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Spatiotemporal Distribution of Pacific Anchovy (*Engraulis japonicus*) Eggs in the West Sea of Korea

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Pacific anchovy (*Engraulis japonicus*) eggs were collected during the spawning season (2000-2003) using a revised ring net in the coastal waters adjacent to the Geum River Estuary in the West Sea of Korea (Yellow Sea). Anchovy eggs were present from May to September, showing a peak in spawning from June to July when the water temperature and salinity were 17-27°C and above 30.00 psu, respectively. During the main spawning season, no clear diel cycle (regarding the 24-h sampling period of dusk, night, dawn, and daytime) was detected in the vertical distribution of anchovy eggs near Eocheong Island (50-60 m depth). Judging from the developmental stages of the collected eggs, it appeared that anchovies spawned mostly at night and that the eggs hatched at dusk and during the night. The density of anchovy eggs was high in the southwest-northeast direction in June, and spawners appeared to move offshore in July. Mean egg density was higher in June 2002 than in June 2003 when water temperatures and salinities were lower. This study on the spatiotemporal distribution of eggs will contribute to developing management plans for the Pacific anchovy in Korea.

Key words: *Engraulis japonicus*, Spawning, Recruitment, Environmental factor, West Sea of Korea

Introduction

The Pacific anchovy *Engraulis japonicus* is an important component in the trophic structure linking plankton to piscivorous fish in the Yellow Sea ecosystem (Zhao et al., 2003). It is a major target of Korean commercial fisheries, and the annual catch, including larvae, has fluctuated between 100,000 and 250,000 MT during the past 30 years (NFRDI, 1998), which implies that the anchovy stock could change plankton community structures and impact the food supply of other commercial species (Xu and Jin, 2005; Kang et al., 2006).

In the Geum River Estuary, the river discharges about 80% of the total annual outflow during the flood season. Choi et al. (1999) reported that the low-salinity (<30.0 psu) plume was distributed over a large area between the Geum River and Eocheong Island, 60 km northwest of the mouth of the river, which suggests that the discharge from the Geum River could affect adjacent coastal waters. A tidal difference greater than 6 m creates a tidal front in the West Sea of Korea (Yellow Sea) (NORI, 2000). Because these tidal fronts can concentrate food particles (Hao et al., 2003), and as a result inshore waters of the West Sea become spawning and nursery grounds during the early life of these fishes (Ryu and Lee, 1984; Hwang, 1998; Chiu and Chen, 2001; Chen and Chiu, 2003). Thus, fish recruitment patterns in the coastal waters, estuary, bay, and around the island must be clarified. Waters around estuaries are well suited for studying the environmental factors that affect the distributions of organisms because of highly variable parameters such as water temperature and salinity compared to open water.

The migration routes of the Pacific anchovy off

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Korea are not well-known, but Korean fisheries scientists generally believe that they overwinter off Jeju Island and begin to spawn during the spring in the South Sea of Korea (NFRDI, 1998), which has been a main fishing ground for anchovies (Chang et al., 1980; Sohn et al., 1984; Choo and Kim, 1998; Kim and Lo, 2001). They then migrate northwestward and the spawning ground is expanded into the Yellow Sea from late spring (Chang et al., 1980; NFRDI, 1998). Based on otolith analysis and back-calculated birthdates of anchovy larvae, we identified three cohorts of anchovies (March-April, May-July, August-September) in the West Sea of Korea (Hwang et al., 2006). Anchovy eggs are known to be present mainly when temperature and salinity conditions are 14-25°C (Kim and Lo, 2001; Lee and Go, 2003, 2006) and 30.3-34.0 psu (Sohn et al., 1984; Lee and Go, 2003, 2006), respectively, in the South Sea of Korea.

Annual variation in spawning conditions and density-independent processes (Houde, 1987) determining the subsequent survival of larvae in the West Sea are poorly understood. As a first step in studying the relationships between recruitment processes and oceanographic conditions during the early life stages (Hjort, 1914; Cushing, 1975; Lasker, 1981), we sought to determine the spatiotemporal variability in the distribution of Pacific anchovy eggs; investigate spawning conditions with respect to the diel cycle, temperature, and salinity; and identify the migration pattern of anchovy spawners in the coastal waters of the West Sea of Korea.

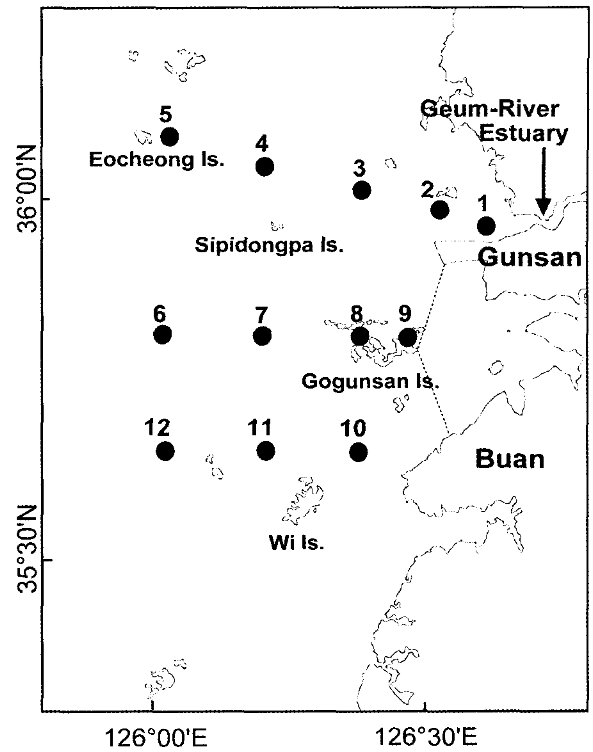

Fig. 1. The study area off Geum-River Estuary from 2000 to 2003. The numbers represent the sampling stations.

Materials and Methods

Cruises were taken aboard the National Fisheries Research and Development Institute (NFRDI) research vessels *Jeonbuk-868* (39 GTs) from 2000 to 2002 and *Tamgu-18* (69 GTs) during 2003 in the coastal waters adjacent to the Geum River Estuary off the West Sea of Korea (Fig. 1; Appendix I). Pacific anchovy eggs were collected monthly using an opening-closing ring net, and a Seabird Conductivity Temperature Depth (CTD) sensor was deployed to measure water temperature and salinity at each station.

The net had a mouth diameter of 80 cm and a mesh size of 315 μm. The filtered water volume was measured with a Hydro-Bios digital flowmeter. To investigate a possible diel cycle in the vertical distribution of anchovy eggs (dusk, midnight, dawn, and noon), the eggs were sampled at station 5 (50-60 m depth) located near Eocheong Island during June and July of 2000 and 2001. The net was towed horizontally just below the surface and over the bottom at 2 knots for 5 to 10 min at stations 1-5 during the daytime from April to October 2001. Two nets were towed simultaneously at all stations to minimize sampling bias in 2001, and the egg density was averaged for the two tows. During the 2002 and 2003 cruises, the sampling area (stations 6-12) was expanded to estimate the spatial distribution of anchovy eggs. Sampling was conducted at a total of 12 stations in June and July because we had observed that anchovy spawning peaked from June to July in 2001. To estimate egg density for the 2002-2003 cruises, three vertical tows covering the entire water column were made at each station during the daytime because the preliminary study conducted in 2000 and 2001 did not show a consistent diel cycle in the vertical distribution of eggs.

Anchovy eggs were fixed onboard with 90% ethyl alcohol, except for one net sample from each station that was fixed with a 10% buffered formalin-seawater solution for egg-stage identification during the 2001 cruises. Eggs were classified into 10 developmental stages in the laboratory. We adopted the 9-stage classification of Kim and Lo (2001) and added a first stage that did not show cleavage.

We tested the differences in the numbers and variation in egg density as a function of water layer with respect to diel cycle between 2002 and 2003 using analysis of variance (ANOVA; SAS, 1989).

Results

Temporal variability of environmental factors and anchovy eggs

Seasonal variation in environmental factors

In 2001, the mean temperature of the surface and bottom layers in the study area increased from April (10.4°C) to July (23.3°C), peaked in August (25.8°C), and decreased in October (18.7°C) (Table 1). Mean salinity decreased from May (31.63 psu) to July (28.71 psu) and increased in September (30.62 psu).

During the study period, temperatures and salinities differed vertically from June to August (Fig. 2). In June, the mean water temperature was 21.7°C on the surface and 17.1°C in the bottom layer. The temperature difference (7°C) between the surface (26.8°C) and bottom layer (19.8°C) peaked in July. In August, the temperatures of the surface and bottom waters were 28.4 and 23.2°C, respectively. Due to freshwater discharge from the river, salinity was lower in the surface layer than in the bottom layer: 28.59 and 30.59 psu, respectively, in June, 27.32 and 30.11 psu in July, and 27.52 and 30.14 psu in August.

Seasonal variation in anchovy egg density

Anchovy eggs occurred from May to September 2001 and peaked in June and July (Fig. 2). Anchovy eggs were not present in April when temperatures were low (<11°C). The mean egg density was 5 eggs/m^3 in May when the temperature rose to 14.1°C. The mean egg densities were 40 and 32 eggs/m^3 in June and July, respectively. Anchovy egg density fell below 1 egg/m^3 in August and September. Anchovy eggs were not found in the study area after October (Table 1).

Optimal temperature and salinity for spawning

Anchovy eggs were found at water temperatures ranging from 10.5 to 28.9°C and salinities between 21.30 and 31.97 psu at all stations from May to September 2001 (Fig. 3). Egg density was high (>75 eggs/m^3) at temperatures between 17 and 27°C and salinities from 30.00 to 31.90 psu; we thus defined these ranges as optimal temperatures and salinities for spawning.

Hatching duration of anchovy eggs

The composition of the developmental stages of the eggs changed with time (dusk, night, dawn, and

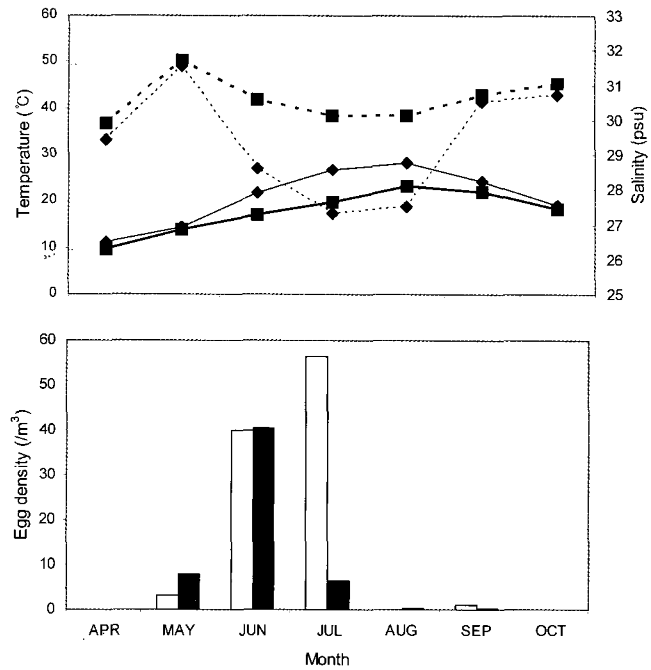

Fig. 2. Monthly variation of water temperature, salinity and egg density in surface (plain) and bottom (bold) waters off Geum-River Estuary in 2001. Solid and dotted lines indicate the water temperature and the salinity, respectively (upper). Open and closed bars indicate the egg density in surface and bottom waters, respectively (lower).

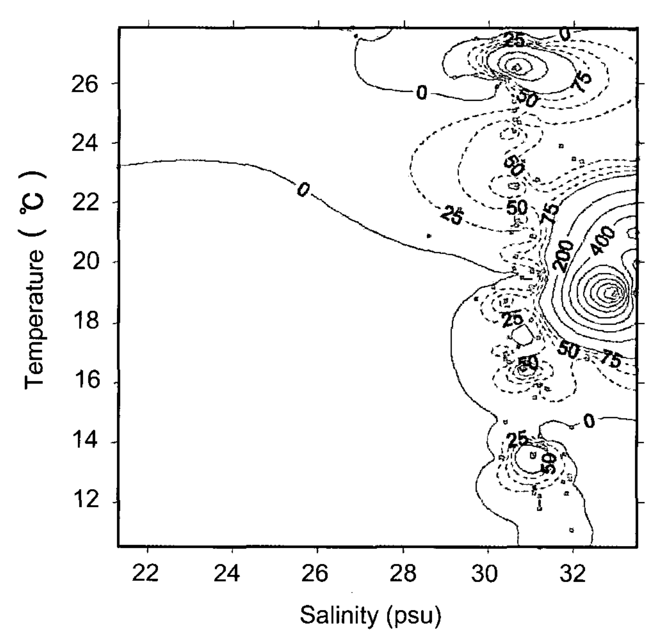

Fig. 3. The relationship between water temperature and salinity with respect to distribution of anchovy eggs. Numbers represent the egg density of anchovy (ind./m^3).

Table 1. Monthly mean water temperature (℃), salinity (psu) and anchovy egg density (ind./m^3) during egg survey off Geum-River Estuary in 2001

	Apr	May	Jun	Jul	Aug	Sep	Oct
Temperature	10.4	14.1	19.4	23.3	25.8	23.3	18.7
Salinity	29.66	31.63	29.59	28.71	28.83	30.62	30.89
Egg density	0.0	5.4	40.3	31.5	0.1	0.7	0.0

daytime) during 24-h sampling periods in June, July, and August 2001 (Fig. 4). All anchovy eggs were at stage I at night in June, while stages I-IV were dominant at night in July. Stages VII and VIII occurred mainly at dusk and during the night in July. In August, stages VII and VIII were dominant at dusk and stages VIII-X at night. At dawn and during the day, we mainly found stages IV-VIII.

Diel variations in the vertical distribution of anchovy eggs

No clear diel cycle was found in the vertical distribution of anchovy eggs at station 5 during the 24-h sampling periods in June and July 2000 and 2001 (Fig. 5). During the 2000 cruises, egg density was highest at dawn in June, but highest at night in July. During the 2001 cruises, however, egg density was highest at noon in June and highest at dawn in July. The distribution of anchovy eggs did not differ consistently with time of day or water depth (Fig. 5) (ANOVA; $p > 0.05$).

Spatial distribution of anchovy eggs in relation to environmental factors

Spatial distribution of environmental factors

Water temperature patterns were different between the surface and the bottom (Fig. 6). Surface water temperature was lowest (19°C) in shallow waters around the Gogunsan Islands (station 8) in June 2002, but the bottom water temperature decreased offshore. Water temperature patterns in July were similar to those in June, although actual temperatures were slightly higher by 2 to 3°C in the surface water and 3 to 4°C on the bottom. Low salinity surface water spread to Sipidongpa Island (station 4) in the fresh-water plume discharged from Geum River, and low-salinity bottom water was limited to the mouth of the estuary in 2002 (Fig. 6).

Water temperature and salinity patterns in 2003 were similar to those in 2002 (Fig. 7), but water temperatures in 2003 were lower by 2 to 3°C compared to 2002. Salinity in 2003 was also lower than in 2002 (Fig. 7).

Spatial distribution of anchovy egg density

Mean egg density during the June cruise was hig-

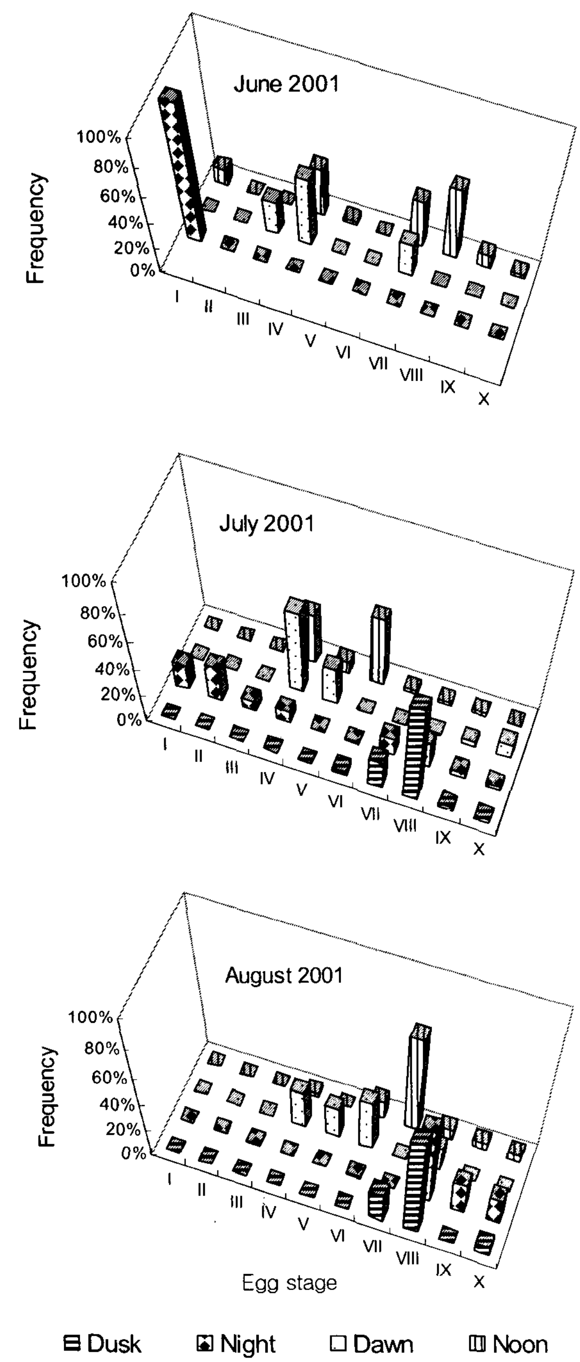

Fig. 4. Percentage occurrence of development of anchovy egg with time. Stages of anchovy egg are according to Kim and Lo (2001).

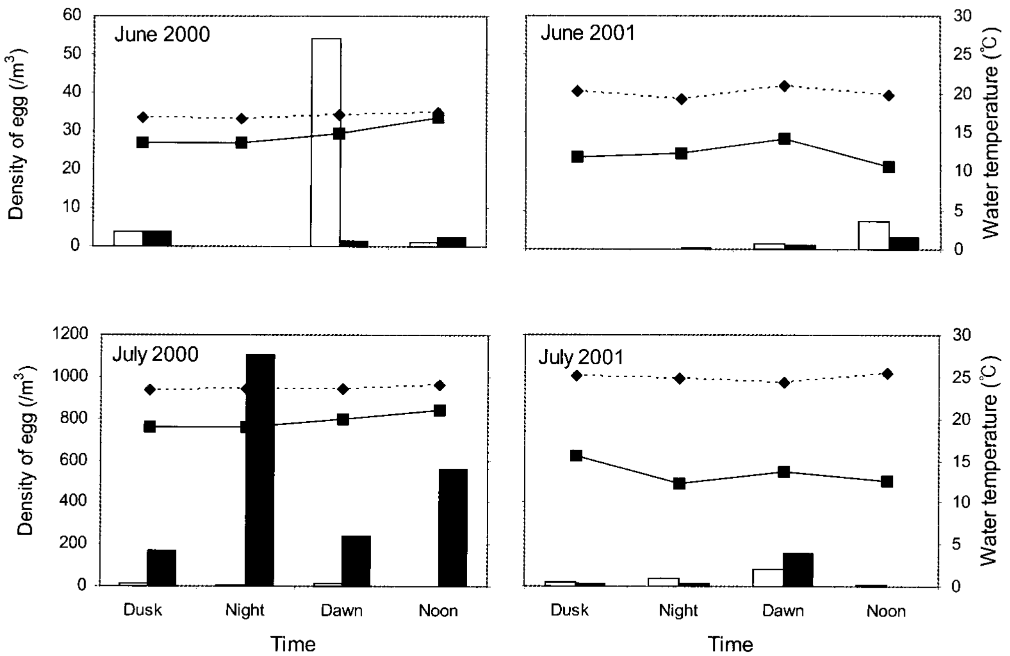

Fig. 5. Diel vertical variation of egg density (ind./m^3) at the station 5 in June and July during 2000-2001. Open and closed bars indicate the egg density in surface and bottom waters, respectively. Square and diamond symbols indicate the water temperatures of bottom and surface waters, respectively.

her in 2002 (94 eggs/m^3) than in 2003 (10 eggs/m^3) when the water temperature and salinity were relatively low (Fig. 8) (ANOVA; $p < 0.01$). In July, the mean egg density decreased to 4 eggs/m^3 in 2002 and 3 eggs/m^3 in 2003. However, the pattern of anchovy egg distribution in June was similar in both years (Fig. 8). Egg density was high at stations 3, 4, 6, and 7 in June 2002 and at stations 2, 3, 4, and 6 in June 2003. In July of 2002 and 2003, anchovy eggs were distributed mainly offshore (station 5).

Discussion

In this study, anchovy eggs were collected from May to September in surface water temperatures above 14°C, with most from June to July. Judging from the relationships between environmental factors and egg distributions, the spawning of Pacific anchovies in the West Sea of Korea seems to occur mostly when water temperatures and salinities are between 17 and 27°C and above 30 psu, respectively. Water temperature at the mouth of the Geum River Estuary was optimal for spawning (17-27°C); however, based on egg distribution, the anchovies did not seem to spawn, likely because the salinity was below the estimated optimum (30.00-31.90 psu). Even though the habitat areas are different, the range of water temperatures and salinities where anchovy eggs occurred were similar in the South Sea of Korea (Sohn et al., 1984; Kim and Lo, 2001; Lee and Go, 2003, 2006). In this study, anchovies spawned mainly at night and their eggs hatched at dusk and during the night of the following day. Therefore, the incubation time of the Pacific anchovy in the study area seems to be at least 1 day, similar to a previous study conducted in the South Sea of Korea (Kim and Lo, 2001). From the egg distributions, we infer that anchovies could delay spawning and move to more suitable areas if at least one of the environment conditions is not suitable.

In this study area, anchovy eggs that were released mostly by the early summer (May-July) cohort were present from June to July. Anchovies of the spring spawning group (March-July) and the summer spawning group (August-September) mix together in the East China Sea (Chiu and Chen, 2001). Moreover, a mixture of the offspring of coastal (April-May) and offshore (March and April-May) spawners occurs in the transition region in the Pacific Ocean off Japan (Takahashi et al., 2001). Anchovies spawn in the inshore waters during June and move offshore to spawn in the South Sea of Korea during July (Choo and Kim, 1998; Choo, 2002). Various anchovy spawning groups have different spawning grounds and different recruitment patterns in the western Pacific Ocean. We postulate that the early summer spawning group spawns in inshore waters and moves

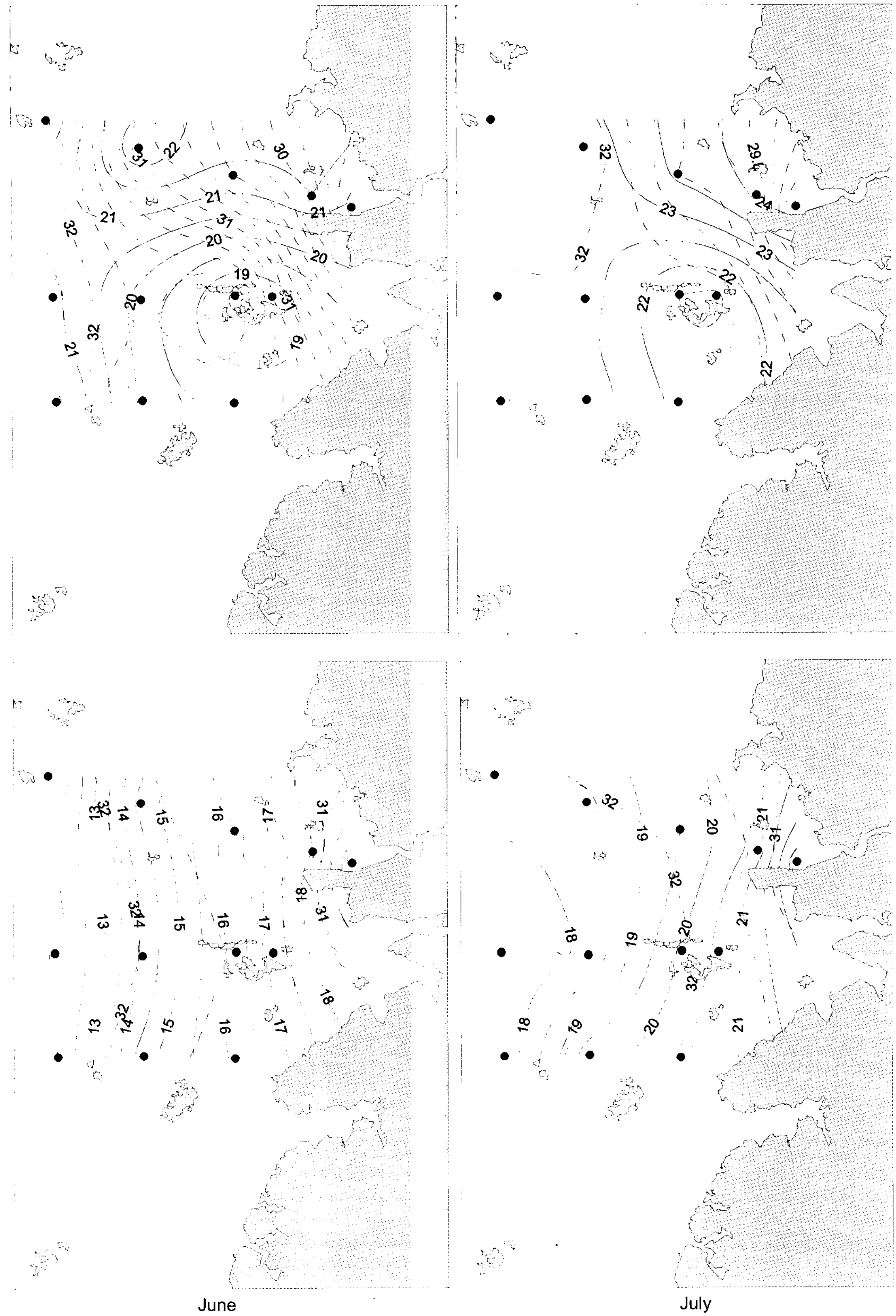

Fig. 6. Spatial distribution of surface water temperature (solid line) and salinity (dotted line) (left upper), and those in bottom waters (left lower) in June 2002. Water temperature and salinity in July 2002 are showed at the right side.

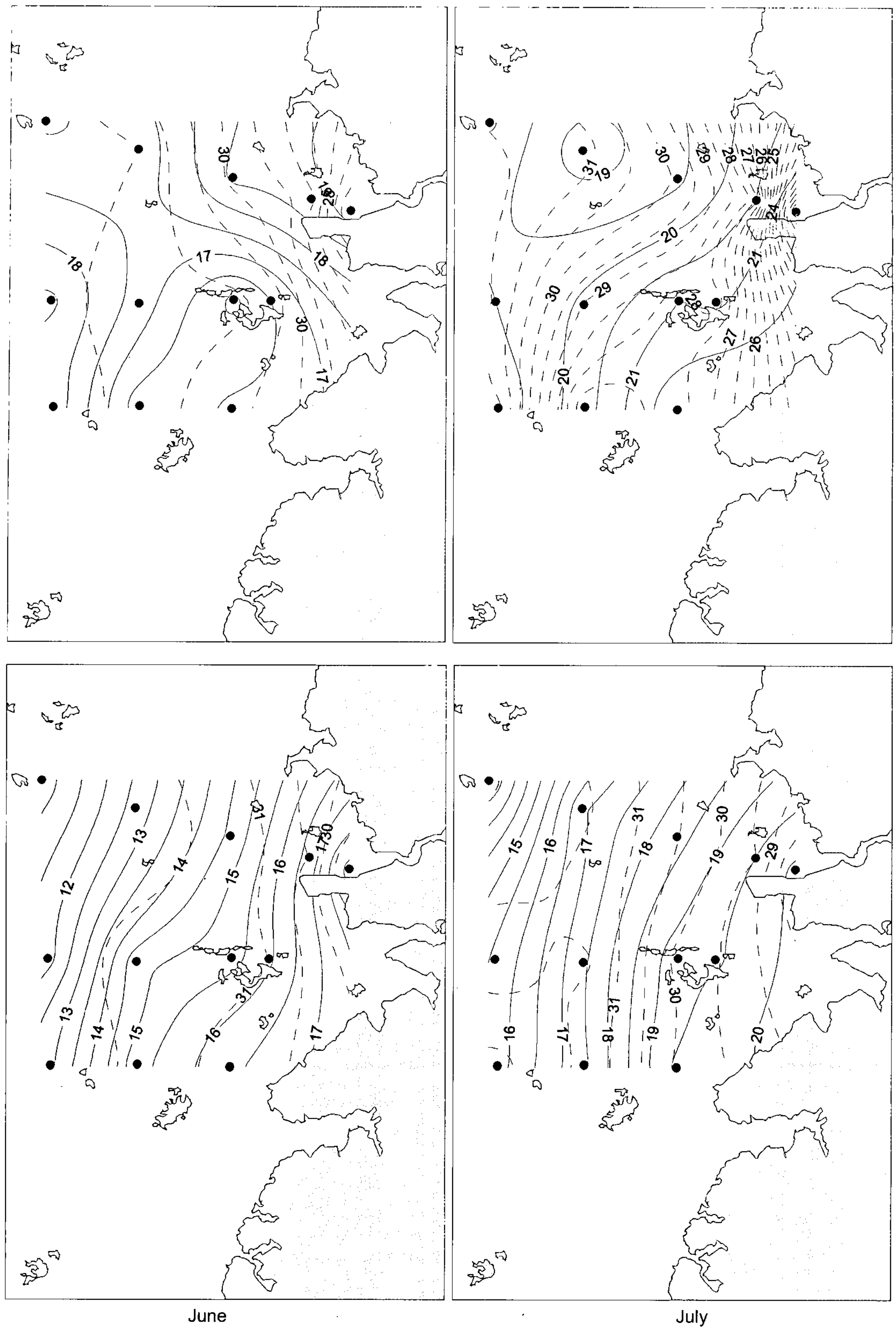

Fig. 7. Spatial distribution of surface water temperature (solid line) and salinity (dotted line) (left upper), and those in bottom waters (left lower) in June 2003. Water temperature and salinity in July 2003 are showed at the right side.

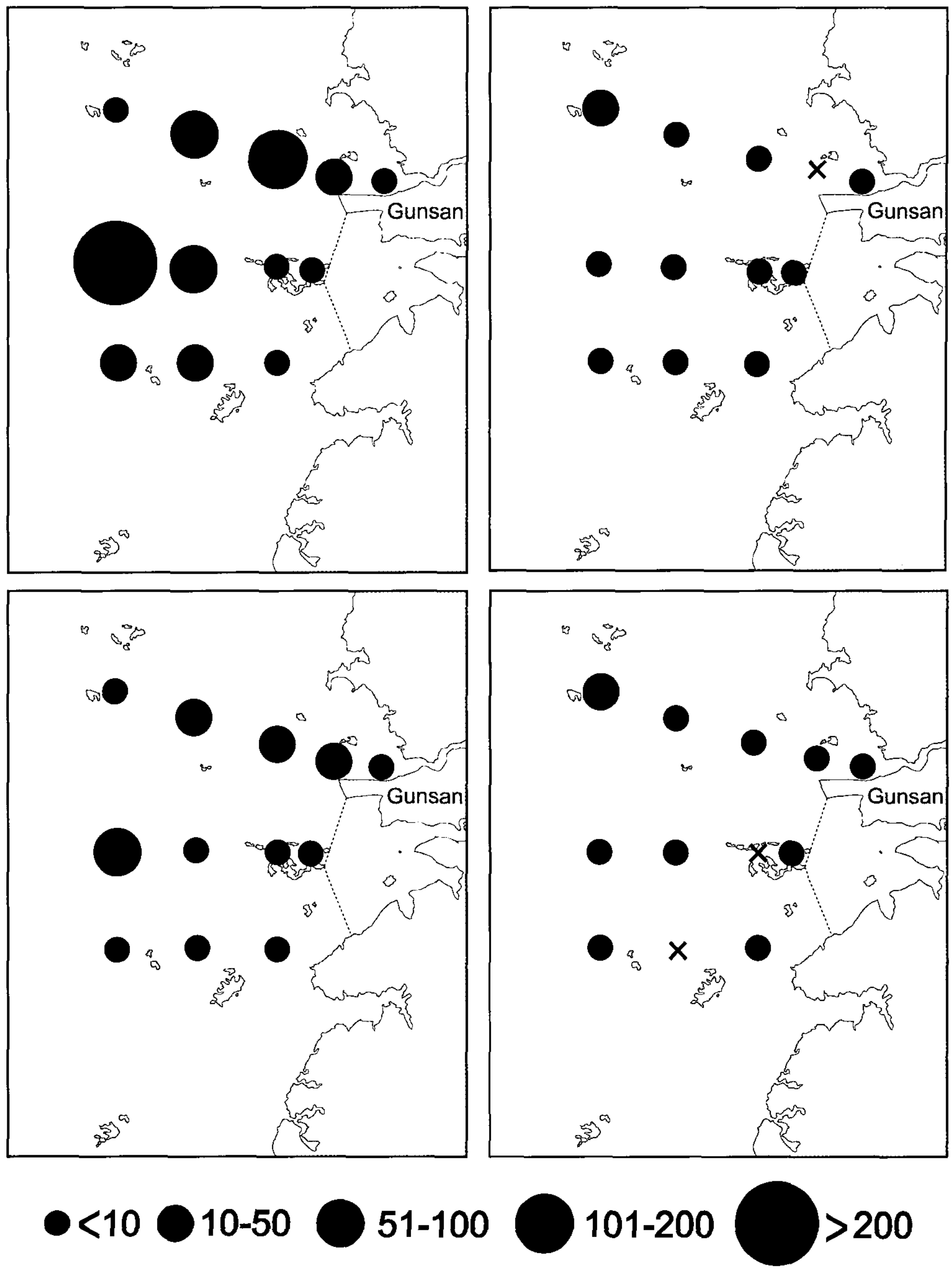

Fig. 8. Spatial distribution of anchovy eggs in June 2002 (left upper), July 2002 (right upper), June 2003 (left lower) and July 2003 (right lower). The letter x represents no sampled site.

offshore before summer in the study area.

The seasonal migration route of fishes is generally known to be in a north-south direction in the Yellow Sea (NFRDI, 1998), but the tidal direction is northeast-southwest in the West Sea of Korea (Yellow Sea) (Kim et al., 2006). The pattern of anchovy egg distribution coincided with tidal pathways (southwest-northeast) in June (Figs. 6-8). This indicates that eggs could be transported to the northeast during the flood tide and/or anchovy spawners could move into inshore surface waters with optimal water temperatures and salinities during the early spawning season. In June and July, the water temperature and salinity differed between the surface and bottom layers due to strong stratification. We postulate that with the help of the northwestward water flow from the estuary (Choi et al., 1999), anchovies could move offshore through bottom waters having optimal environmental conditions (Figs. 6-8) and/or could move out in July.

Strong tidal fronts occur to the off of the West Sea of Korea (NORI, 2000). These tidal fronts can concentrate food particles (Hao et al., 2003) and serve as a transitional zone and nursery ground for anchovy larvae (Chiu and Chen, 2001; Chen and Chiu, 2003). Thus, the coastal waters of the Geum River Estuary would be important as spawning and nursery grounds for anchovies. The spawning periods for anchovies coincide with the rainy season in the study area, which experiences episodic flood discharges of freshwater from the Geum River (Choi et al., 1999). In addition, tidal flat reclamation is under way in this area, which could potentially alter tidal currents. To conserve the spawning and nursery grounds of anchovies, the ongoing human interventions should be evaluated.

The daytime distribution pattern of anchovy eggs did not differ between surface and bottom waters or between time of the day, probably because of strong tidal mixing. This implies that anchovy adults were not affected by depth or time in vertically well mixed shallow water (Iversen et al., 1993). In deep-water areas, diel and vertical variations in anchovy egg distribution have been reported in the East Sea (Kim and Choi, 1988), which were related to stratification of the water column. In future studies, replicated vertical tows covering the whole water column should be used to estimate egg density in the West Sea of Korea during the main spawning period (June-July) and to monitor egg distribution and study recruitment processes.

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Appendix I. The cruise dates, tow times, tow methods, tow depths and tow numbers for the different survey during 2000-20

Time of survey	Station	Tow time	Tow method	Tow depth	No.of tow
18 Jun 2000	5	1910	Horizental	Surface&Bottom	ea. 1
〃	5	2340	〃	〃	〃
19 Jun 2000	5	0640	〃	〃	〃
〃	5	1220	〃	〃	〃
18 Jul 2000	5	1950	Horizental	Surface&Bottom	ea. 1
〃	5	2300	〃	〃	〃
19 Jul 2000	5	0630	〃	〃	〃
〃	5	1110	〃	〃	〃
19 Apr 2001	1	0950	Horizental	Surface&Bottom	ea. 2
〃	2	1220	〃	〃	〃
〃	3	1327	〃	〃	〃
〃	4	1447	〃	〃	〃
〃	5	1625	〃	〃	〃
17 May 2001	1	1020	Horizental	Surface&Bottom	ea. 2
〃	2	1120	〃	〃	〃
〃	3	1225	〃	〃	〃
19 May 2001	4	0630	〃	〃	〃
〃	5	0750	〃	〃	〃
20 Jun 2001	1	1210	Horizental	Surface&Bottom	ea. 2
〃	2	1320	〃	〃	〃
〃	3	1430	〃	〃	〃
21 Jun 2001	4	1026	〃	〃	〃
〃	5	1150	〃	〃	〃
〃	5	1150	〃	〃	ea. 2
〃	5	1900	〃	〃	〃
〃	5	2300	〃	〃	〃
22 Jun 2001	5	0700	〃	〃	〃
18 Jul 2001	1	1100	Horizental	Surface&Bottom	ea. 2
〃	2	1215	〃	〃	〃
〃	3	1320	〃	〃	〃
〃	4	1435	〃	〃	〃
〃	5	1550	〃	〃	〃
〃	5	1900	〃	〃	ea. 2
〃	5	2300	〃	〃	〃
19 Jul 2001	5	0700	〃	〃	〃
〃	5	1200	〃	〃	〃
16 Aug 2001	1	1046	Horizental	Surface&Bottom	ea. 2
〃	2	1145	〃	〃	〃
〃	3	1255	〃	〃	〃
〃	4	1405	〃	〃	〃
〃	5	1515	〃	〃	〃
	5	1900			
	5	2300			
17 Aug 2001	5	0700			
	5	1240			
17 Sep 2001	1	1330	Horizental	Surface&Bottom	ea. 2
〃	2	1430	〃	〃	〃
〃	3	1530	〃	〃	〃
〃	4	1640	〃	〃	〃
〃	5	1800	〃	〃	〃
24 Oct 2001	1	1010	Horizental	Surface&Bottom	ea. 2
〃	2	1110	〃	〃	〃
〃	3	1235	〃	〃	〃
〃	4	1350	〃	〃	〃
〃	5	1520	〃	〃	〃

Appendix I. Continued

Time of survey	Station	Tow time	Tow method	Tow depth	No.of tow
8 Jun 2002	1	1040	Vertical	Whole column	3
〃	2	1120	〃	〃	〃
〃	3	1220	〃	〃	〃
〃	4	1320	〃	〃	〃
〃	5	1430	〃	〃	〃
19 Jun 2002	6	0950	〃	〃	〃
〃	7	1100	〃	〃	〃
〃	8	1240	〃	〃	〃
〃	9	1320	〃	〃	〃
21 Jun 2002	10	0930	〃	〃	〃
〃	11	1040	〃	〃	〃
〃	12	1200	〃	〃	〃
18 Jul 2002	1	1055	Vertical	Whole column	3
〃	2	1140	〃	〃	〃
〃	3	1240	〃	〃	〃
〃	4	1340	〃	〃	〃
〃	5	1450	〃	〃	〃
19 Jul 2002	6	0610	〃	〃	〃
〃	7	1025	〃	〃	〃
〃	8	1135	〃	〃	〃
〃	9	1225	〃	〃	〃
20 Jul 2002	10	0910	〃	〃	〃
〃	11	0805	〃	〃	〃
〃	12	0650	〃	〃	〃
17 Jun 2003	1	1536	Vertical	Whole column	3
〃	2	1620	〃	〃	〃
〃	3	1703	〃	〃	〃
〃	4	1757	〃	〃	〃
18 Jun 2003	5	1853	〃	〃	〃
	6	0800	〃	〃	〃
〃	7	1300	〃	〃	〃
〃	8	1400	〃	〃	〃
〃	9	1450	〃	〃	〃
〃	10	1125	〃	〃	〃
〃	11	1000	〃	〃	〃
〃	12	0850	〃	〃	〃
21 Jul 2003	1	1020	Vertical	Whole column	3
〃	2	1100	〃	〃	〃
〃	3	1140	〃	〃	〃
〃	4	1240	〃	〃	〃
〃	5	1331	〃	〃	〃
〃	6	1510	〃	〃	〃
23 Jul 2003	7	1355	〃	〃	〃
〃	8	1300	〃	〃	〃
〃	9	1220	〃	〃	〃
〃	10	1505	〃	〃	〃
21 Jul 2003	11	1715	〃	〃	〃
〃	12	1600	〃	〃	〃