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Temporal and Spatial Variation in Fish Larvae in Gamak Bay and Yeoja Bay, South Sea of Korea

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Fish larvae were collected monthly with an ichthyoplankton net from 18 stations (including four stations located in eelgrass beds) in Gamak Bay and Yeoja Bay, southern Korea, in 2007. In total, 33 species of fish larvae were collected, of which *Engraulis japonicus* (48.5%), *Tridentiger trigonocephalus* (21.5%), and *Omobranchus elegans* (9.2%) were dominant. Dominant species varied seasonally: *Hexagrammos otakii* during December and January, *Pholis nebulosa* during January and March, *Acanthogobius flavimanus* in April, *T. trigonocephalus* in May, *E. japonicus* during June, July, September, and November, and *Sillago japonica* in August. Dominant species also differed between sites inside and outside the bays. *Leiognathus nuchalis*, *O. elegans*, and *T. trigonocephalus* were more abundant inside, while *H. otakii* was more abundant outside. From cluster analysis, three groups were identified according to sampling months (January-April, May-September, and October-December) and two groups according to station (inside and outside bays). The occurrence of small larvae of almost all major fish species indicated that the bays were used as spawning and nursery grounds. An exception was *Lateolabrax japonicus*, whose specimens were relatively large (>19 mm TL), suggesting that this fish may spawn offshore, with its juveniles approaching the bays with growth.

Key words: Larval fish, Gamak Bay, Yeoja Bay, Variation, Eelgrass

Introduction

Ichthyoplankton has been investigated in estuaries or bays because these areas are easily influenced by human activity (i.e., pollution) (Lasker, 1987). In Korea, ichthyoplankton has been surveyed at various sites, including Jinhae Bay (Yoo et al., 1992), Yoja Bay (Yoo et al., 1993), Kwangyang Bay (Yoo and Cha, 1988; Cha and Park, 1994), Asan Bay (Kim et al., 1994), Sunchon Bay (Han et al., 2001), the Youngsan River estuary (Kim et al., 2003), and Yeongil Bay (Han et al., 2003). All of these studies focused on the role of bays as spawning or nursery grounds for fishes.

Yeoja Bay is characterized by its shallow water (average depth ~5.4 m) and narrow entrance, resulting in poor water exchange between areas inside and outside of the bay (Yoo et al., 1993; Kim et al., 2009). In contrast, Gamak Bay is characterized by slightly deeper water (average depth ~6.8-9 m) and wide entrance, resulting in three different water masses (An et al., 2009). Thus, although these two neighboring bays are close to one another, they have some differences in topographic and oceanographic conditions. In a recent study, Kim et al. (2009) used dragnets to compare the community structure of young fish between the eelgrass beds in Yeoja Bay and those in Gamak Bay. The results showed no differences in community structure, but slight differences in the abundance and growth rate of *Lateolabrax japonicus* between the two neighboring eelgrass beds (Kim et al., 2009). It also documented that eelgrass beds play key roles as nursery grounds or shelters for fish such as *L. japonicus*, *Leiognathus nuchalis*, *Pholis nebulosus*, *Takifugu niphobles*, *Tridentiger trigonocephalus*, and *Syngnathus schlegeli* in the southern seas of Korea. However, only a few studies have examined the use of eelgrass beds as spawning grounds. Such research may provide important information and increase our understanding

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of the ecosystem structure of bays including eelgrass beds. Thus, this study aimed to clarify overall variations in fish larvae inside and outside two neighboring bays which include eelgrass beds.

Materials and Methods

Water temperature, salinity, pH, and dissolved oxygen (DO) were measured and ichthyoplankton was collected by horizontal hauls using an RN80 net (diameter of net mouth 80 cm, mesh size 330 µm) for 10 min once a month between January and December 2007 at 18 stations in the Yeoja and Gamak bays of Yeosu, in the South Sea of Korea (Fig. 1). The locations of stations were determined by the method of Margalef (1978). The volume of water filtered by the net was measured by a flow meter (Hydro Co., USA) attached at the mouth of the net. Collected samples were fixed in 5% neutral formalin on board the research ship before being transferred to the laboratory for sorting, species identification, and measurement. Species were identified according to Okiyama (1988). We classified the stations into four areas: inside Yeoja Bay (Yi1, Yi2, Yi3, Yi4, Ye1, Ye2), outside Yeoja Bay (Yo1, Yo2, Yo3, Yo4), inside Gamak Bay (Gi1, Gi2, Ge1, Ge2), and outside Gamak Bay (Go1, Go2, Go3, Go4) to better understand the distribution characteristics of the fish larvae. Of these sampling sites, Ye1-Ye2 and Ge1-Ge2 are located in eelgrass beds inside Yeoja Bay and Gamak Bay, respectively.

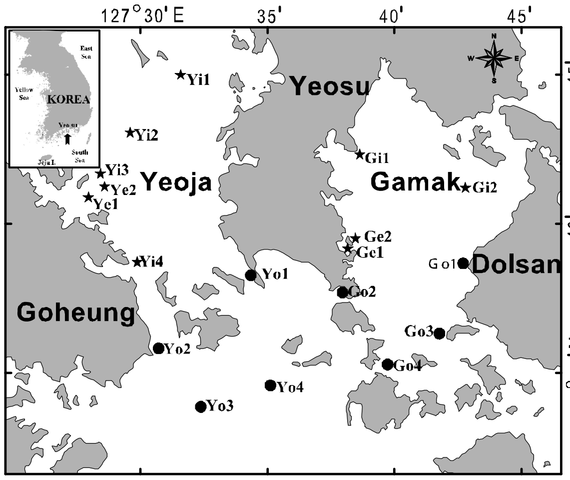

Fig. 1. Map showing the sampling stations to collect fish larvae in Gamak Bay and Yeoja Bay between January and December, 2007. Stars indicate the stations inside the bays and circles outside the bays.

On the basis of the number of larval fish caught each month, a species diversity index (H′; Shannon and Weaver, 1948) was calculated, and a dendrogram was constructed using the unweighted pair group with arithmetic mean (UPGMA) method after the Bray-Curtis similarity was calculated for cluster analysis (Zar, 1999). For the cluster analysis, species contribution to the grouping was evaluated according to SIMPER analysis. All statistical analyses were performed using PRIMER ver. 5.0.

Results

Hydrology

Sea surface temperature (SST) in the study area ranged from 7.2-24.9°C (mean±SD: 15.9±0.8°C) and was lowest in January and highest in September (Fig. 2A). The sea surface salinity was 29.3-33.2 psu (mean±SD: 32.5±0.5 psu), with lowest values in September and highest values in January-April (Fig. 2B). Sea surface pH was 7.6-8.3 (mean±SD: 8.0±0.2) and was lowest in November-December (Fig. 2C). Sea surface DO ranged from 5.1-11.2 mg/L (mean±SD: 8.8±0.8 mg/L), with lowest values in October and highest values in December (Fig. 2D).

Larval fish species composition and distribution

Fish larvae were classified into four orders, 24 families, and 33 species; 22 species were identified to the species level. Of these, *Engraulis japonicus* (48.63%), *T. trigonocephalus* (21.33%), and *Omobranchus elegans* (9.2%) were predominant (Table 1). The dominant species varied seasonally with *Hexagrammos otakii* dominating during December and January, *Pholis nebulosa* during January and March, *Acanthogobius flavimanus* in April, *T. trigonocephalus* in May, *E. japonicus* during June and July and during September and November, and *Sillago japonica* in August. At Yeoja Bay, *E. japonicus*, *L. nuchalis*, *O. elegans*, *T. trigonocephalus*, and *P. nebulosa* were more abundant inside, while *H. otakii* was more abundant outside the bay (Table 2). At Gamak Bay, Gobiidae sp., *O. elegans*, *T. trigonocephalus*, and *S. japonica* were more abundant inside, and *H. otakii* was more abundant outside (Table 3).

Relationship between larval fish occurrence and SST

Samples collected during June and November 2007 contained 7-3,655 *E. japonicus* individuals/100 m^3, with total lengths ranging from 1.6 to 8.6 mm (3.7±1.4 mm; Table 1). Of these, 87% were collected at

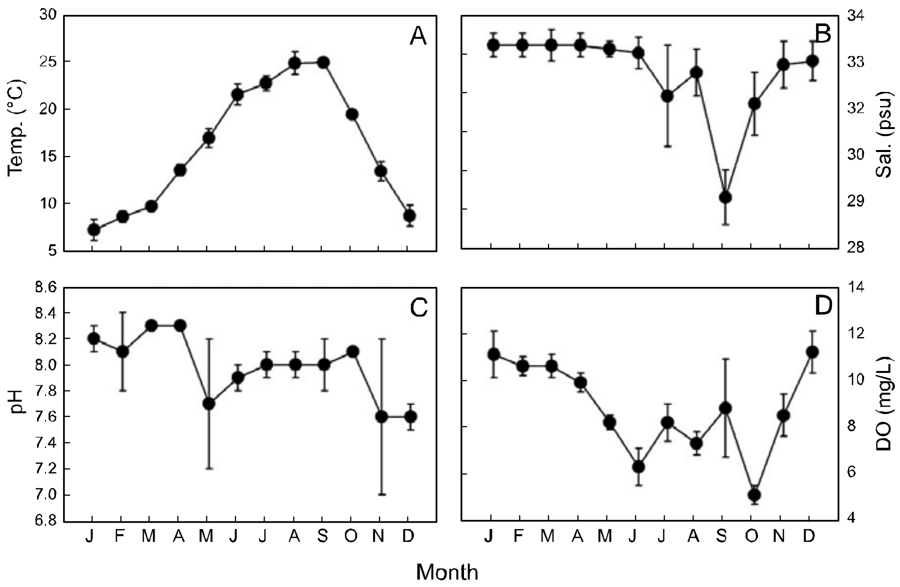

Fig. 2. Monthly variation of sea surface temperature (A), salinity (B), pH (C) and dissolved oxygen (D) in Gamak Bay and Yeoja Bay between January and December, 2007.

Table 1. Temporal variation in the number of individuals for larval fish collected in Gamak Bay and Yeoja Bay between January and December, 2007 (inds./1,800m^3)

Scientific name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	%
Engraulis japonicus	0	0	0	0	4	1,674	3,655	35	108	30	7	0	48.63
Clupea pallasii	0	4	0	0	0	0	0	0	0	0	0	0	0.04
Konosirus punctatus	0	0	0	0	0	3	0	0	0	0	0	0	0.03
Syngnathus schlegeli	0	0	0	0	2	0	7	0	0	0	0	0	0.08
Sebastes inermis	0	0	0	3	0	5	0	0	0	0	0	1	0.08
Platycephalus indicus	0	0	0	0	0	0	0	1	0	0	0	0	0.01
Hexagrammos otakii	27	0	0	0	0	0	0	0	0	0	6	508	4.77
Pseudoblennius cottoides	0	0	0	0	0	1	0	0	0	0	0	0	0.01
Liparis tanakai	3	0	0	0	0	0	0	0	0	0	0	3	0.05
Lateolabrax japonicus	0	0	0	2	2	0	0	0	0	0	0	0	0.04
Sillago japonica	0	0	0	0	0	0	141	174	3	0	0	0	2.81
Leiognathus nuchalis	0	0	0	0	0	0	395	42	0	0	0	0	3.85
Haemulidae sp.	0	0	0	0	0	0	0	1	0	0	0	0	0.01
Acanthopagrus schlegeli	0	0	0	0	0	22	8	0	0	0	0	0	0.26
Pagrus major	0	0	0	0	0	74	1	0	0	0	0	0	0.66
Terapon jarbua	0	0	0	0	0	2	0	0	10	0	0	0	0.11
Stichaeidae sp.	0	0	0	0	0	5	0	0	0	0	0	0	0.04
Ernogrammus hexagrammus	23	4	0	0	0	0	0	0	0	0	0	0	0.24
Pholis nebulosa	27	55	7	8	0	0	0	0	0	0	0	0	0.86
Enneapterygius sp.	0	7	0	0	0	0	0	0	0	0	0	0	0.06
Blenniidae sp.	0	0	0	0	0	0	0	0	0	0	3	0	0.03
Omobranchus elegan	0	0	0	0	0	887	61	46	39	10	0	0	9.20
Repomucenus sp.	0	0	0	0	0	0	0	0	0	3	0	0	0.03
Acanthogobius flavimanus	0	0	0	174	0	73	0	0	0	0	0	0	2.18
Luciogobius sp.	0	0	0	0	3	0	2	0	0	0	0	0	0.04
Synechogobius hasta	0	0	0	4	0	0	0	0	0	0	0	0	0.04
Tridentiger trigonocephalus	0	0	0	0	76	212	2,035	92	3	0	0	0	21.33
Gobiidae sp.	0	0	0	0	4	334	0	12	0	0	0	0	3.09
Scomber japonicus	0	0	1	22	0	0	0	0	0	0	0	0	0.20
Paralichthyidae sp.	0	0	0	0	0	0	8	0	0	0	0	0	0.07
Pleuronectidae sp.	0	0	0	0	0	0	0	0	0	2	0	25	0.24
Cynoglossidae sp.	0	0	0	0	0	0	71	9	5	0	0	0	0.75
Unidentified sp.	0	0	0	0	0	5	15	0	0	0	0	0	0.18
No. of species	4	4	2	6	6	13	12	9	6	4	3	4	
%	0.71	0.62	0.07	1.88	0.80	29.1	56.4	3.63	1.48	0.40	0.14	4.74	100

Table 2. Spatial variation in the number of individuals for larval fish collected in Yeoja Bay between January and December, 2007 (inds./1,200m^3)

Scientific name	Inside				Eelgrass		Outside			
	Yi1	Yi2	Yi3	Yi4	Ye1	Ye2	Yo1	Yo2	Yo3	Yo4
Engraulis japonicus	362	341	687	125	18	998	514	25	96	39
Konosirus punctatus	0	0	3	0	0	0	0	0	0	0
Syngnathus schlegeli	0	0	0	0	0	0	2	0	0	0
Sebastes inermis	0	0	0	0	0	0	5	1	0	0
Hexagrammos otakii	0	1	16	7	0	13	135	45	50	11
Pseudoblennius cottoides	0	0	0	0	0	0	0	0	1	0
Liparis tanakai	1	0	0	0	0	0	3	0	0	0
Sillago japonica	0	33	3	2	45	49	0	0	4	42
Leiognathus nuchalis	254	12	0	3	0	0	21	21	0	10
Acanthopagrus schlegeli	0	0	3	2	0	0	15	2	0	2
Pagrus major	22	0	0	0	2	40	0	0	0	0
Terapon jarbua	0	2	3	0	2	0	0	2	0	3
Ernogrammus hexagrammus	0	0	23	0	0	0	0	4	0	0
Pholis nebulosa	12	1	30	2	0	2	7	0	0	25
Enneapterygius sp.	0	0	7	0	0	0	0	0	0	0
Blenniidae sp.	0	0	0	0	0	2	0	0	0	0
Omobranchus elegans	0	529	118	2	0	9	26	2	2	2
Acanthogobius flavimanus	0	48	0	0	37	5	8	0	0	0
Luciogobius sp.	0	0	0	0	0	0	4	0	1	0
Synechogobius hasta	0	0	4	0	0	0	0	0	0	0
Tridentiger trigonocephalus	19	40	321	0	91	383	45	33	29	71
Gobiidae sp.	19	6	0	0	4	27	0	6	43	0
Paralichthyidae sp.	0	6	0	0	2	0	0	0	0	0
Pleuronectidae sp.	0	0	2	0	0	2	2	0	0	0
Cynoglossidae sp.	0	5	0	0	0	3	7	4	2	4
Unidentified sp.	0	6	0	0	0	0	10	0	0	0
No. of species	7	12	12	7	8	11	14	11	8	25

SSTs of 20.3-23.3°C. There were 6-508 individuals/100 m^3 of *H. otakii* collected in January and during November and December 2007 (Table 1), with total lengths ranging from 7.0-20 mm (8.6 ± 2.5 mm), and 79% occurring at SSTs of 7.6-10.4°C. Samples collected during January and April 2007 included 7-55 *P. nebulosus* individuals/100 m^3, with total lengths ranging from 5.0-35 mm (21 ± 10 mm), and 62% being collected at SSTs of 7.3-8.9°C. Approximately 10-887 *O. elegans* individuals/100 m^3 were collected during June and October 2007; their overall lengths ranged from 1.7 to 8.0 mm (4.0 ± 2.3 mm), and 75% were collected at SSTs of 22.3-23.4°C. There were 3-174 individuals/100 m^3 of *S. japonica* collected during July and September 2007; their total lengths were 1.2-9.0 mm (3.3 ± 1.6 mm), and 75% were collected at SSTs of 22.3-23.4°C. During May and September 2007, 3-2,035 individuals/100 m^3 of *T. trigonocephalus* were collected, with total lengths in the range of 1.5-6.5 mm (2.5 ± 1.1 mm), and 71% were collected at SSTs of 22.6-23.3°C.

Diversity and community structure

Species diversity ranged from 0.24-1.60 (0.92 ± 0.39) and was lowest in December and highest in August. Cluster analysis based on the number of individuals collected in each month yielded three groups: group A (January-April), group B (May-September), and group C (October-December) (Fig. 3). In group A, the contribution of *P. nebulosa* was highest (93.3%). However, in group B, the contribution of *E. japonicus* was highest (42.5%), followed by that of *T. trigonocephalus* at 35.0%. In group C, *E. japonicus* made the highest contribution at 88.9%, followed by *H. otakii* at 8.4%. Cluster analysis based on the numbers of individuals collected at each station yielded two groups: group A (inside the bays) and group B (outside the bays) (Fig. 4). Although the groups did not correspond exclusively to stations inside and outside the bays, they showed a tendency to divide in this way.

Discussion

This study compared larval fish compositions in Yeoja Bay and Gamak Bay with the compositions of young fish previously reported by Kim et al. (2009) to further clarify the function of bays including

Table 3. Spatial variation in the number of individuals for larval fish collected in Gamak Bay between January and December, 2007 (inds./1,200m^3)

Scientific name	Inside		Eelgrass		Outside			
	Gi1	Gi2	Ge1	Ge2	Go1	Go2	Go3	Go4
Engraulis japonicus	27	1,687	21	362	11	53	54	93
Clupea pallasii	0	0	4	0	0	0	0	0
Syngnathus schlegeli	4	0	3	0	0	0	0	0
Sebastes inermis	3	0	0	0	0	0	0	0
Platycephalus indicus	0	0	0	0	1	0	0	0
Hexagrammos otakii	66	44	2	19	24	2	93	13
Liparis tanakai	0	0	0	0	0	2	0	0
Lateolabrax japonicus	0	0	2	0	0	2	0	0
Sillago japonica	74	2	15	13	1	0	26	9
Leiognathus nuchalis	74	0	7	24	0	7	0	4
Haemulidae sp.	0	0	0	0	0	1	0	0
Acanthopagrus schlegelii	0	0	0	0	0	0	0	6
Pagrus major	0	0	1	0	0	0	10	0
Stichaeidae sp.	5	0	0	0	0	0	0	0
Pholis nebulosa	0	7	1	0	0	8	2	0
Blenniidae sp.	0	0	0	0	0	1	0	0
Omobranchus elegans	169	1	11	43	1	29	91	8
Repomucenus sp.	1	1	0	0	0	0	1	0
Acanthogobius flavimanus	0	0	7	2	83	25	4	28
Tridentiger trigonocephalus	37	28	446	605	205	35	26	4
Gobiidae sp.	245	0	0	0	0	0	0	0
Scomber japonicus	0	0	0	0	10	1	10	2
Pleuronectidae sp.	21	0	0	0	0	0	0	0
Cynoglossidae sp.	0	0	0	0	32	0	26	2
Unidentified sp.	4	0	0	0	0	0	0	0
No. of species	13	7	12	6	7	12	9	10

eelgrass (*Z. marina*) beds as spawning grounds. We found a total of 33 larval fish species in Yeoja and Gamak bays in the South Sea of Korea, whereas a total of 40 young fish species were previously reported from eelgrass beds (Kim et al., 2009). Among these species, 14 species were found as both larval (this study) and young (Kim et al., 2009) fish, including *E. japonicus*, *K. punctatus*, *Clupea pallasii*, *H. otakii*, *A. schlegeli*, and *Pagrus major* (Table 4).

The diversity index was highest for larval fish in August and for young fish in July (Kim et al., 2009). These data indicate that both larval and young fish are most diverse in Yeoja and Gamak bays during warm months. No meaningful differences were found when comparing the species composition and abundance of fish larvae in eelgrass beds (Ye1, Ye2, Ge1, and Ge2) with those at stations inside and outside the bay (Tables 2, 3).

Hannan and Williams (1998) suggested that optimal recruitment of ocean-spawned juveniles to seagrass habitats may depend on the availability of suitable habitat near a bay entrance. In contrast, in this study, cluster analysis produced two groups, inside (group A) and outside (group B) the bays (Fig. 4). For August, when species diversity was highest, the two bays tended to be slightly divided into inside and outside areas according to the criteria of 25°C SST (Fig. 5A) and 32.6 psu salinity (Fig. 5B).

Engraulis japonicus was the predominant species, with larvae appearing in May-November and young fish in April-October (Table 4). *Engraulis japonicus* is known to spawn from March to November (mainly May-July) along the Korean coast (Lim and Ok, 1977), which is consistent with our results, in which the numbers of larval *E. japonicus* individuals peaked during June and July (Table 1). However, the larval distribution of *E. japonicus* may not be related to the presence of eelgrass beds, as this species occurs broadly across the South Sea. *Hexagrammos otakii* larvae appeared in November, December, and January and young fish occurred in February-May, implying that the species uses this area as spawning and nursery grounds. Kang et al. (2004) reported that *H. otakii* spawn from September to December on the west coast of Korea, which is the same as or earlier than our results. This difference may be due to regional variation, as the species spawns from November to January on the south coast of Korea (Kim et al., 1993), which is consistent with our results (Table 1). The total lengths of *L. japonicus*

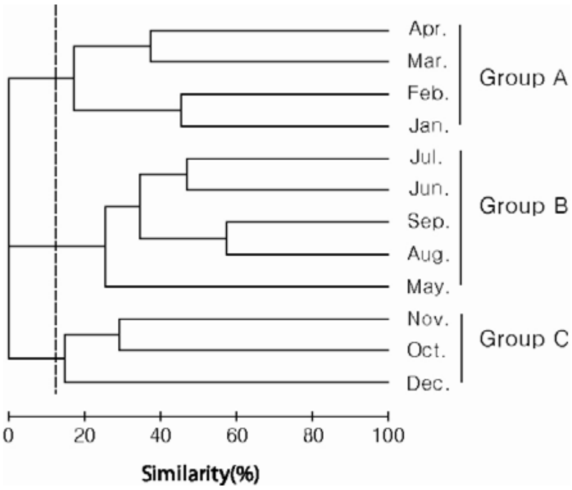

Fig. 3. Dendrogram illustrating relationship among sampling months based on the number of individuals collected in Gamak Bay and Yeoja Bay between January and December, 2007.

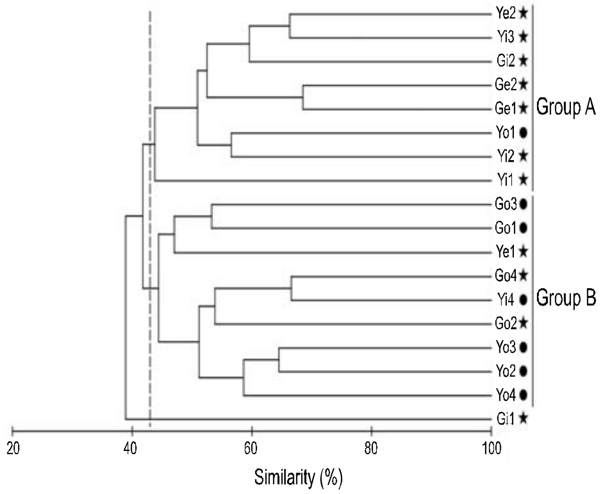

Fig. 4. Dendrogram illustrating relationship among sampling stations based on the number of individuals collected in Gamak Bay and Yeoja Bay between January an December, 2007. Stars and circles indicate inside and outside the bays, respectively.

juveniles collected during April-May were 19-27 mm, the size estimated by Han et al. (1999) to characterize fish 2-3 months after hatching. This result suggests that this species does not spawn near eelgrass beds, but instead spawns and hatches offshore and approaches bays as it grows, to live as young fish in eelgrass beds with abundant food. However, *P. major* larvae were collected in June-July and young fish were collected in July, suggesting that *P. major* use the waters inside bays as their spawning and nursery grounds. *Pholis nebulosa* larvae occurred in January-April and young fish in January-June, suggesting that this fish also uses waters inside the bays as spawning and nursery grounds. When the numbers of larval individuals inside and outside the bays were compared by species, *T. trigonocephalus* was most frequent in the eelgrass beds (Tables 2, 3), suggesting that it is a typical species using the eelgrass beds as a spawning ground. The numbers of larval individuals of *O. elegans* and *P. nebulosa* were higher inside than outside the bays. These species likely use the waters

Table 4. Occurrence of larvae (present study) and young fish (Kim et al., 2009) in the Yeoja Bay and Gamak Bay

Species	Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Engraulis japonicus	larvae					—	—	—	—	—	—	—	
	young				—	—	—	—	—	—	—		
Clupea pallasii	larvae		—										
	young				—	—							
Konosirus punctatus	larvae						—						
	young								—	—			
Hexagrammos otakii	larvae	—										—	—
	young			—	—	—							
Lateolabrax japonicus	larvae												
	young				—	—	—	—	—	—	—	—	—
Acanthopagrus schlegeli	larvae						—	—					
	young						—	—	—	—			
Pagrus major	larvae						—	—					
	young							—					

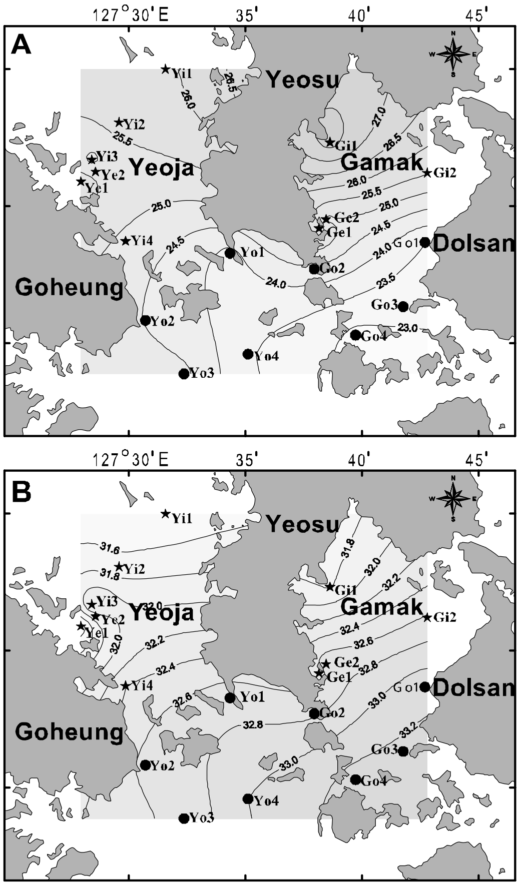

Fig. 5. Isothermal lines (A) and isohalines (B) in Gamak Bay and Yeoja Bay on August, 2007.

inside the bays, which offer abundant food supply and shelter, strategically as spawning and nursery grounds.

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