosity is assumed to be $5 \times 10^2 \text{m}^2\text{sec}^{-1}$, while a larger value of $1 \times 10^3 \text{m}^2 \text{sec}^{-1}$ is assumed for the four flat bottom models.

Because the current over a flat bottom is essentially unstable and the enhanced velocity is induced. SEKINE (1992) pointed out by use of a simplified two layer model proposed by IKEDA (1983) that a western boundary current over the flat bottom is baroclinically unstable, while a flow over the continental slope south of

Japan is almost stable by the stabilizing effect of the continental slope. Therefore, in order to suppress the enhanced velocity in a flat bottom model, larger coefficient of the eddy viscosity is given for the flat bottom models. The numerical time integration of ten years is carried out for each model and the numerical solutions in the stationary state or quasi-stationary state are analyzed.

3. Results
Results showing the statinary velocity fields of F30 are displayed in Fig. 3. A coastal flow along western and northern coasts is formed in the upper layer and the total flow pattern shows a non-large meander path. In the lower layer, three anticyclonic eddies exist at southeast of Kyushu and south of Shikoku and southeast of Kii Peninsula. The volume transport function showing the total transport in the upper and lower layer and thickness of the upper layer of F30 are shown in Fig. 4. Since the lower layer has a larger layer thickness, velocity fields of the lower layer is relatively
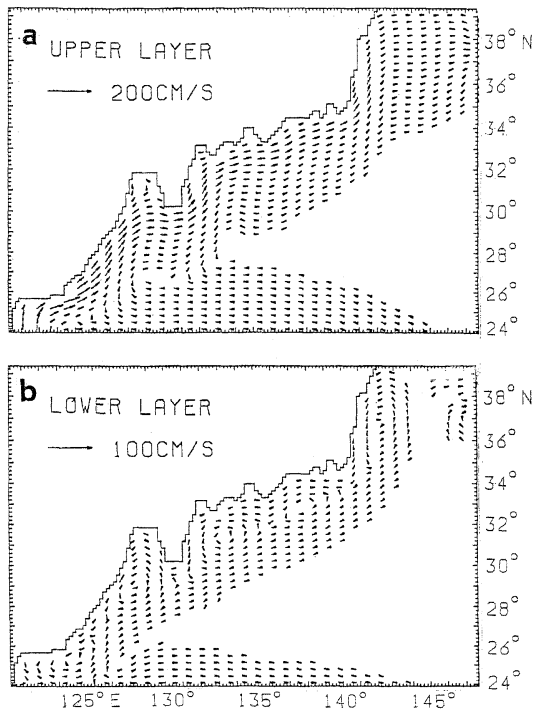
Fig. 3. Result of F30 shown by (a) upper layer ve-
locity and (b) lower layer velocity in a station-
ary state. No velocity vectors less than 10 cm
sec^{-1} in the upper layer and 5 cm sec^{-1} in the
lower layer are plotted.

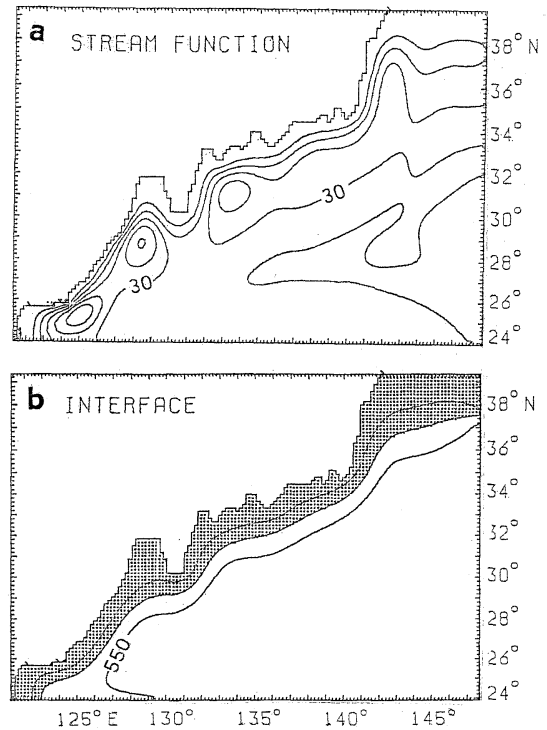
Fig. 4. (a) Volume transport function and (b) the
upper layer thickness of F30 in a stationary
state. The contour interval is the same as in Fig.
2.

exaggeratedly appeared in the volume trans-
port function. A clear compensation of the sur-
face pressure gradient is not carried out by the
gradient of interface in the stationary state
(Fig. 4b) and a lower layer velocity is formed
(Fig. 3), which indicates the occurrence of the
baroclinic instability.

Stationary velocity fields of F55 are shown in
Fig. 5. Although essentially similar flow pat-
tern to F30 (Fig. 3) is obtained, amplitude of
the meander of the mean flow in the upper
layer is enhanced in F55. Two anticyclonic ed-
dies southwest of Kyushu and south of
Shikoku are also enhanced in the lower layer
and their existence is also detected in the upper
layer. A small cyclonic eddy is formed at south-
east of Kii Peninsula in the lower layer, which
is shown by C in Fig. 5.

In contrast to F30 and F55, a stationary solu-
tion is not obtained in F70 and F80. In both
cases, a large meander path is essentially

formed and a spin-up and spin-down of a
cyclonic eddy southeast of Kyushu is repeated
(Fig. 6). The large cyclonic eddy is formed in
the spin-up periods, while it decays in the spin-
down periods. The period of the spin-up and
spin-down of the cyclonic eddy is about 50 days
for both cases. The flow pattern during the
spin-up period of the cyclonic eddy essentially
corresponds to the small meander of the
Kuroshio southeast of Kyushu (SOLOMON,
1978; SEKINE and TOBA, 1981ab), which is a
trigger meander prior to the formation of the
large meander path. However, the spin-up and
spin-down of the cyclonic eddy in the numerical
model give no large influence on the total flow
pattern of the Kuroshio south of Kii Peninsula
and the large meander path is formed station-
ary. As for the velocity fields of these models
(Fig. 7), a typical large meander path is
formed in the upper layer velocity south of Kii
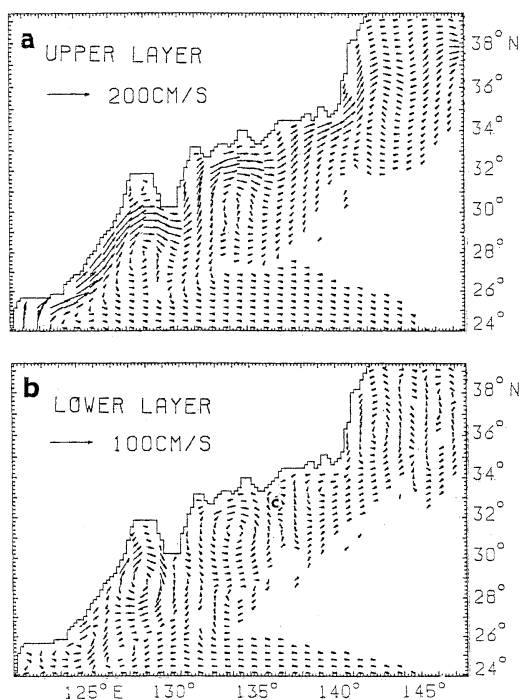Peninsula and the cyclonic eddy accompanied

Fig. 5.   Same as in Fig. 3 but for F55. The location of the cyclonic eddy southeast of Kii Peninsula in the lower layer is shown by c.

by the large meander path is formed in the lower layer. Two anticyclonic eddies southeast of Kyushu and south of Shikoku are significantly enhanced and they are also clear in the upper layer flow.

It is noted from Figs. 6b,d and 7a that in periods of the spin-down of the cyclonic eddy sothwest of Kyushu, a southwestward flow with a velocity of 30 cm sec^{-1} is formed in the lower layer at the southwestern part of the anticyclonic eddy at the separation area. Although the Ryukyu Current with an approximate maximum velocity of 50 cm sec^{-1} (YUAN et al., 1998) is not modeled in this numerical model, the simulated southwestward flow is the opposite direction to the observed northeastward Ryukyu Current along the continental slope off Nansei Islands. Therefore, it is inferred that the southwestward flow formed in F70 and F80 and the Ryukyu Current blocks each other and their velocities are decreased. In period of the spin-up of the anticyclonic eddy (Figs. 6a,c and 7b), since the anticyclonic eddy

develops so eastward and the surrounding flow of the anticyclonic eddy dominates, while the southwestward flow is unclear.

It is also noticed that in F70 and F80 the northward shift of the current path west of Kyushu is more prominent in the upper layer in comparison with those of F30 and F55. Considering that the large meander path is formed in F70 and F80 and the non-large meander path appears in F30 and F55, the northward shift of the current path in case of the large meander path agrees with the observational evidence (KAWABE, 1995; YAMASHIRO and KAWABE, 1996, 2002; OKA and KAWABE, 2003) and the results of the numerical models so far proposed (AKITOMO et al., 1991 and 1997). From the difference of the results between F30–F55 and F70 F80, it is resulted that the formation of the large meander path in F70 and F80 is caused by the northward shift of the current path west of Kyushu and the downstream southward shift by the topographic effect of Kyushu. Namely, because the large northward shift in west of Kyushu yields a large Rossby Lee wave in east to Kyushu, the large meander path has a possibility to be formed as a Rossby Lee wave which induced by the topographic effect of Kyushu.

Although the non-large meander path is formed in F80 of ZHANG and SEKINE (1995a), the large meander path is formed in F80 of this study. Because the non-large meander path in their model is formed by the downstream advection of the large meander, which yields the decay of the large meander path. In the present study, as the inflow is given at east of Taiwan (Fig. 1), the eastward velocity south of Kyushu and its downstream advection of the large meander path are weak and the large meander path is formed. The difference between the two models shows that the range of the non-large meander path in the exceedingly large current velocity of the Kuroshio south of Japan.

Results of T30, T55, T70 and T80 are shown in Fig. 8. Although time dependent quasi-stationary solution is obtained in F70 and F80 (Figs. 6 and 7), the stationary solution is obtained in T70 and T80. All the eddies formed in the flat bottom models are relatively weak and a coastal flow along the western and northern
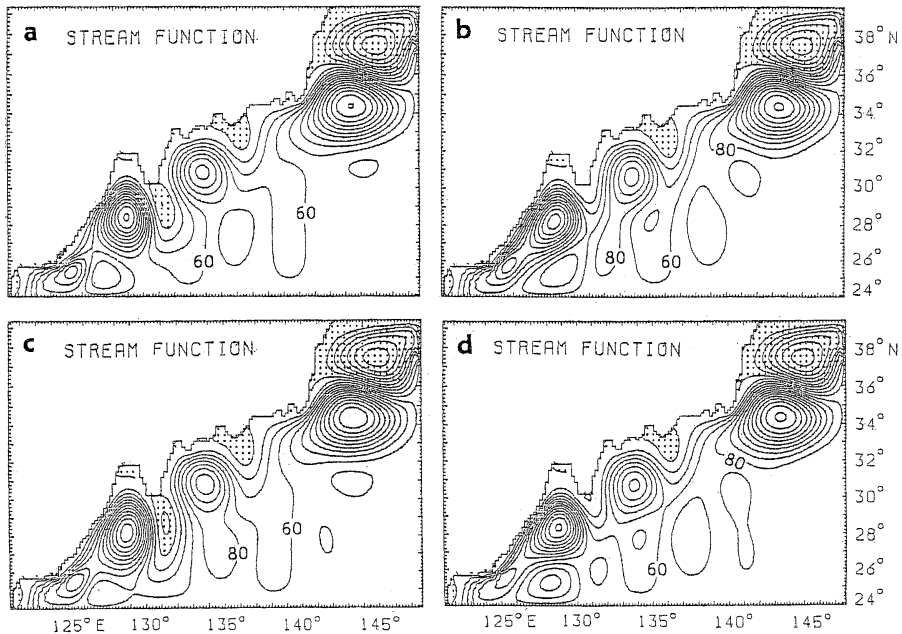
Fig. 6.   Time change in the volume transport function of F70 at (a) 1200 days, (b) 1225 days, (c) 1250 days and
(d). 1275 days The contour interval of the stream function is 20 Sv. The regions with negative stream func-
tion are stippled.

boundaries is formed. In general, the bottom topographic effect is enhanced in a two layer model and the large meander appears in case of significantly large offshore advection effect from continental slope (e.g., SEKINE, 1990). It should be noticed from the lower layer velocity shown in Fig. 9 that the southwestward flow is commonly formed along the continental slope off Nansei Islands. The southwestward flow is maintained stationary and it is confined to the lower layer. Because the lower layer flow has a strong tendency to flow along the contour of f/h, where f is the Coriolis parameter and h is the thickness of the lower layer, which is well approximated by total depth, the southwestward flow along the continental slope off Nansei Islands is generated by the bottom guiding effect along isopleth of depth.

As the northeastward Ryukyu Current flows along the continental slope of the Nansei Islands, the northeastward Ryukyu Current is weakened by the opposite southwestward flow simulated in the present model. Furthermore, the Ryukyu Current is considered as a barotropic response of the ocean to the seasonal change in the wind stress (SEKINE and KUTSUWADA, 1994; KAGIMOTO and YAMAGATA, 1997), the vertically homogeneous flow is expected for the Ryukyu Current. However, it is commonly observed that there exists a vertical velocity change in the Ryukyu Current and the Ryukyu Current is confined to the shallowest margin of the continental slope off Nansei Islands (YUAN et al., 1994, 1998; ZHU et al,2003).

As for these observational evidences, it is inferred that the northeastward Ryukyu Current is blocked by the southwestward flow with a vertical velocity shear. Namely, the collision of the southwestward flow and the Ryukyu Current yields the vertical velocity change in the Ryukyu Current. Together with the southwestward flow formed in the flat bottom models, more detailed discussion will be made in the next section.

4. Summary and discussion
We have examined the coastal and bottom topographic effect of Tokara Strait on the
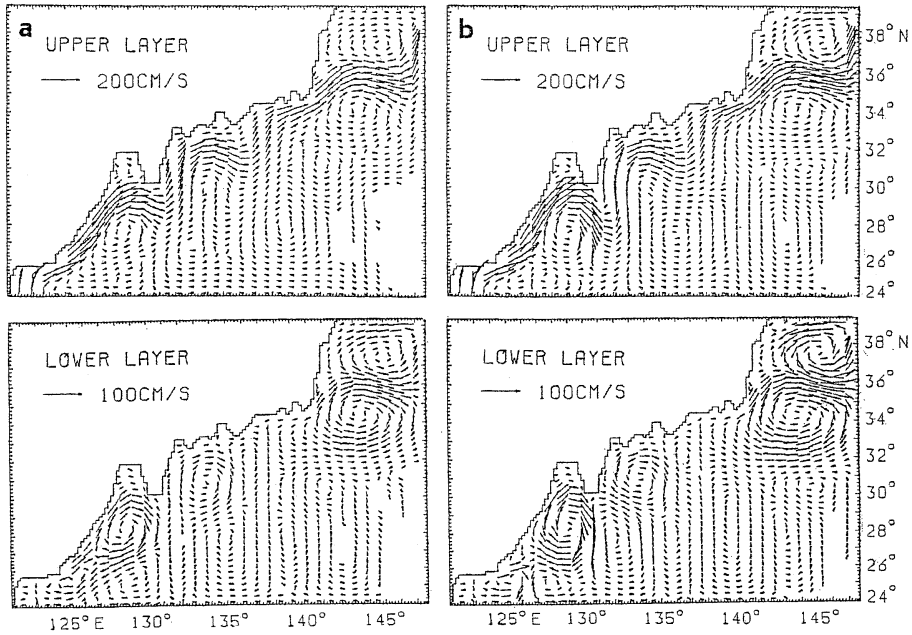
Fig. 7. Velocity fields of F70 (a) in the period of the spin-down of the cyclonic eddy southeast of Kyushu and those (b) in the period of spin-up of the cyclonic eddy.
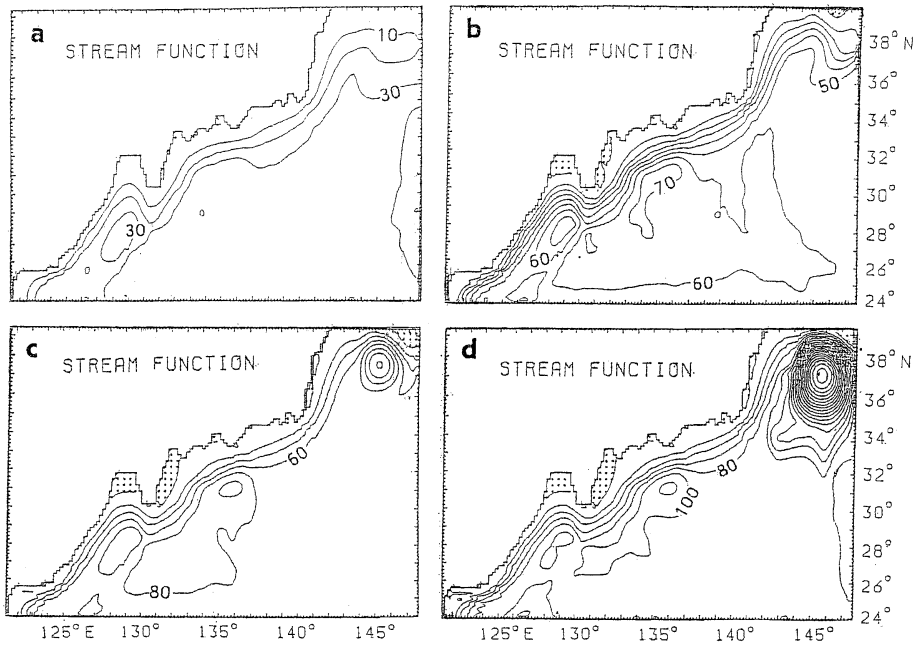
Fig. 8. Volume transport function of (a) T30, (b) T55, (c) T70 and (d) T80 in a stationary state. The contour intervals in T30 and T55 are 10 Sv and those in T70 and T80 are 20 Sv. Areas with negative volume transport function are stippled.
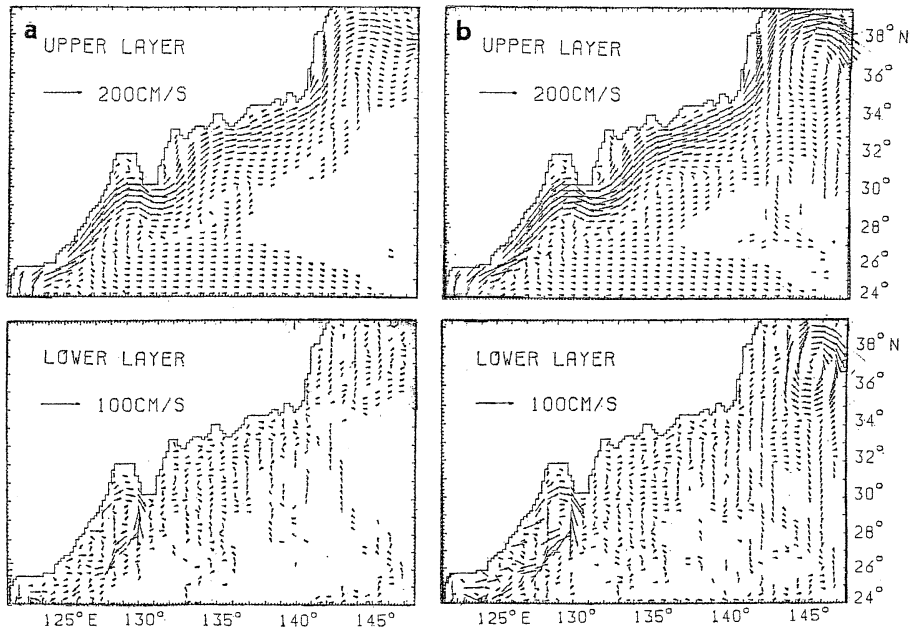
Fig. 9. Same as in Fig. 7 but for (a) T55 and (b) T80.

velocity distribution of the Kuroshio south of Kyushu, as a succeeding study of the numerical experiment of ZHANG and SEKINE (1995a,b). The main results of the present study are summarized as follows:

(1) It is resulted from the numerical experiments that the Tokara Strait is essentially considered as a separation region of the Kuroshio from the western boundary in the East China Sea. An strong anticyclonic eddy is formed in this region in a flat bottom model and the southwestward flow is formed in the lower layer at the southwestern part of the anticyclonic eddy during its spin-down periods.

(2) In the realistic bottom model, the southwestward flow along the continental slope off Nansei Islands is commonly generated by the topographic guiding effect along isopleth of depth. This southwestward flow is an opposite direction to the Ryukyu Current and the Ryukyu Current is blocked by the southwestward flow. Although the Ryukyu Current is essentially formed as a barotropic flow, the vertical shear is observed. It is suggested that the vertical shear of the Ryukyu Current is caused by the blocking of the southwestward flow.

(3) In case of the large meander path, the northward shift of the current path at the western region of the Tokara Strait is clear in the upper layer in comparison with those in the non-large meander path. This agrees with the results of the previous observations and the numerical studies so far proposed. It is suggested that the large meander path is essentially considered as a Rossby Lee wave formed by the coastal topography of Kyushu.

(4) Although the non-large meander path is formed in F80 in ZHANG and SEKINE (1995a), the large meander path is formed in F80 of the present study. As the inflow of ZHANG and SEKINE (1995a) was made at the western region of the Tokara Strait, the eastward advection of the large meander path is enhanced. The range of non-large meander path in exceedingly large current velocity of the Kuroshio is suggested.

On the observed velocity distribution of the Ryukyu Current, it is inferred that the observed confinement of the Ryukyu Current to the shallower margin of the continental slope off Nansei Islands (YUAN et al., 1994; 1998; ZHU et al., 2003) may be generated by the blocking by the southwestward flow denoted in (2). Even if the topographic effect of the continental

slope is weak, the southwestward flow is formed by the spin-down of the anticyclonic eddy mentioned in (1), the residual flow may be exists only in the margin of the continental slope. It is also inferred that because the southwestward flow is formed by the topographic guiding effect of the continental slope off Nansei Islands, the stronger southwestward flow is mainly confined to the lower layer. If the southwestward flow is formed during the spin-down of the anticyclonic eddy, the surface trapped southwestward velocity still exists in the upper layer (Fig. 7a), there is a possibility that the minimum of the southwestward flow exists in the intermediate layer. Therefore, the northeastward Ryukyu Current has a has a maximum velocity at the intermediate layer and the smallest blocking effect is expected in the intermediate layer. This agrees with the observed velocity maximum of the Ryukyu Current at a depth of 600 m (YUAN *et al.*, 1998). However, more detailed discussion is needed to explain the observed velocity distribution of the Ryukyu Current, which will be carried out in the next step of this study.

It is pointed out from (4) that the path pattern of the Kuroshio depends on not only the volume transport but also the velocity distribution at the Tokara Strait. YAMASHIRO and KAWABE (2002) suggested the clear difference in the shape of the Kuroshio axis south of Kyushu between the large meander path periods and the non-large meander path. They also pointed out that a realistic flow through the Tokara Strait should be given in the numerical model, while the inflow should not be given at the Tokara Strait as a boundary condition in almost numerical model so far proposed. The different results between F80 of the present study and that of ZHANG and SEKINE (1995a), which is mentioned in (4), correspond to this event. Therefore, more realistic modeling south of Kyushu including the Ryukyu Current is needed in the next stage of this study.

Acknowledgments:

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Partial stock transportation of three clupeoid, *Engraulis japonicus, Etrumeus teres* and *Sardinops melanostictus*, larvae into the shirasu fishery ground of Tosa Bay, Japan

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Abstract : In Tosa Bay, three species of clupeoid (*Engraulis japonicus, Etrumeus teres* and *Sardinops. melanostictus*) larvae were collected monthly by the commercial shirasu trawl between October 2001 and September 2002. *E. japonicus* occurred all year round, *E. teres* from October to July and *S. melanostictus* from November to April. Hatching dates, estimated by daily ring increment of otoliths were distributed all year round in *E. japonicus*, October to March and May to July in *E. teres* and October to March in *S. melanostictus*. Furthermore, from larva net collections made offshore in the bay from April 2002 to March 2003, eggs hardly or never occurred from July to February for *E. japonicus*, from April to October for *E. teres* and from April to December for *S. melanostictus*. Considering these facts with information by other institute, larvae of *E. japonicus, E. teres* and *S. melanostictus* which occur in November to January would not be born in Tosa Bay. Since their early larvae were collected with a larva net during the autumn, they must be transported after hatching from outside Tosa Bay. Hence, each larva assemblage of three clupeoid seems to originate from plural spawning stocks.

Keywords : *shirasu fishery, clupeoid larva, daily age, transportation, Tosa Bay*

1. Introduction

The shirasu (clupeoid larvae) fishery middle trawl is performed in Tosa Bay (Ochiai, 1981), where a large fishery ground of three clupeoid, *Engraulis japonicus, Etrumeus teres* and *Sardinops melanostictus* shirasu are formed, and their major spawning stocks exist (Hattori, 1982 ; Kuroda, 1988 ; Watanabe *et al.*, 1997 ; Zenitani and Kimura, 1997 ; Zenitani and Yamada, 2000 ; Uehara and Mitani, 2002). Therefore, Tosa Bay has played an important role as spawning and nursery grounds. However, little is known about the assemblage mechanisms of the shirasu, *i.e.* a formation of the fishery grounds after spawning. Our previous paper (Djumanto *et al.*, in press)

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clarified seasonal abundance and changes in sizes of the three clupeoid species. In the present paper, we report recruitment patterns into the fishery ground of the shirasu by examination of otolith daily rings, and compare the distribution pattern of their eggs and early larvae between the shoreline and offshore.

2. Materials and methods

Four stations (T1–T4) with increasing depth (5, 10, 15 and 20 m) from the mouth of the Niyodo River were sampled monthly for juveniles of three clupeoid species (*Engraulis japonicus, Etrumeus teres* and *Sardinops melanostictus*) using fishermen's middle trawlers (mesh size of bag-net : 2 mm) between October 2001 and September 2002 (Fig. 1). The trawl structure used and collection methods were described in Djumanto *et al.* (in press). Collections of eggs and early larvae were made by oblique tows (from near the bottom to the surface) with a larva net (1.3 m mouth diameter and 0.5 mm mesh aperture) at nine stations
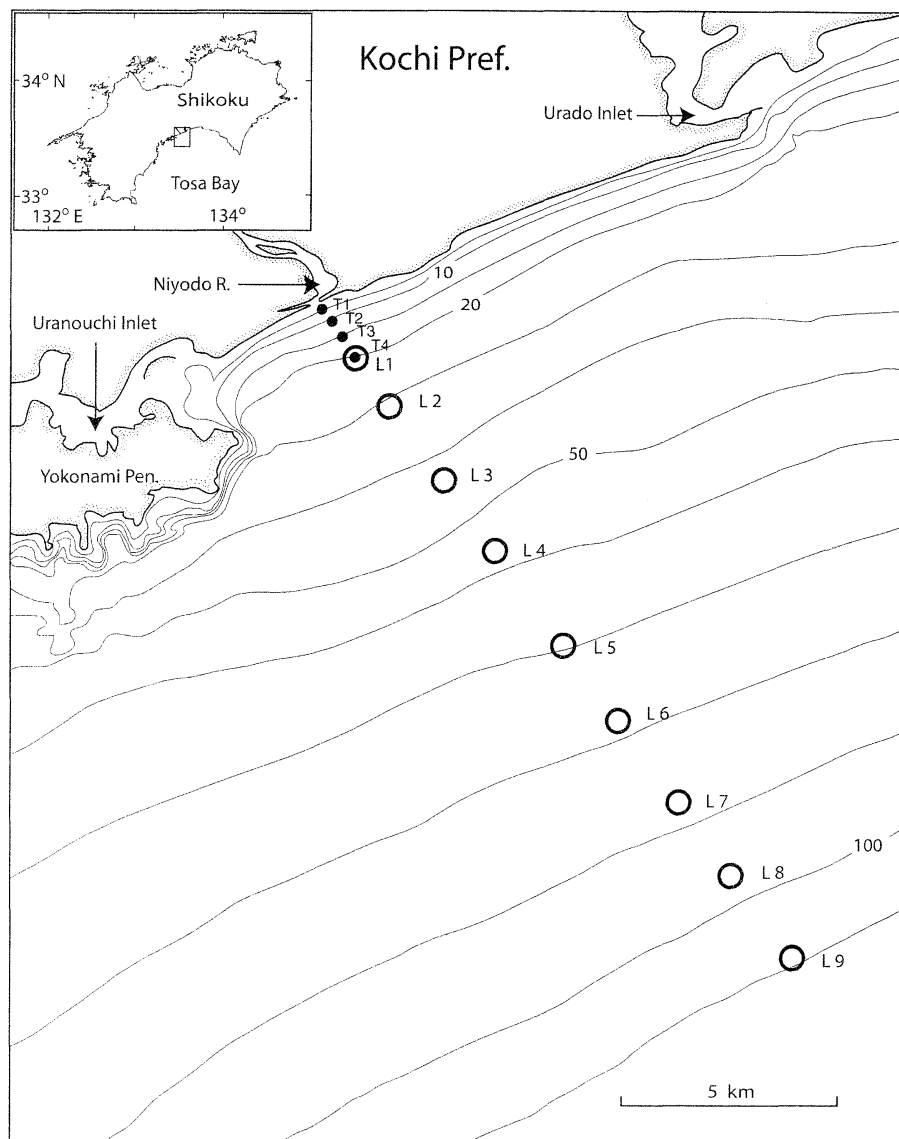
Fig. 1. A chart of Tosa Bay showing the stations where ichthyoplankton were collected. Shirasu trawls were performed at solid circles (T1–T4) arranged by different depths (5, 10, 15 and 20 m) from October 2001 to September 2002. Oblique tows by a larva net (1.3 m mouth–diameter, 0.5 mm mesh aperture) were made at open circle stations (L1–L9) from April 2002 to March 2003.

(L1–L9) performing a transect south–east from the mouth of the Niyodo River between April 2002 and March 2003 (Fig.1). All samples were preserved in 10% sea–water formalin then transferred to 80% ethanol, subsequently fish specimens were sorted and measured their sizes by developmental stages (KENDALL et al., 1984)

in the laboratory. Unlabeled lengths are body lengths (notochord length in yolk – sac, preflexion and flexion larvae, and standard length in postflexion larva and juveniles). Water temperatures and salinities were measured using STD at each station.

A maximum of 100 and 50 specimens from
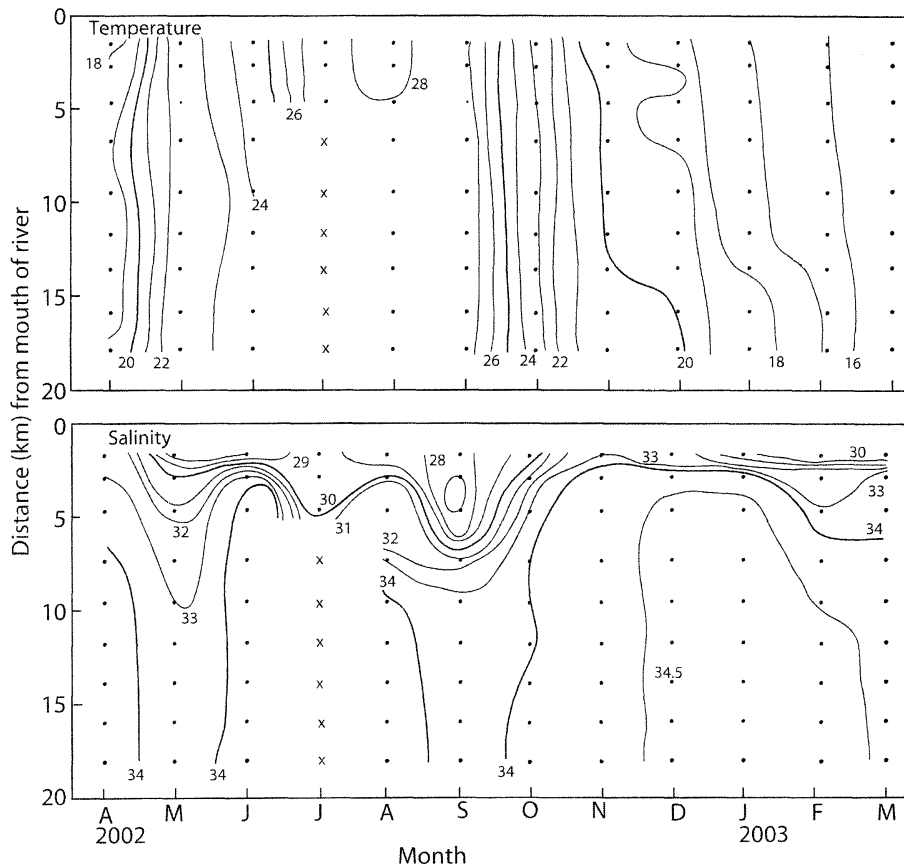
Fig. 2.   Seasonal changes of horizontal distributions of water temperatures (°C, 5 m depth layer) and salinities (psu, surface) in Tosa Bay from April 2002 to March 2003. Dots indicate sampling stations and crosses indicate no survey.

the shirasu trawl and larva net collections, respectively, for each species on each sampling date was selected randomly for age determination from otolith (sagitta). The right side sagittae were removed from specimens, and fixed on a microscope slide face up with epoxy resin. Rings outside the nucleus of the sagittae were counted with a light microscope at 400–600 times magnification, and the mean of five replicate counts was used as the estimated ring number. Hatching dates were estimated from the increment of daily rings and the collection date. The daily periodicity of increment formation on sagitta in *E. japonicus*, *E. teres* and *S. melanostictus* was ascertained by TSUJI and AOYAMA (1984), HAYASHI and KAWAGUCHI (1994) and HAYASHI et al. (1989), respectively.

3. Results
Temperature and salinity

Seasonal changes in the horizontal distribution of water temperatures and salinities offshore from the mouth of the Niyodo River in Tosa Bay are shown in Fig. 2. Temperatures were approximately equal when examined horizontally through the waters, but changed seasonally. For salinities, horizontal discontinuity layers were formed around 5 km offshore in spring and summer, and salinity tended to be higher in nearer stations from the shore during autumn and winter.

Comparison of size between larva net and shirasu trawl collections

From larva net collections, all three species
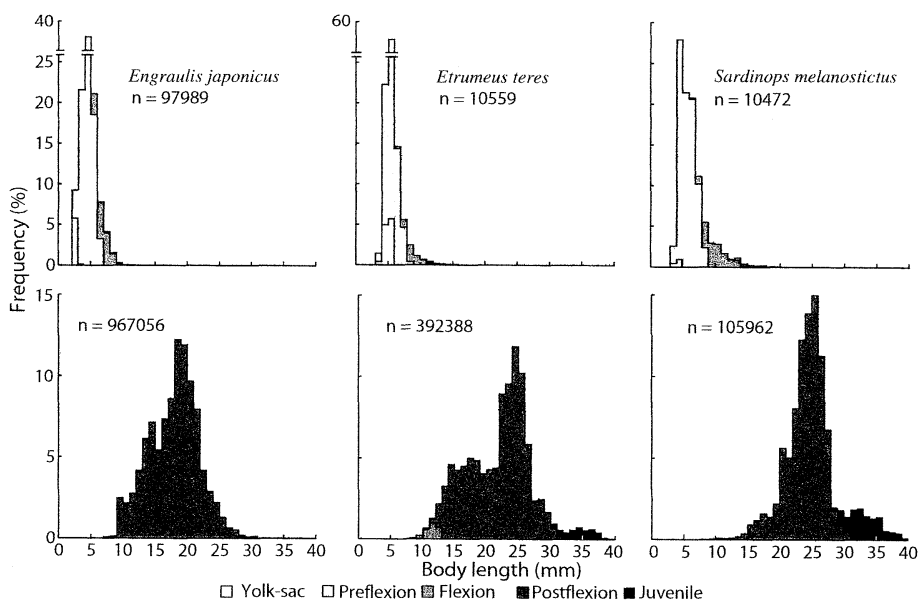
Fig. 3. Body length frequencies of three clupeoid fishes collected by a larva net (upper) and a shirasu trawl (bottom) in Tosa Bay during study period.

were mainly composed of preflexion stage larvae, with a mode at *ca.* 5 mm (Fig. 3). Larvae over 10 mm were rather abundant for *Sardinops melanostictus*, as opposed to never for *Engraulis japonicus*.

In the shirasu trawl samples, juveniles over 30 mm occurred appreciably for *Etrumeus teres* and *S. melanostictus* but never for *E. japonicus*. All three species were composed of chiefly the postflexion larvae. Modes were considered to be 18.1–19.0 mm for *E. japonicus*, 17.1–18.0 and 24.1–25.0 mm for *E. teres* and 25.1–26.0 mm for *S. melanostictus*.

Seasonal changes of eggs and early larvae

E. japonicus eggs occurred from February to April, with a further isolated production of eggs in June and September, and were chiefly distributed 5–10 km and 10–15 km offshore in April and June, respectively (Fig. 4). In winter, eggs were dispersed, and tended to be abundant over 20 km offshore. Early larvae were collected all year round, with peak in April, when they were aggregated around 5 and 15

km offshore. In other months, larvae tended to be dispersed along the transect.

E. teres eggs and early larvae occurred chiefly from October to March, and were more abundant in the period between January and March (Fig. 5). Dense distributions were found over 15 km offshore for eggs, but distinctive distributions for larvae were difficult to ascertain.

For *S. melanostictus*, the eggs were collected from January to March, and were concentrated around 10 km offshore in January (Fig. 6). The larvae, however, started to be found over 10 km offshore in November, and the distribution changed monthly, *i.e.* near the shore in January, around 10 km offshore in February and over 15 km offshore in March.

Age (days) of larvae and juveniles

For the larva net collected larvae, the ages of all three species were concentrated at 6–10 days old (Fig. 7). On the other hand, for the shirasu trawl samples, the ages were distributed from 6 to 68 for *E. japonicus*, 4 to 80 for *E. teres* and
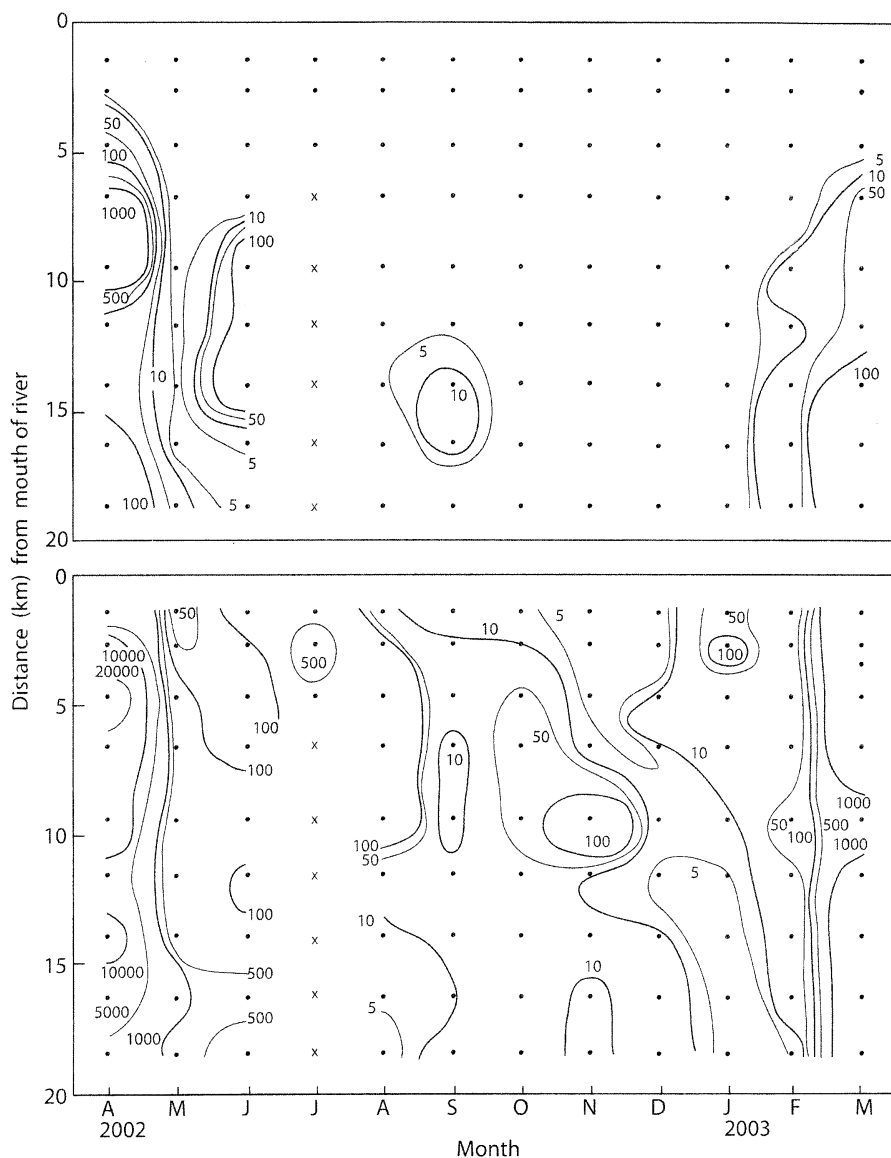
Fig. 4. Monthly changes of horizontal density (n/1000 m³) of egg (upper) and larva (bottom) in *Engraulis japonicus*. Dots indicate sampling stations and crosses indicate no survey.

from 5 to 64 days for *S. melanostictus*. Furthermore, there was little differentiation of age ranges among the three species. Their modes were found at 26–30 days old for *E. japonicus*, 11–15 days old for *E. teres*, and 16–20 days old for *S. melanostictus*.

Relationship between egg monthly distribution and hatching dates of larvae

E. japonicus eggs were most abundant in April, with few or no eggs from July to January (Fig. 8). Hatching dates of the larvae by both collection methods were distributed almost over the year, with a peak in July for the larva net and in October for the shirasu trawl collections.
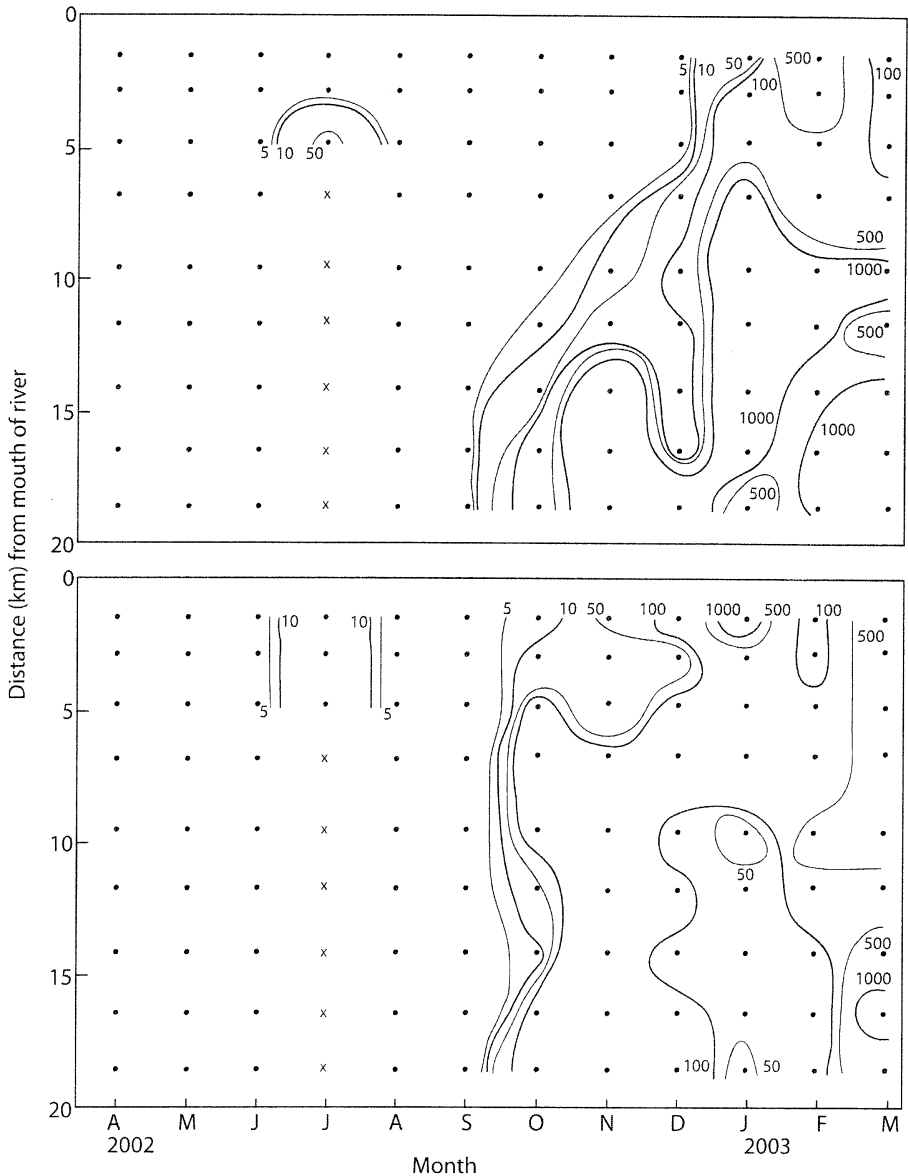
Fig. 5.   *Etrumeus teres.* Otherwise same as in Fig. 4.

Eggs of *E. teres* were collected in July and from October to March, with a peak in February (Fig. 9). They were, however, utterly absent from April to June. Hatching dates of the larvae collected with the larva net were distributed from October to March, peaking in November and larvae collected by the shirasu trawl were distributed from May to July with a peak in June and from October to March with a peak in December.

S. melanostictus eggs occurred from January to March with a peak in January (Fig. 10). Hatching dates of the larvae by the larva net were distributed from November to March, being most abundant in January from the larva net collection method, and from October to March, with the greatest abundance in January from the shirasu trawl.
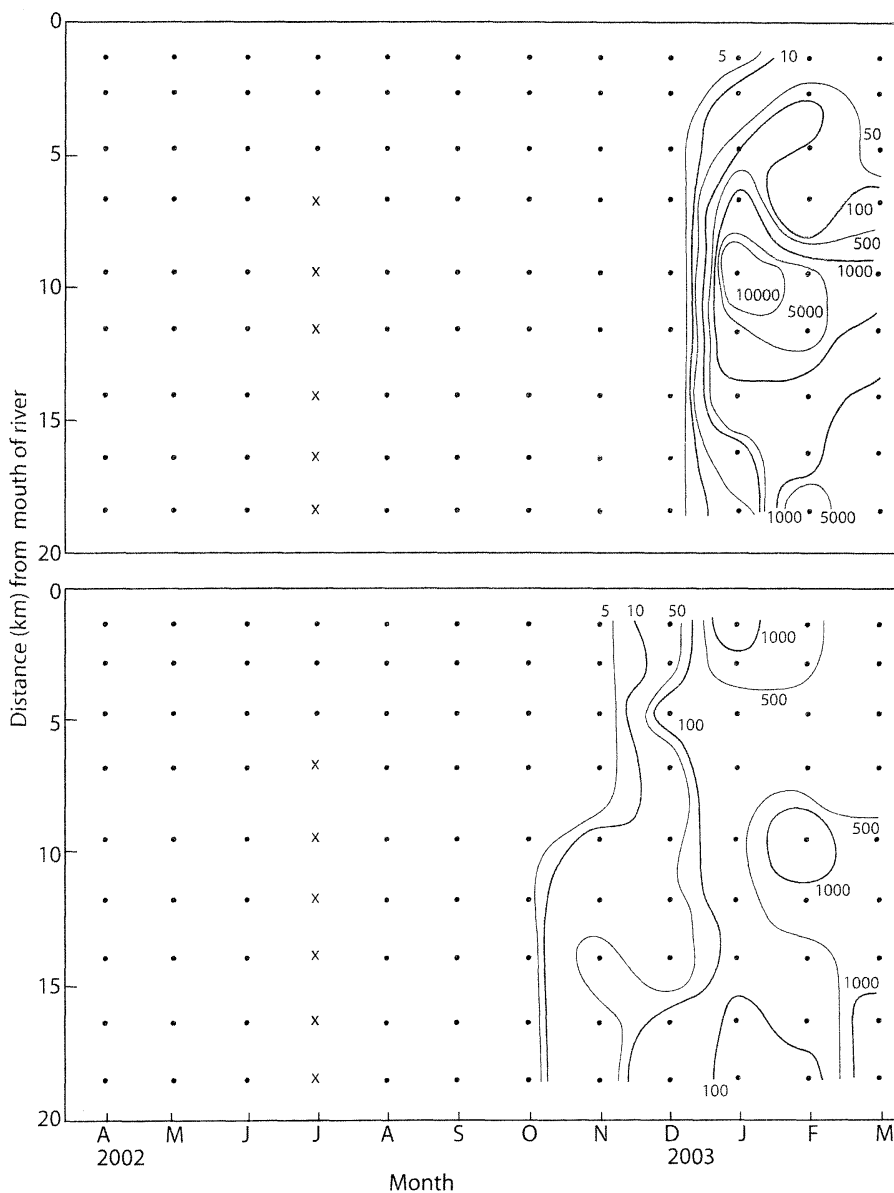
Fig. 6. *Sardinops melanostictus*. Otherwise same as in Fig. 4.

4. Discussion

Owing to the fact that mesh sizes were 0.5 and 2 mm in the larva net and shirasu trawl bag–net, respectively, it is possible that larger larvae avoided the larva net, and conversely, smaller larvae may pass through the mesh of the bag–net during the trawl. However, Fig. 3 shows that *Engraulis japonicus*, *Etrumeus teres* and *Sardinops melanostictus* larvae are likely to assemble in fishery grounds near the coast over 10, 10 and 15 mm in size, respectively, just after attaining postflexion stage. This fact shows that the formation of the fishery ground of clupeoid larvae is attributable to higher swimming ability as a result of the development of the caudal fin (KENDALL *et al.*, 1984).

Since the larva net collection method had not
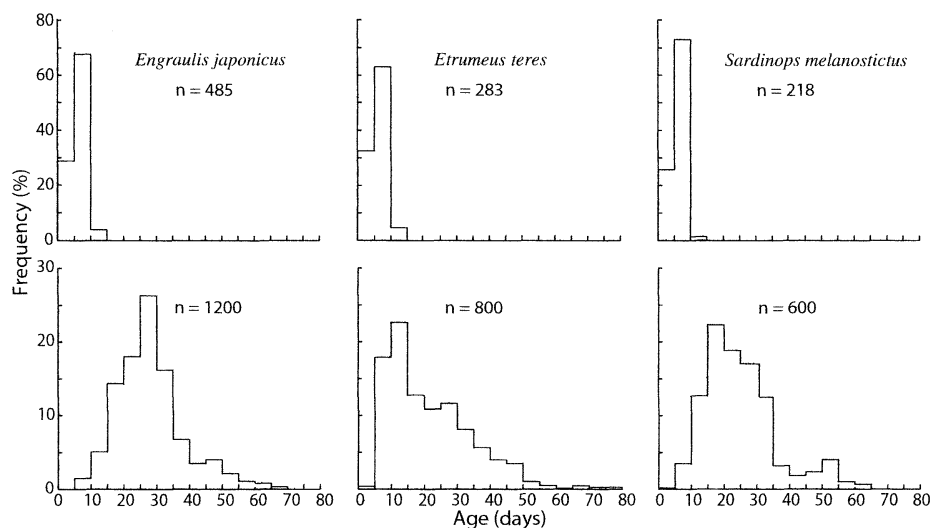
Fig. 7.   Age frequency of three clupeoid larvae collected by a larva net (upper) and a shirasu trawl (bottom) in
    Tosa Bay during the study period.

been carried out before April 2002, we studied
the origins of the shirasu trawl specimens by
examining information (ISHIDA et al., 1999,
2000, 2001, 2002, 2003) from the National Re-
search Institute in more detail.

No or few eggs corresponding to the shirasu
trawl larvae which hatched between July and
August, May to July, and October to December
for E. japonicus, E. teres, and S. melanostictus,
respectively, were found in our study waters.
Although data were from different years, E.
japonicus also showed the same situation from
October to January.

Hatching dates of early larvae were distrib-
uted in July and November, when the shirasu
larvae of E. japonicus and S. melanostictus, re-
spectively, had hatched. In E. teres, no early
larvae had hatched between May and July,
when hatching dates of the shirasu larvae were
distributed.

First, E. japonicus had spawned in July to
September not only outside the western and
eastern parts of Tosa Bay, but also inside this
bay in 2002 (ISHIDA et al., 2003). Hence, it is
likely that we could not collect eggs, because
eggs were distributed offshore over our present
waters in the summer of 2002 (ISHIDA et al.,

2003). However, eggs which could not be col-
lected by us in the present waters, had been dis-
tributed outside the western part of this bay in
the autumn every year (ISHIDA et al., 1999,
2000, 2001, 2002, 2003). Therefore, it is certainly
that the autumn born stocks of the shirasu
trawl were transported from outside the west-
ern side of Tosa Bay.

Second, in E. teres, eggs being the origin of
specimens born in May–July of the shirasu
trawl were hardly collected in our present wa-
ters, but usually occurred inside Tosa Bay and
outside the eastern part of the bay (ISHIDA et
al., 1999, 2000, 2001, 2002, 2003). For the speci-
mens born in Autumn 2002, however, their
original eggs had only occurred marginally
outside the eastern part of Tosa Bay (ISHIDA et
al., 2003). Thus, the autumn born stock of this
species was likely to be transported from out-
side the eastern part of the bay, at least in 2002.

Finally, S. melanostictus eggs had been a lit-
tle found only outside the eastern part of the
bay in the autumn of 2001 (ISHIDA et al., 2002),
when a number of shirasu larvae had been
born. It is likely that they had also been trans-
ported from outside the eastern part of the
bay.
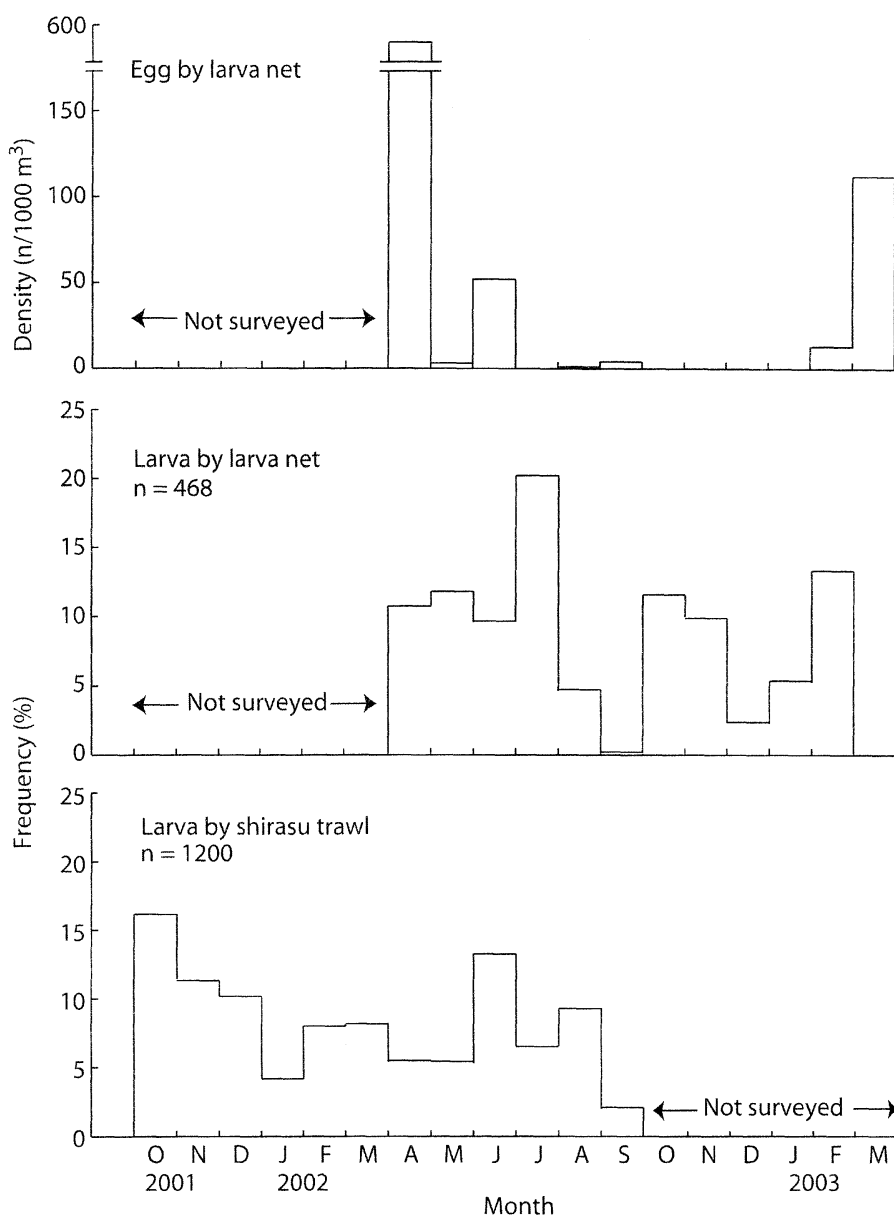
Fig. 8. Comparison of seasonal changes between egg abundance and hatching period of the larvae in *Engraulis japonicus*.

Consequently, in all three species, it is suggested that the larvae and juveniles caught by the shirasu trawl in Tosa Bay are composed of different stocks, a part of which being recruited from outside the western part of the bay in *E. japonicus*, and from outside the eastern part of the bay in *E. teres* and *S.*

melanostictus. Since in all species, early larvae born in autumn were present in our study waters, recruitment from outside the bay seems to occur at the early larval stage.
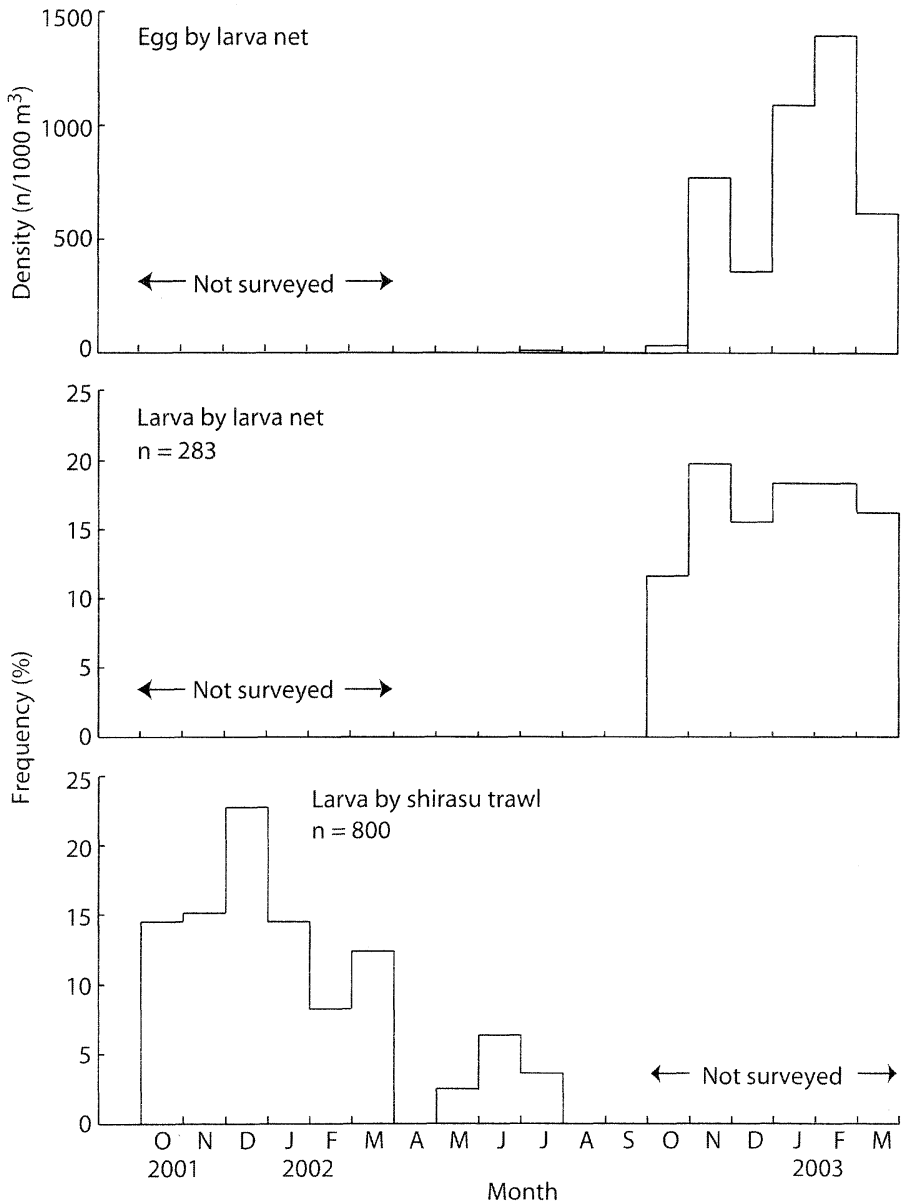
Fig. 9. *Etrumeus teres*. Otherwise same as in Fig. 8.

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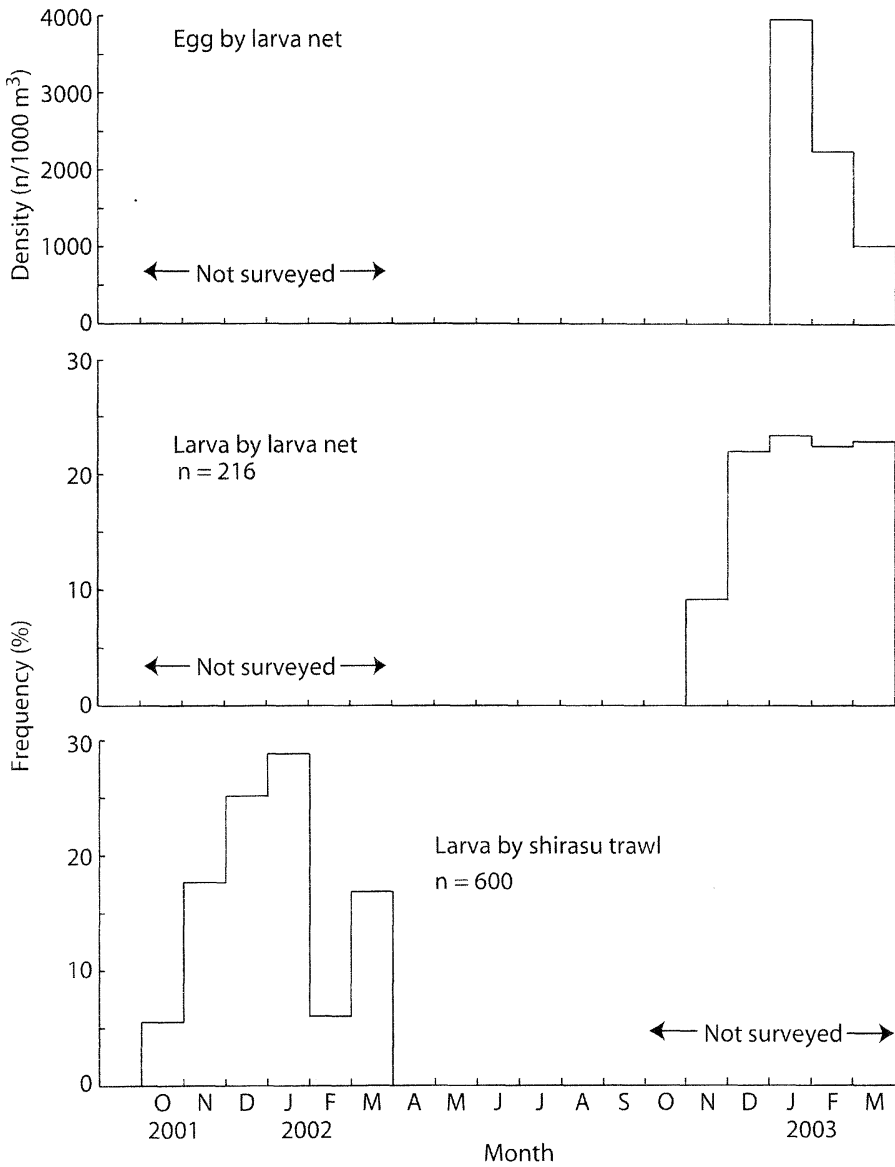
Fig. 10. *Sardinops melanostictus.* Otherwise same as in Fig. 8.

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Seasonal abundance of three clupeoid larvae and juveniles occurring in the shirasu fishery ground in central Tosa Bay, Japan

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Abstract : The community of three clupeoid (*Engraulis japonicus, Etrumeus teres* and *Sardinops melanostictus*) larvae and juveniles were examined monthly in their fishery ground in central Tosa Bay, Japan between October 2001 and September 2002. A total of *ca.* 1.5 million clupeoid larvae and juveniles were collected at four depths (5, 10, 15 and 20 m) in areas off the Niyodo River mouth. *E. japonicus* occurred all year round, and was the most abundant (*ca.* 61% of total), followed by *E. teres* (*ca.* 25%) and *S. melanostictus* (*ca.* 7%). Dominant species changed seasonally, *i.e. E. japonicus* dominated from April to October with two peaks in April and August, *E. teres* dominated from November to February with a peak in February, and *S. melanostictus* dominated in March with a peak in February. Sizes were more widely distributed and larger for both *E. teres* (7–41 mm with two modes) and *S. melanostictus* (7–41 mm with one mode) than for *E. japonicus* (7–37 mm with one mode). Age determined by ring increments on otoliths (sagittae) showed multi-modal patterns in all species, *i.e.* modes were identified around 29–30 and 49–50 days for *E. japonicus*, 9–10, 29–30, 39–40 and 49–50 days for *E. teres*, and 17–18, 25–26, 31–32 and 51–52 days for *S. melanostictus*. According to relationships between monthly changes in the modes of size, age and hatching date, migrant and resident stocks were present, and all three species tended to be longer residents in the fishery ground during winter.

Keywords : Clupeoid Larvae and Juveniles, Tosa Bay, Shirasu Fishery Ground

1. Introduction

"*Shirasu*" is a commercial Japanese term for the larvae and juveniles of fish, particularly eel and clupeoid fishes. In southern Japan, fisheries for catching clupeoid shirasu are common and commercially important, and the coastal waters facing Tosa Bay yield particularly high catches. The forming of fishery grounds for clupeoid shirasu must be no more than assemblages of their larvae and juveniles in coastal waters. Descriptions of larval and juvenile ichthyofauna have been reported in some areas (Ishiyama, 1950; Hori, 1971; Hayashi *et al.*, 1988). *Engraulis japonicus* is the main species

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in catches and studied on their early life history (Tsuji and Aoyama, 1984; Mitani, 1988a, b, c). These specimens were fragmentally shared by fishermen, and were sampled irregularly. Therefore, in order to obtain more detailed information on the community of larvae and juveniles, we employed fishermen and periodical collections were conducted. In the present paper, to better understand the mechanisms underlying the formation of shirasu fishery grounds, we examined seasonal recruitment of three clupeoid species in Tosa Bay.

2. Materials and methods

Larvae and juveniles of clupeoid species (shirasu) were sampled monthly at four stations (T1-T4) of increasing depth (5, 10, 15 and 20 m) from the mouth of the Niyodo River using trawlers between October 2001 and September 2002 (Fig. 1). Two boats towed a net along a depth-contour for *ca.* 1,000 m along each
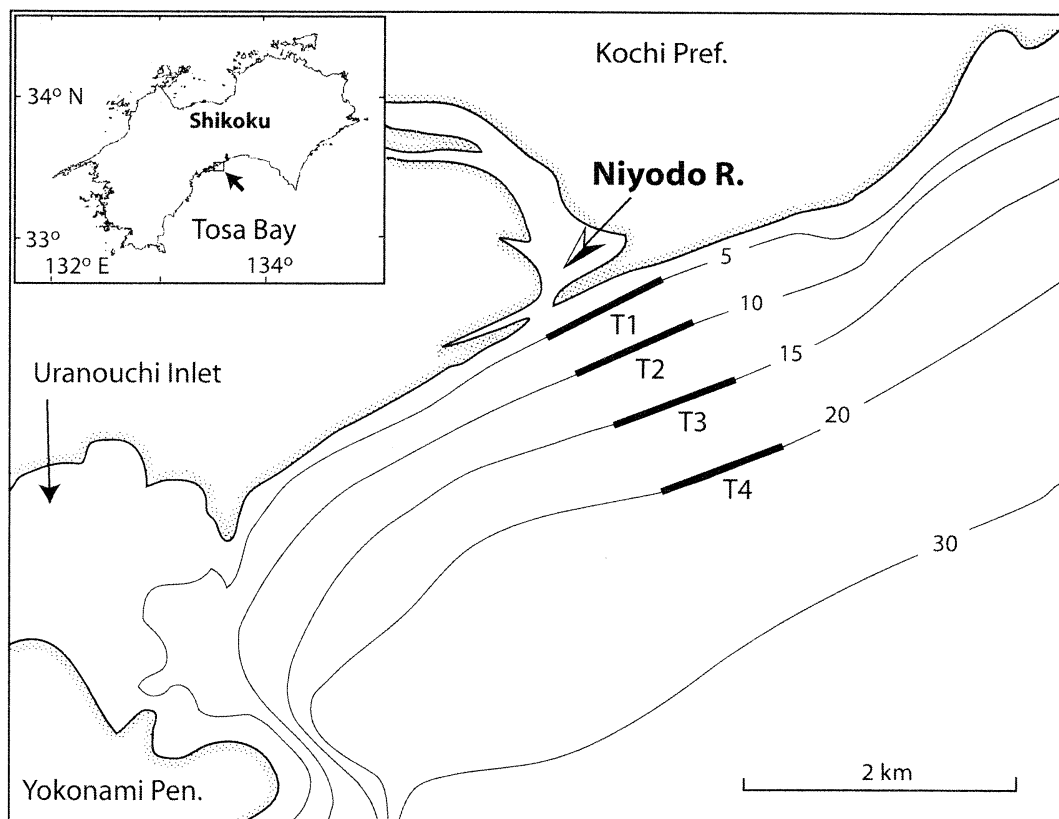
Fig. 1   A chart of Tosa Bay showing the stations (T1–T4) where larvae and juveniles were collected by shirasu trawls from October 2001 to September 2002. Stations were arranged by different depths (5, 10, 15 and 20 m).

station, the mesh aperture of bag-net was 2 mm. Water temperatures and salinities were measured using STD.

All samples fixed in 10% sea-water formalin were then transferred to 80% ethanol until clupeoid fishes were sorted based on developmental stages (KENDALL *et al.*, 1984) in the laboratory. In this study, unlabeled lengths indicate notochord length for preflexion and flexion larvae and standard length for postflexion larvae and juvenile.

A maximum of 100 specimens from collections for each species on each sampling date was selected randomly for age determination from otolith (sagitta). The right side sagittae were removed from specimens, and fixed on a microscope slide face up with epoxy resin. Rings outside the nucleus of the sagitta were counted with a light microscope at ×400–600,

and the mean of five replicate counts was used as the estimated ring number. Hatching dates were estimated from the increment of daily rings and the collection dates. The daily periodicity of increment formation on sagitta in *E. japonicus*, *E. teres* and *S. melanostictus* was determined by TSUJI and AOYAMA (1984), HAYASHI and KAWAGUCHI (1994) and HAYASHI *et al.* (1989), respectively.

3. Results
Temperature and salinity

Seasonal changes in average water temperature and salinity among the depths (0.5 m interval) of all stations are shown in Fig. 2. The temperature was highest (27.7℃) in September, and lowest (15.9℃) in February. Highest and lowest salinities were recorded at 34.6 and 32.6 psu in February and October, respectively.
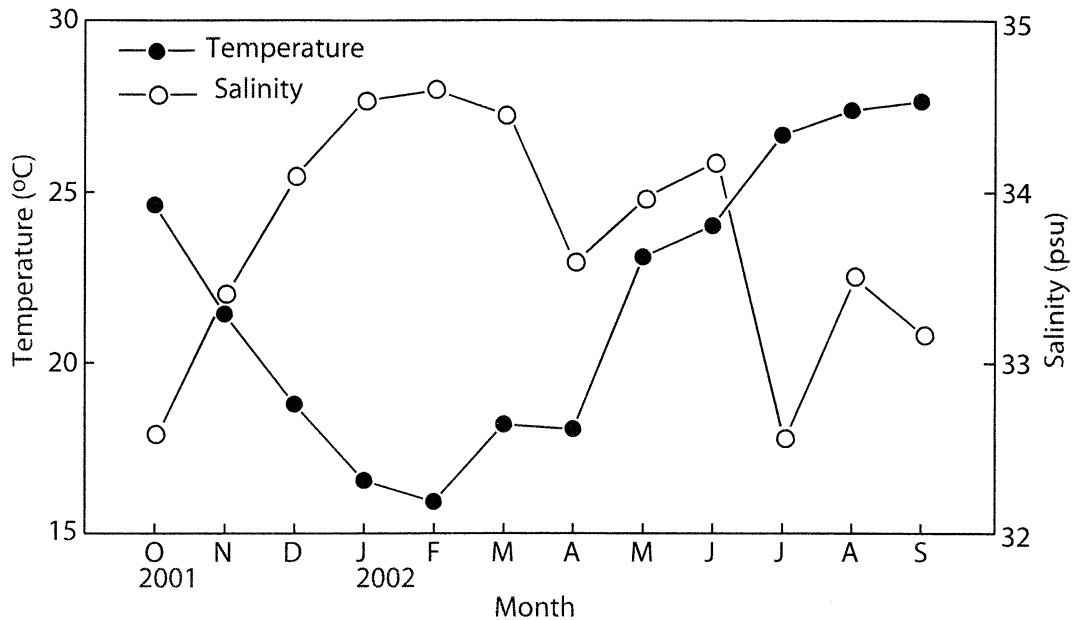
Fig. 2 Seasonal changes of mean temperatures and salinities off the mouth of Niyodo River in Tosa Bay from October 2001 to September 2002.

Table 1. List of clupeoid larvae and juveniles collected by a shirasu trawl in Tosa Bay from October 2001 to September 2002. Total number of fish larvae and juveniles = *ca.* 1.6 million. ne, not examined; +, less than 0.5%.

Species	%	Range of BL (mm)	Range of Age (day)
Engraulis japonicus	61	6.5–37.4	6–68
Etrumeus teres	25	6.6–40.5	4–80
Sardinops melanostictus	7	6.6–40.8	5–64
Sardinella zunasi	+	ne	ne
Spratelloides gracillis	+	ne	ne
Other species	7	ne	ne

The salinity was sporadically lower in July due to heavy rain. Consequently, seasonal patterns of the two physical parameters tended to be reciprocal.

Composition of clupeoid larvae and juveniles

Of *ca.* 1.6 million fish larvae and juveniles collected during the study period, *ca.* 1.5 million fish belonged to the clupeoid species. These comprised five species, with the dominant species being *Engraulis japonicus* (60.8% in numerical percentage), *Etrumeus teres* (24.7%) and *Sardinops melanostictus* (6.7%) (Table 1). Seasonal abundance of the three species is shown in Fig. 3. *E. japonicus* was present all

year round, and was dominant in October and from April to September. *E. teres* was collected all year round except in August and September, and was dominant from November to February. On the other hand, *S. melanostictus* was present in limited numbers from November to April, and became dominant only in March. The dominant species thus changed on a seasonal basis.

Total compositions of size and developmental stage of three species were shown in Fig. 3 of DJUMANTO *et al.* (2004). Juveniles larger than 30 mm were appreciably common for *E. teres* and *S. melanostictus*, but rare for *E. japonicus*. All species were chiefly composed of the
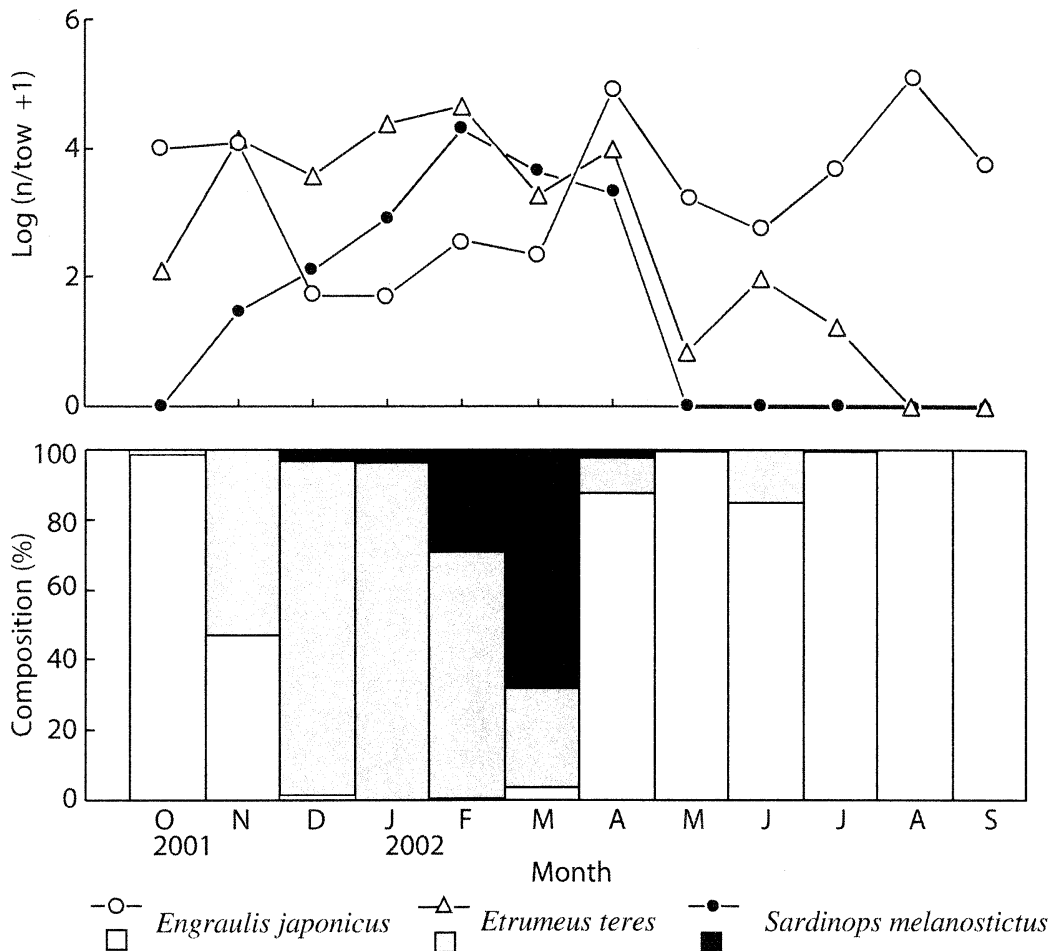
Fig. 3 Monthly fluctuations of CPUE (upper) and monthly compositions (bottom) in larvae and juveniles of three clupeoid species collected by a shirasu trawl off the mouth of Niyodo River in Tosa Bay from October 2001 to September 2002.

postflexion larva stage. Modes were considered to be 18.1–19.0 mm for *E. japonicus*, 17.1–18.0 and 24.1–25.0 mm for *E. teres* and 25.1–26.0 mm for *S. melanostictus*.

Ages were distributed from 6 to 68 days for *E. japonicus*, from 4 to 80 days for *E. teres*, and from 5 to 64 days for *S. melanostictus* (Fig. 4). Thus, age ranges for the three species were almost equal. Age frequencies also showed a multi-modal pattern, and modes were found roughly at 29–30 and 49–50 days for *E. japonicus*, 9–10, 29–30, 39–40 and 49–50 days in *E. teres*, and 17–18, 25–26, 31–32 and 51–52 days in *S. melanostictus*. Therefore, younger speci-

mens tended to occur in *E. teres* followed by *S. melanostictus* and *E. japonicus*.

Seasonal changes in size and age

In order to examine the duration of residency in the three clupeoid larvae and juveniles, their size, age and hatching date distributions were compared for each month (Figs. 5–7).

E. japonicus : Modal size increased from October to November, December to February, and June to July, and did not vary substantially during the other months. Size ranges widened from January to March, and were relatively narrow in other months. Modal age was 21–30
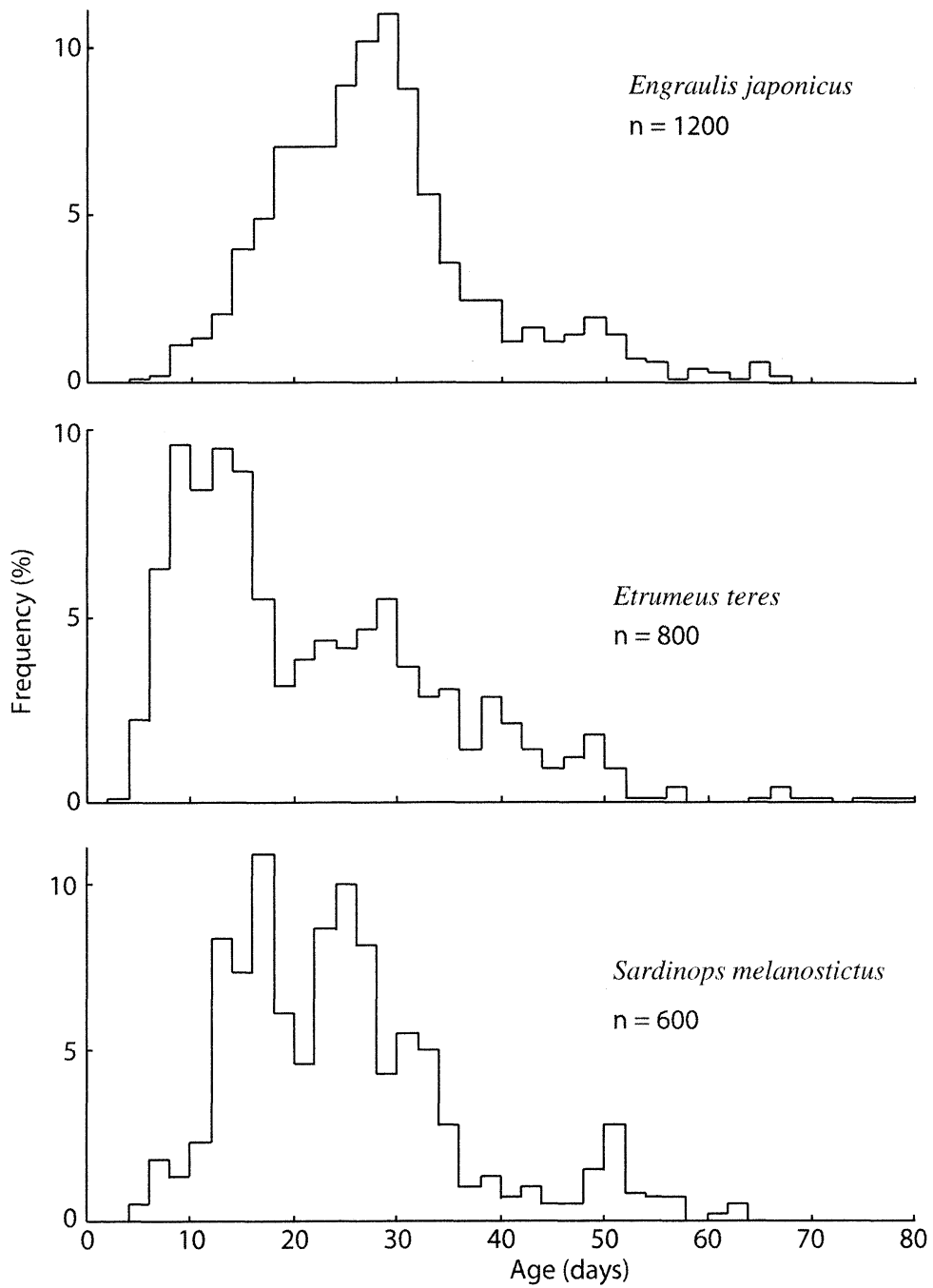
Fig. 4 Age frequencies of three clupeoid fishes collected by a shirasu trawl off the mouth of Niyodo River in Tosa Bay from October 2001 to September 2002.
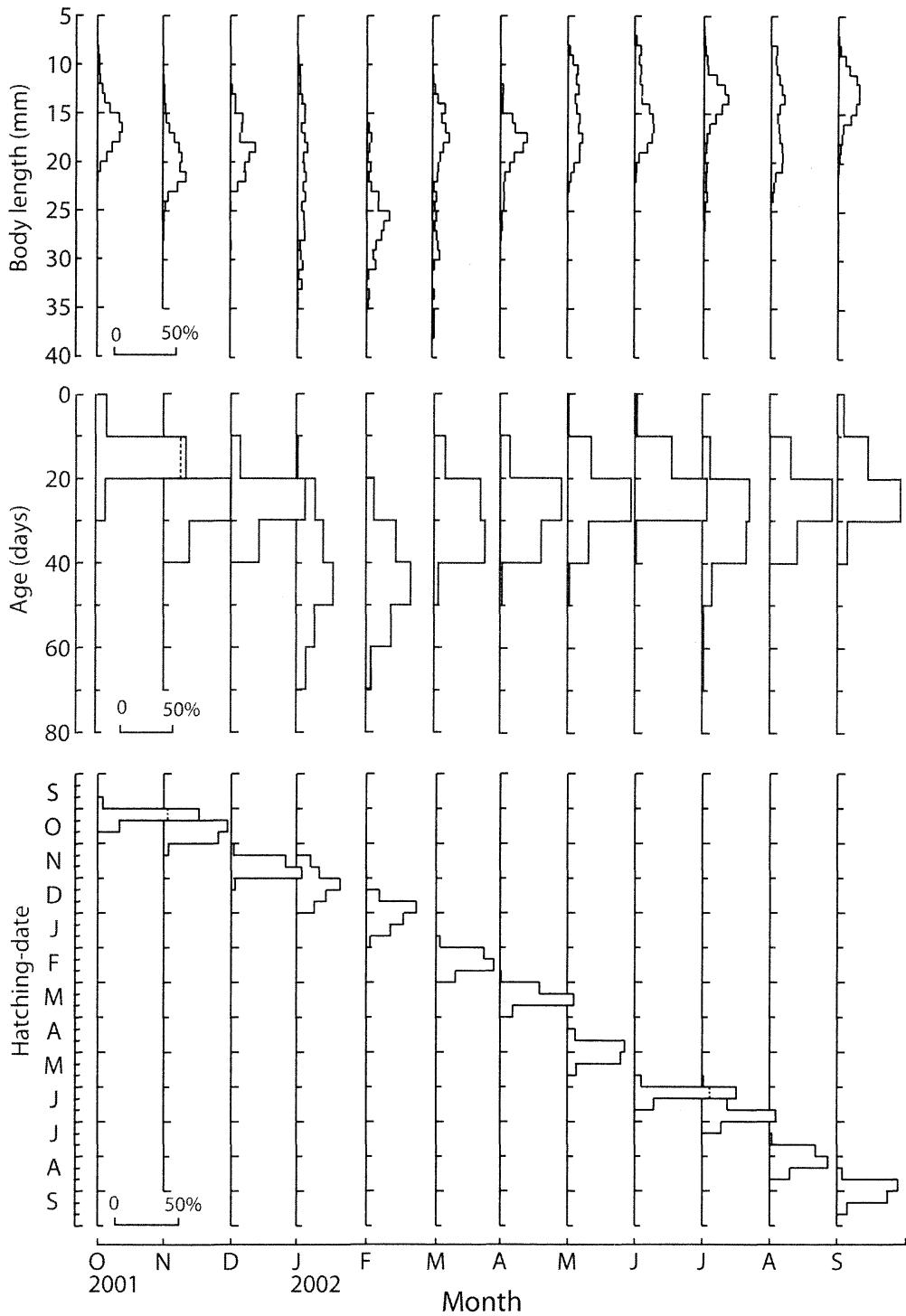
Fig. 5 Seasonal changes in the body length, age and hatching-date distributions of *Engraulis japonicus* collected by a shirasu trawl from October 2001 to September 2002.
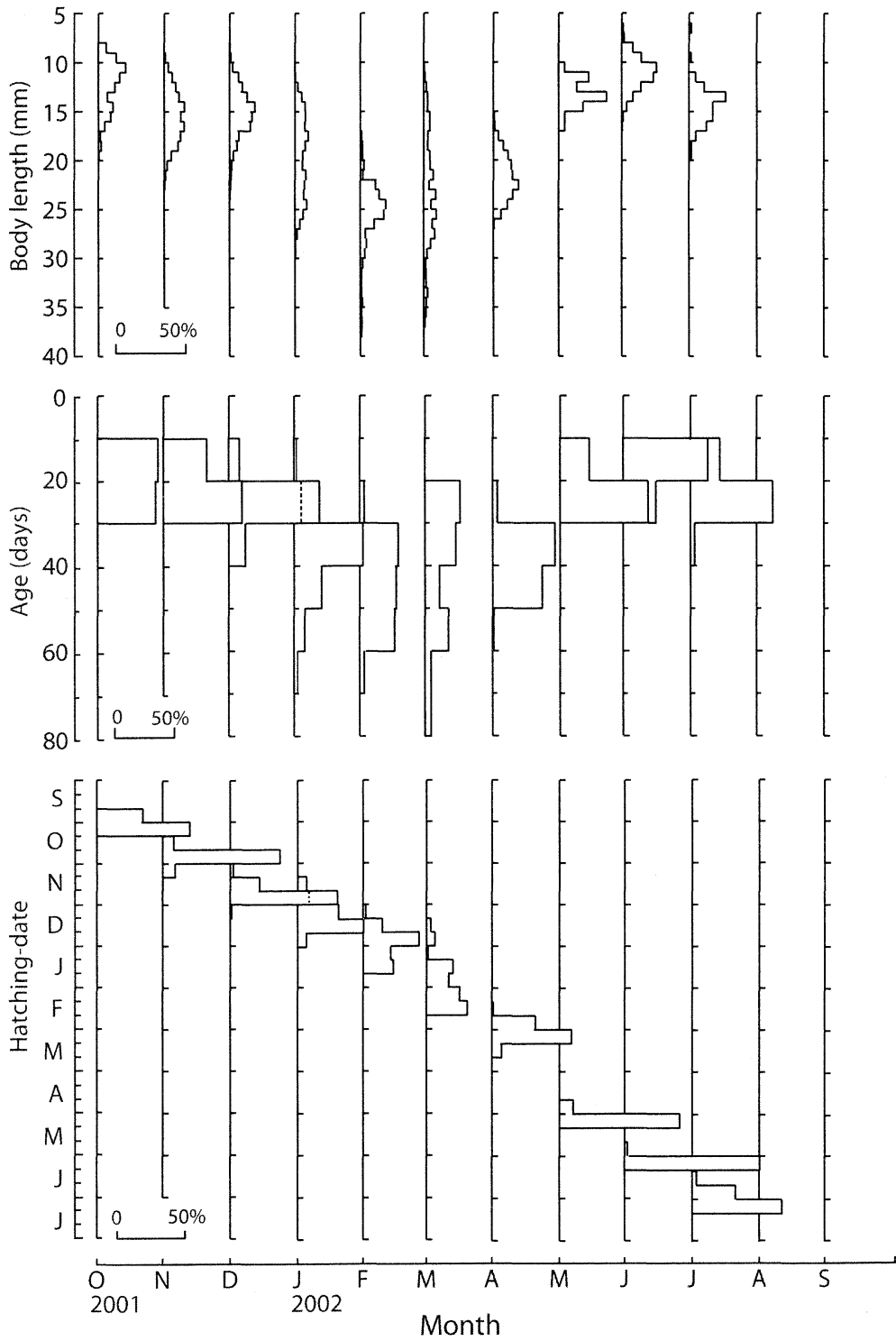
Fig. 6 *Etrumeus teres*. Otherwise same as in Fig. 5.
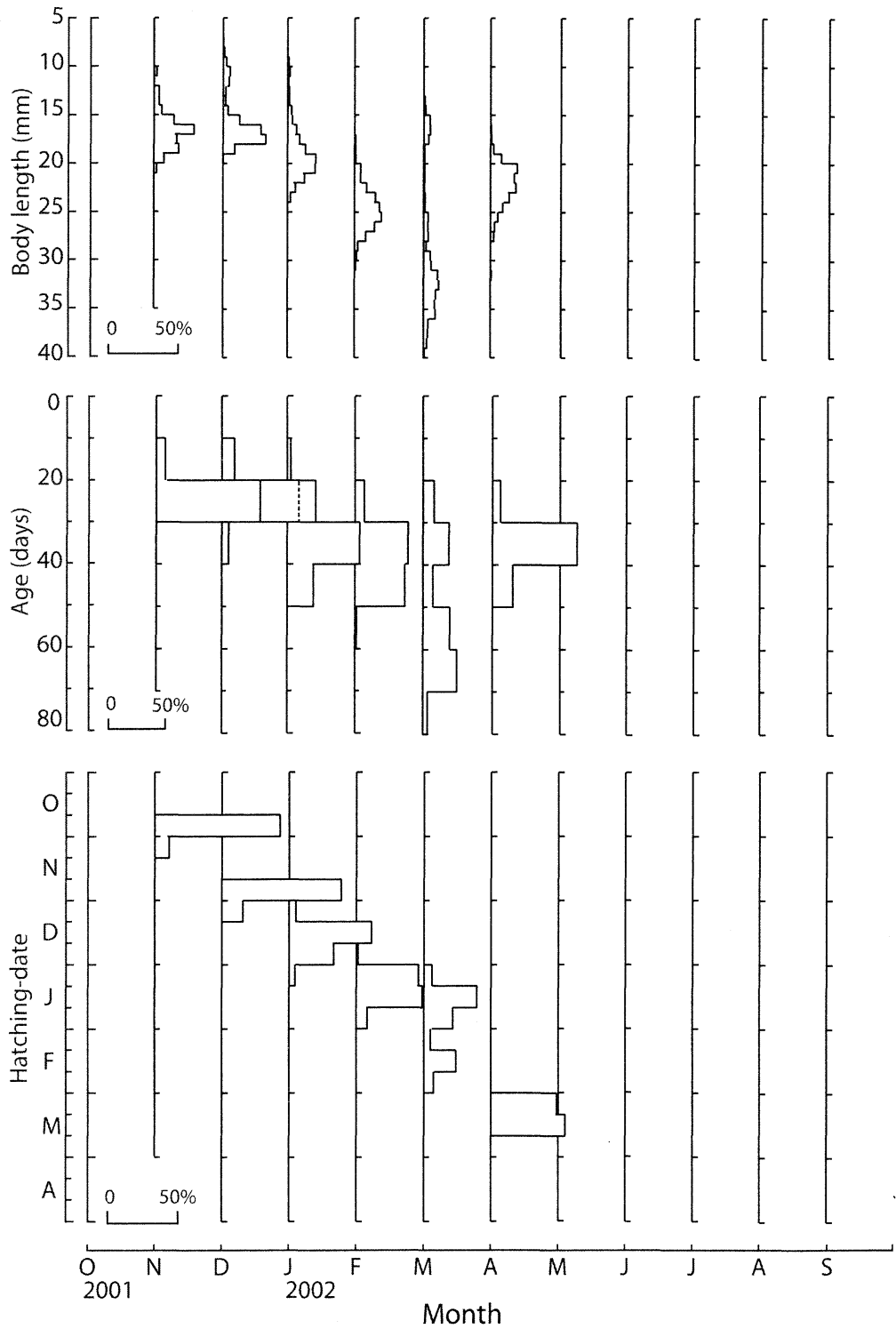
Fig. 7 *Sardinops melanostictus.* Otherwise same as in Fig. 5.

days in most months, but increased to 41–50 days in January and February, when age ranges were also wider than in other months. Hatching dates were distributed over the year, and overlapped between October and November, December and January, January and February, and June and July. The frequency distributions of other months exhibited no distinct patterns.

E. teres: Modal size increased from December to March and June to July, and remained roughly the same in other months. Size ranges widened in January-March, and were relatively narrow in other months. Modal age of 21–30 days was most frequent, and younger and older modes were present in October and June, and from January-April, respectively. Hatching dates were distributed over the year except August and September, and overlapped between January and February, and February and March, and in other months were largely isolated.

S. melanostictus : Modal size increased from January to March, but little differentiation was seen between November and December. Size ranges were wider from January to March, but were narrower in November, December and April. Modal age was at 21–30 days from November to December, 31–40 days in January, February and April, and exhibited two peaks at 31–40 and 61–70 days in March. Hatching dates were distributed from November to April, and distribution overlaps were seen from January to March.

Seasonal changes in horizontal distribution

In autumn (October-December), both *E. japonicus* and *E. teres* were dispersed, and tended to be extend their distributions beyond 2 km offshore (Fig. 8). In winter (January-March), all species were clearly aggregated 0.5 1 km offshore, while they expanded somewhat beyond 1 km offshore in spring (April-June). In summer (July-September), the most dense aggregation of *E. japonicus* was formed near the coast.

4. Discussion

Etrumeus teres larvae and juveniles were dominant from November to February, and were the major shirasu component in Tosa Bay (Fig. 3). Other coasts facing the Pacific seldom or never yield this species of shirasu (ISHIYAMA, 1950; HORI, 1970). This differentiation makes the shirasu community of Tosa Bay unique.

Larvae and juveniles of *Engraulis japonicus* and *E. teres* continued to occur in the fishery ground over most of the year (Fig. 3). This phenomenon is attributable to recruitment from stocks outside as well as inside Tosa Bay (DJUMANTO et al., 2004). *Sardinops melanostictus* larvae and juveniles occurred chiefly in winter for shorter periods than the two species above. This shows that outside stocks have the spawning period as Tosa Bay stock.

Overlapping degree of the hatching date distribution between months for three species indicate that a continual influx and departure of individuals from the fishery ground occurs. This tendency was also found in *E. japonicus* shirasu from Sagami Bay, central Japan (MITANI, 1988a). However, there were overlaps in hatching date distributions in each species. Based on these results of monthly changes of size, age and hatching date, *E. japonicus* were apparently resident during October-November, December-January-February, and June-July, and showed growth during these periods. *E. teres* and *S. melanostictus* hatched from December to February tended to remain for one month and grew in the fishery ground. Although it is unusual that species would be resident for longer periods when the water is coldest, this phenomenon may be attributable to 1) food, 2) density of the fish larva community, or 3) specificity of the cohort.

1) Food: It has been clarified that copepods are a major food source for the shirasu period of the three species (YAMASHITA, 1955, 1957a, b; YOKOTA, 1961; KUWAHARA and SUZUKI, 1984; MITANI, 1988b, c). The longer residence periods in winter may be supported by sufficient biomass of copepods as a food source. Little is known about the seasonal distribution of copepods in coastal waters, such as the fishery grounds of shirasu in Tosa Bay, but HIROTA (1998) reported seasonal abundance of copepods in surf zones of Tosa Bay where their densities were rather lower in winter. Hence, it is
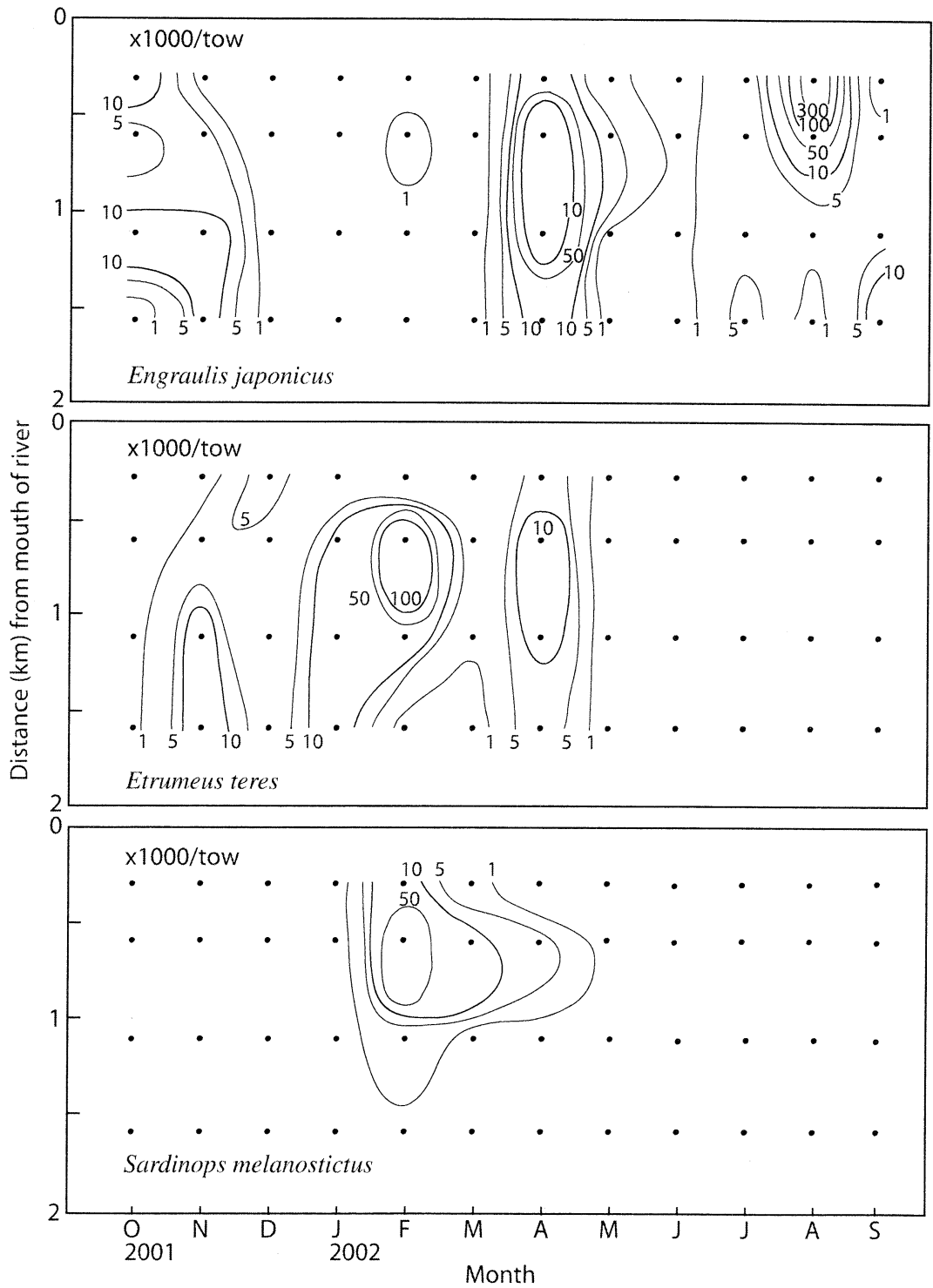
Fig. 8   Seasonal changes of horizontal distributions of three clupeoid shirasu in coastal Tosa Bay from October 2001 to September 2002.

unlikely that residency in winter is attributable to food abundance.

2) Density of the fish larva community: For the *Plecoglossus altivelis altivelis* larvae occurring along surf zones, AZUMA *et al.* (2003) speculated that transition from short- to long-term residence may be caused by an expansion of the distribution range of larvae during the mass-recruitment period, and this expansion contributed to a moderate increase in larval density in the surf zone during the mass-recruitment period. The present study also showed that cohorts became resident in October (*E. japonicus*), December, January (three species) and June (*E. japonicus*), whenever CPUE of all fish decreased (Fig. 3). This indicates that clupeoid larvae are dispersed offshore in a similar manner as *P. a. altivelis* larvae.

3) Specificity of the cohort: It should be noted that long-term resident cohorts of the three species seem to originate from stocks of outside Tosa Bay, other than *E. japonicus* born in June (DJUMANTO *et al.*, 2004). Because earlier larvae should be more easily transported, immigrants seem to grow in new waters, and are less likely to be transported further. Thus, Tosa Bay may be a terminal and supply a nursery ground for transported larvae. Furthermore, they must be recruited into the adult stocks in Tosa Bay. It is suggested this phenomenon is also found in other waters facing the Pacific, and thus these waters seem to supply fish stocks to one another.

Long-term residency of clupeoid larvae is probably attributable to the increased density of larvae and/or origination (immigrants or natives) of cohort.

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資　料

第 42 巻第 2 号掲載欧文論文要旨

加納光樹*,†・佐野光彦*・河野　博**：干潟域におけるマハゼの着底に伴う食性変化

　マハゼの浮遊期仔魚から底生期稚魚にかけての食性変化を明らかにするために，多摩川河口の干潟域で採集した287個体（体長9.7-15.9 mm）の消化管内容物を精査した。本種の主要な餌生物は，着底に伴なって，枝角類やカラヌス・キクロプス類などの動物プランクトンからハルパクチクス類などの小型底生甲殻類へと変化した。着底期の稚魚では，餌生物の大きさが減少し，消化管充満度が低くなる傾向がみられた。

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陳　苗陽*・関根義彦*：黒潮に及ぼすトカラ海峡の陸岸海底地形効果に関する数値実験

　二層数値モデルを用いて黒潮に及ぼすトカラ海峡の陸岸地形効果を調べた。数値モデル実験により，トカラ海峡の西部海域は黒潮が東シナ海にある西岸海域から離岸する海域と考えることができ，離岸に関連して高気圧渦が生じることが示された。また，南西諸島の陸棚斜面の等深線に沿う流れの性質からこの海域に南西向きの流れが下層に生じることが示された。この南西流は琉球海流と同じ場所を反対方向に流れるため，両者は衝突することになり，両者の流れが変化することが示唆された。本来琉球海流は風の海面応力の季節変化に対する順圧応答として形成されるため，鉛直に一様な流れとなる。しかし，観測では流速の鉛直変化（鉛直シアー）の存在が指摘されており，この南西流との合流で鉛直速度シアーが生じる可能性が示唆された。

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Djumanto*・木下　泉*・美藤千穂*・布部淳一*：土佐湾のシラスパッチ網漁場へのニシン亜目3種（カタクチイワシ・ウルメイワシ・マイワシ）の仔魚個体群の部分的輸送

　土佐湾において，2001年10月から2002年9月までの間，シラスパッチ漁業を用いて，イワシ亜目3種（カタクチイワシ・ウルメイワシ・マイワシ）の仔魚を毎月採集した。カタクチイワシは周年，ウルメイワシは10月から7月にかけて，そしてマイワシは11月から4月にかけてそれぞれ出現した。耳石（扁平石）の日周輪から推測された孵化日は，カタクチイワシで周年，ウルメイワシで10−3月と5−7月に，マイワシで10−3月に，それぞれ分布していた。さらに，2002年4月から2003年3月にかけて毎月，同湾沖合で行った稚魚ネットの採集物では，卵は，カタクチイワシで7−2月の間，ウルメイワシで4−10月の間，そしてマイワシで4−12月の間，ほとんどもしくは全く出現しなかった。これらの事実を他の研究機関が行った調査結果と考え合わせると，シラス漁場に11−1月に出現する3種の仔魚は，いずれも土佐湾では産卵されなかったことになる。それらの早期仔魚が稚魚ネットによって秋季，採集されていることから，それらは土佐湾外で孵化後，湾内に輸送されたに違いない。従って，シラス漁場に集積される3種の仔魚群集は複数の個体群から構成されていることが示唆された。

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Djumanto・木下　泉*・美藤千穂*・布部淳一*：土佐湾中央部におけるシラス漁場に出現するニシン亜目3種の季節変化

　2001年10月から2002年9月にかけて毎月，土佐湾中央部のシラス漁場において，ニシン亜目3種（カタクチイワシ，ウルメイワシ，マイワシ）の仔稚魚群集に関して調査を行った。仁淀川河口沖の水深（5，10，15，20m）で分けた4定点で，1年間約150万尾のニシン亜目の仔稚魚が採集された。カタクチイワシは周年出現し，最も多く採集され（全個体数の61%），ウルメイワシ（25%）とマイワシ（7%）がそれに続いた。優占種は，4-10月の間では4，8月に盛期を持つカタクチイワシ，11-2月の間では2月に盛期を持つウルメイワシ，3月では2月に盛期を持つマイワシで，季節的に変化した。体長組成は，1個のモードをもつカタクチイワシ（体長7-23mm）よりも，2個のモードをもつウルメイワシ（7-41mm）と1個のモードをもつマイワシ（7-41mm）で広かった。耳石（扁平石）の日

周輪から推測された日齢は3種ともに複雑モードがみられ，おおよそカタクチイワシで29-30と49-50日，ウルメイワシで9-10，29-30，39-40と49-50日に，そしてマイワシで17-18，25-26，31-32と51-52日にそれぞれ見られた。日齢とサイズのモードおよび孵化日の季節変化の関係から，3種とも漁場に滞在する個体群がみられ，特に，冬季でその傾向が顕著であった。

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学 会 記 事

1. 2004年6月4日（金）東京海洋大学海洋環境棟会議室において幹事会が開かれた。
   45回の総会議案を検討した。その後、評議員会が開かれた。

2. 2004年6月19日（土）日仏会館会議室において，平成16年度学術研究発表会が開かれた。発表題目と発表者は次の通り。

1. ダム排砂により海域に流入した土粒子の沈降拡散モデルの検討
   ……………○賀上裕二（（株）水圏科学コンサル）
   ・和田明・太田吉陽（日大・大學院）

2. 内浦湾における内部潮汐と乱流エネルギー逸散率との関係……………………………○福地紫
   北出裕二郎・松山優治（海洋大）

3. WOCEデータセットによる全球海洋の密度比の分布………………………○嶋田啓資・吉田次郎
   井上龍一郎（海洋大）

4. 断続光の植物プランクトンの生長への効果
   ……………○大久保べに・福井昴・荒川久幸
   森永勤（海洋大）・杉島凱夫（シーシーエス（株））

5. 現場用濁度計の比較実験
   …………○成田美穂・荒川久幸・森永勤（海洋大）
   宅和哲郎（（株）東京久栄）

6. 物体の水中視程からみた魚食性肉食魚の摂餌行動
   …………………………○森川由隆（三重大・生資）
   クリストファー・ポール・ノーマン（JST）・
   本多直人（水工研）

7. 沿岸環境モニタリングシステムの開発と応用
   ……………………………松山優治・北出裕二郎
   ○石原義之（海洋大）・川上高志（日油技研工）
   杉山正憲（内浦漁協）・鈴木基生（静岡栽培セン）

8. 瀬底島サンゴ礁における二酸化炭素分圧と大気─海洋間のCO_2フラックス
   …………………○藤村弘行・北田幸男・渡慶次亮子・
   真栄平司・大森保（琉大・理）

9. 水中バックホウによるマコンブ漁場の雑海藻除去効果 …………………北川英雄（信幸建設（株））
   大槻忠（エコ・テクノ研）・森永勤（海洋大）

10. インターネットでみる仏領ケルゲレン諸島（インド洋・南極域）の概要……八木宏樹（小樽商大・生物）

11. 海鷹丸第9次航海で観測されたケルゲレン海堆の海洋構造と深層流の流量について
    ………………………………鳴海吉洋（海洋大）

3. 2004年6月19日（土）日仏会館会議室において第45回（平成16年度）総会が開かれた。議事の内容は次の通り。

1）平成16・17年度評議員選挙結果報告
2）平成16・17年度会長選挙結果報告
3）平成16・17年度副会長・幹事・監事の選出
   副会長：山口征矢・八木宏樹
   幹事：
     庶務：森永勤　山崎秀勝
     会計：小池隆　荒川久幸
     編集：田中祐志　北出裕二郎
     研究：長島秀樹　河野博
     渉外：石丸隆　小池康之
     監事：村野正昭　岸野元彰
     編集委員長：吉田次郎
4）平成15年度事業報告
   a）庶務関係
   会員異動状況

	H15年4月	入会	退会	逝去	資格変更	16年3月
名誉会員	2	―	―	―	―	2
正会員	268	6	5	1	1	269
学生会員	10	2	5	―	―	7
賛助会員	10	―	2	―	―	8

   b）活動状況
   評議員会　1回(15/6/2)
   幹事会　4回(15/3/3, 15/6/2, 15/10/14, 15/11/18)
   総会　1回（15/6/14　日仏会館於）
   学術研究発表会　1回（15/6/14　日仏会館於）
   学会誌発行　40巻4号～41巻3号
   学会賞授与　前田昌調（宮崎大学　H15/6/14）
   論文賞授与　堀本奈穂（東京海洋大学H15/6/14）
   日仏科学シンポジウム（共催）
   文部科学
   学会誌「La mer」40 (4), 41 (1), 41 (2・3) 発刊

5）平成15年度収支決算報告および監査報告（別紙参照）

収入の部

前年度繰越金	59,017	
正会員会費	901,000	延べ150名(外為含む)
学生会員会費	18,000	5名(4000×4名, 2000×1)
賛助会員会費	130,000	8社　13口
学会誌売上金	158,649	
広　告　料	120,000	
別刷印刷費	537,900	
著者負担印刷費	730,083	
雑　収　入	53,704	要旨集売上, 学術著作権使用料他
合計	2,708,353	

支出の部

学会誌印刷費	1,847,800	40 (4), 41 (1.2-3のみ一部支払)
送料・通信費	197,836	
事　務　費	563,410	人件費, 事務用品他
交　通　費	20,090	
会　議　費	17,955	会場使用料他
学会賞経費	33,016	メダル, 賞状他
雑　　費	24,810	郵便, 銀行振込手数料　総会バイト料他
次年度繰越金	3,436	
合計	2.708.353	

原案通り承認された。

6）平成16年度事業計画（案）審議
　1）会費値上げ・論文掲載料・論文印刷ページの改定
　2）評議員会　総会　学術研究発表会　幹事会
　3）La merの発刊
　4）ケルゲレン諸島学術調査事業に参画
　5）日仏科学シンポジウム（共催）

7）平成16年度予算（案）審議

収入の部

前年度繰越金	3,436	
正会員会費	1,320,000	165×8,000円
65歳以上会費	150,000	25×6,000円
学生会員会費	20,000	5×4,000円
賛助会員会費	130,000	8社　13口
学会誌売上金	160,000	
広　告　料	60,000	
別刷印刷費	540,000	
著者負担印刷費	800,000	16偏×50,000円
雑　収　入	60,000	学術著作権使用料他
合計	3,243,436	

支出の部

前年度未払金	226,145	41 (2-3) の1部
学会誌印刷費	2,000,000	41 (4), 42 (1, 2, 3) ×500,000円
送料・通信費	190,000	
事　務　費	700,000	人件費, 事務用　備品他
交　通　費	20,000	
会　議　費	20,000	会場使用料, 総会バイト料他
学会賞経費	35,000	メダル研磨代　賞状他
雑　　費	25,000	郵便, 銀行振込手数料　総会バイト料他
予　備　費	27,291	
合計	3,243,436	

原案通り承認された。

4. その他

　引き続いて磯田豊会員への学会賞授与と受賞記念講演が行われた。また藤村弘行会員へ論文賞受賞授与が行われた。終了後アトレ恵比寿店ライオンで懇親会が開かれ盛会裡に終了した。

5. 新入会員

氏名	所属	紹介者
YESSY ARVELYNA	東京海洋大学海洋工学部 〒135-8533 東京都江東区越中島2-1-6	吉田次郎
黒部典子	近畿大学研究員 〒世田谷区喜多見4-28-23	森永　勤

6. 退会（逝去者含）
　隆島史夫　平野敏行

賛　助　会　員

日仏海洋学会入会申込書

（正会員・学生会員）

	年度より入会	年　　月　　日申込
氏　名 ローマ字		年　　月　　日 生
勤務先　　住　所　〒 　　　　　機関名 　　　　　電　話		
自　宅　住　所　〒 　　　　　電　話		
紹介会員氏名		
送付金額　　　　　　　　円	送金方法	
会誌の送り先（希望する方に〇をつける）	勤務先　　　　　自　宅	

（以下は学会事務局用）

受付	名簿 原簿	会費 原簿	あて名 カード	学会 記事

入会申込書送付先：〒150-0013 東京都渋谷区恵比寿 3-9-25

（財）日仏会館内

日 仏 海 洋 学 会

郵便振替番号：00150−7−96503

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う　み

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2004年5月

日 仏 海 洋 学 会