Korean J. Ichthyol. 18(1), 36~44, 2006

Study on the Distribution Patterns of Anchovy Eggs and Larvae and Environmental Characteristics in the Eastern Part of Jeju Strait, Korea

Seung-Jong Lee* and You-Bong Go[1]

Marine and Environmental Research Institute, Cheju National University, 3288 Hamdeok-ri, Jocheon-eup, Bukjeju-gun, Jeju-do 695-814, Korea
[1]Division of Applied Marine Science, Cheju National University, 1 Ara-dong, Jeju-do 690-756, Korea

The distribution patterns of anchovy eggs and larvae and environmental characteristics such as oceanographic conditions and meteorological factors in the eastern part of Jeju Strait, Korea from June to October 2003 were investigated. During the sampling periods, the anchovy spawned on the coastal area mainly and approximately 85% of total egg abundance occurred in only two months, from July to August, suggesting that the main spawning season of anchovies is considered in summer from July and August in the study area. Relatively high proportions of the anchovy larvae larger than 20 mm TL observed in the eastern part area. These facts suggest that anchovy larvae gradually moved out to the eastern part of study area. Most wind speeds were markedly reduced to below 10 m/s with the exception of a few days and the precipitation was concentrated (37%) from July to August when the anchovy eggs and larvae occurred abundantly. Results of correlation analysis showed that the anchovy egg abundance correlated with the increasing chlorophyll *a* and copepod biomass. It is considered that the plankton biomass in the sea area would have significant effects on the anchovy spawning. In addition, salinity variations also had significant effects on the abundance of anchovy larvae, with increasing water temperature.

Key words : distribution, anchovy, egg, larvae, Jeju Strait

Introduction

Jeju Strait, which is located on the southwestern coast of Korea, is basically affected by various water masses such as the Tsushima Warm Water, Yellow Sea Cold Water, Korean Coastal Water and Yangtze River Coastal Water according to the season (Park, 1985; Kim and Lee, 1991). These water masses show the difference of strength and flow patterns throughout season (Pang *et al.*, 1992; Pang and Hyun, 1998).

Pacific anchovy (*Engraulis japonica*) is a small pelagic fish that has its spawning grounds in the southern coastal waters of Korea, and also has continuous long periods of spawning during spring and summer (Lim and Ok, 1977; Chang *et al.*, 1980; Kim, 1992; Kim and Lo, 2001). Moreover, anchovy from larval to adult stages are regarded as one of the most common food organisms of various marine animals such as mackerel, skipjack, tuna and squid, and play an important role in the marine ecosystem (Odate, 1957; Hayashi, 1966).

The purpose of this paper is to clarify the spawning ecology of anchovy, especially the distri-

*Corresponding author: sjlee1225@hanmail.net

bution patterns of anchovy eggs and larvae, and the relationships between the organisms and environmental factors such as oceanographic and meteorological conditions in the eastern part of Jeju Strait.

Materials and Methods

Surveys were carried out in the eastern part of Jeju Strait from June to October 2003 (Fig. 1). Anchovy eggs and larvae were collected by horizontal hauls lasting 10 minutes from the surface and 10 m depth with a plankton net (45 cm in diameter, 0.33 mm mesh) at 15 stations. The nets, fitted with a flowmeter, were towed horizontally at a speed of 2～3 kt, and then the volume of water filtered by the net was estimated.

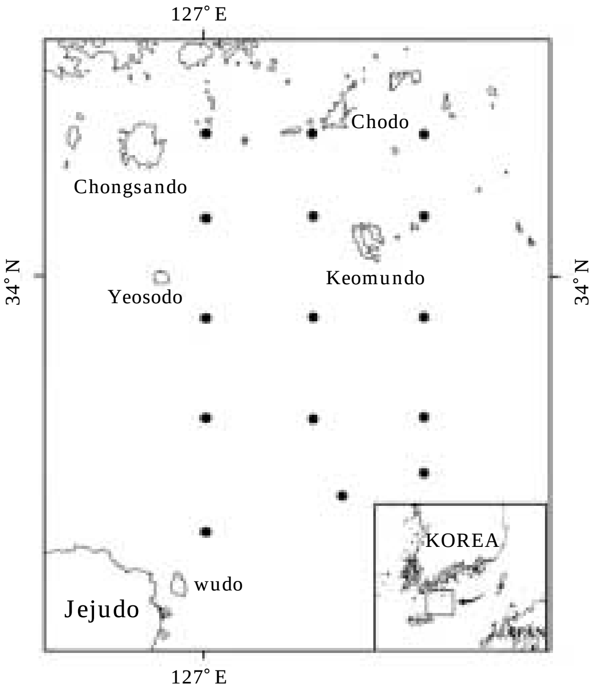

Fig. 1. Map showing the study area in the eastern part of Jeju Strait. Monthly sample were collected at 15 stations (black circle) from June to October 2003.

Samples including zooplankton were immediately fixed with buffered 10% seawater formalin on board and the identification and counting of the anchovy eggs and larvae were carried out under a dissecting microscope in the laboratory. For all anchovy larvae, total length (TL) was measured to the nearest 0.1 mm.

For each sample, in addition to calculating the anchovy eggs and larvae abundances (per 1,000 m^3), a biomass of copepod per unit filtered volume (m^3) was estimated. Water samples for determining chlorophyll *a* concentration were taken from water surface and 10 m depth with Niskin bottles, and were later measured by the method of Parsons *et al.* (1984) in the laboratory. Water temperature and salinity observed by a conductivity-temperature-depth profiler (CTD) at each station.

Meteorological data such as wind speed, direction and precipitation at the Keomun Island and Chongsan Island, within the study area, were obtained from the Jeju Regional Meteorological Office.

Correlation analysis was performed to examine the relationships between the anchovy eggs and larval abundances and environmental factors at each station. For the analysis, all data were standardized by log10-transformed the numbers.

Table 1. Monthly mean (±Standard deviation) values of environmental factors observed in the eastern part of Jeju Strait

	Depth	June	July	August	September	October
Water temperature (°C)	0 m	20.1±1.8	26.0±1.7	26.7±1.0	23.5±0.8	18.5±2.7
	10 m	19.3±1.8	23.2±1.0	24.6±1.8	23.1±0.9	18.3±2.9
	Aver.	19.7±1.8	24.6±1.4	25.7±1.4	23.3±0.9	18.4±2.8
Salinity(psu)	0 m	32.3±0.5	31.3±0.7	30.3±0.6	31.1±0.3	32.5±0.5
	10 m	32.6±0.3	31.8±0.3	31.2±0.5	31.3±0.2	32.8±0.6
	Aver.	32.5±0.4	31.6±0.5	30.8±0.6	31.2±0.3	32.7±0.6
Chlorophyll *a* (μg/L)	0 m	1.168±0.364	1.063±0.272	1.258±0.768	1.878±1.028	1.612±0.495
	10 m	1.222±0.383	1.293±0.415	1.373±0.839	1.691±0.871	1.755±0.648
	Aver.	1.195±0.374	1.178±0.344	1.316±0.804	1.785±0.950	1.684±0.572
Copepod (ind./m^3)	0 m	35.8±117.1	4.4±5.5	45.7±40.5	41.9±36.6	155.2±418.8
	10 m	58.7±132.4	46.5±71.5	31.5±29.8	108.8±132.0	169.5±204.1
	Aver.	47.3±124.8	25.5±38.5	38.6±35.2	75.4±84.3	162.4±311.5

Results

Monthly changes of environmental factors

Table 1 shows the monthly changes of environmental factors in study area during the observation period from June to October 2003. The water temperature ranged from 18.5°C (October) to 26.7°C (August) at the surface and from 18.3°C (October) to 24.6°C (August) at 10 m depth, and about 1.5∼2.0°C higher at surface than at 10 m depth in summer from June to August. Salinity ranged from 30.3 psu (August) to 32.5 psu (October) at surface and from 31.2 psu (August) to 32.8 psu (October) at 10 m depth, indicating a difference of approximate 1.0 psu lower at the surface than at 10 m depth in August. The chlorophyll *a* concentration ranged from 1.063 μg/L (July) to 1.878 μg/L (September) at the surface and from 1.222 μg/L (June) to 1.755 μg/L (October) at 10 m depth, suggesting a lower concentration at the surface than at 10 m depth. The mean copepod biomass ranged from 4.4 ind./m^3 (July) to 155.2 ind./m^3 (October) at the surface and from 31.5 ind./m^3 (August) to 169.5 ind./m^3 (October) at 10 m depth.

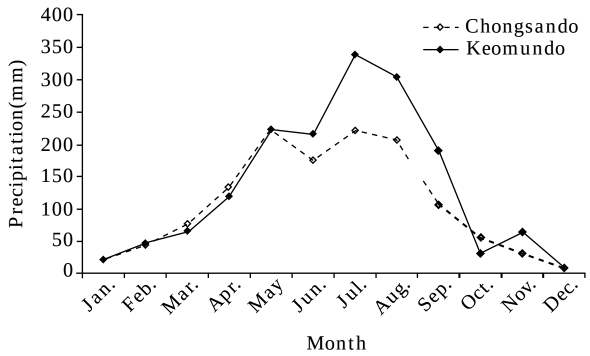

Fig. 2. Monthly changes of precipitation (mm) in the Chongsan Island and Keomun Island in 2003 (by the Jeju Regional Meteorological Office).

Weather conditions

Fig. 2 and 3 shows the weather conditions such as precipitation and wind in the study area. First, monthly variation of precipitation in Keomun Island and Chongsan Island within the survey area in 2003 is shown in Fig. 2. Throughout the year, annual variation patterns of precipitation at each area were very similar, with a peak in July. Moreover, about 37% of the total precipitation was concentrated during two months from July to August. Fig. 3 shows the monthly variation of wind conditions, computed using hourly data of the wind speed and direction at Keomun Island in 2003. Variation patterns of wind conditions in each area were also very similar to precipitation. Between January and April, a relatively strong northwesterly wind (>10 m/s of wind speed) prevailed. In May, however, the northwesterly wind blew weakly and the wind direction seemed to change gradually to a southeasterly wind. Furthermore, most wind speeds were markedly reduced to below 10 m/s with the exception of a few days from July to September when the anchovy eggs and larvae occurred abundantly. A northwesterly wind began prevailing again from October.

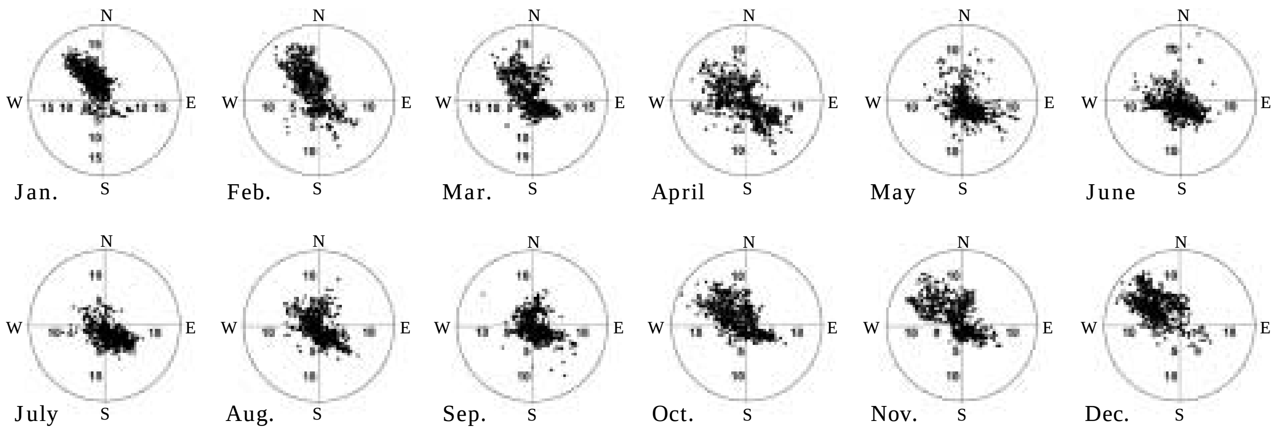

Fig. 3. Variation of the hourly average wind condition at Keomun Island in 2003 (by the Jeju Regional Meteorological Office, wind speed unit; m/s).

Variations of anchovy eggs and larvae abundances

Monthly variations of mean abundances of anchovy eggs and larvae from June to October are shown in Table 2.

At the surface, the mean egg abundance ranged from 122 (±440) to 305 (±721) No./1,000 m^3 and mean larval abundance ranged from 1 (±3) to 262 (±457) ind./1,000 m^3, and the mean egg abundance ranged from 10 (±21) to 220 (±522) No./1,000 m^3 and the mean larval abundance ranged from 6 (±21) to 1,033 (±1,875) ind./1,000 m^3 at a depth of 10 m. On the average the eggs and larvae abundance showed a maximum value in July and August, respectively. While, no anchovy eggs were observed in September and October.

As a result, the mean abundance of eggs and larvae reached a peak during the summer season, indicating that the major spawning of anchovy occurs in the season being of high temperature in the eastern part of Jeju Strait.

Horizontal distributions in abundance of anchovy eggs and larvae

Horizontal distributions of anchovy eggs and larvae are shown in Fig. 4 and 5.

Anchovy eggs appeared around the Chongsan

Table 2. Mean (±Standard deviation) abundances of anchovy eggs and larvae collected in this study

	June	July	August	September	October
Egg (No./10^3 m^3)					
0 m	153±561	305±721	122±440	0	0
10 m	10±21	220±522	130±367	0	0
Average	82±291	263±622	126±404	0	0
Larvae (ind./10^3 m^3)					
0 m	18±34	2±9	262±457	4±16	1±3
10 m	6±21	31±93	1,033±1,875	14±46	0
Average	12±28	17±51	648±1,166	9±31	0.5±1.5

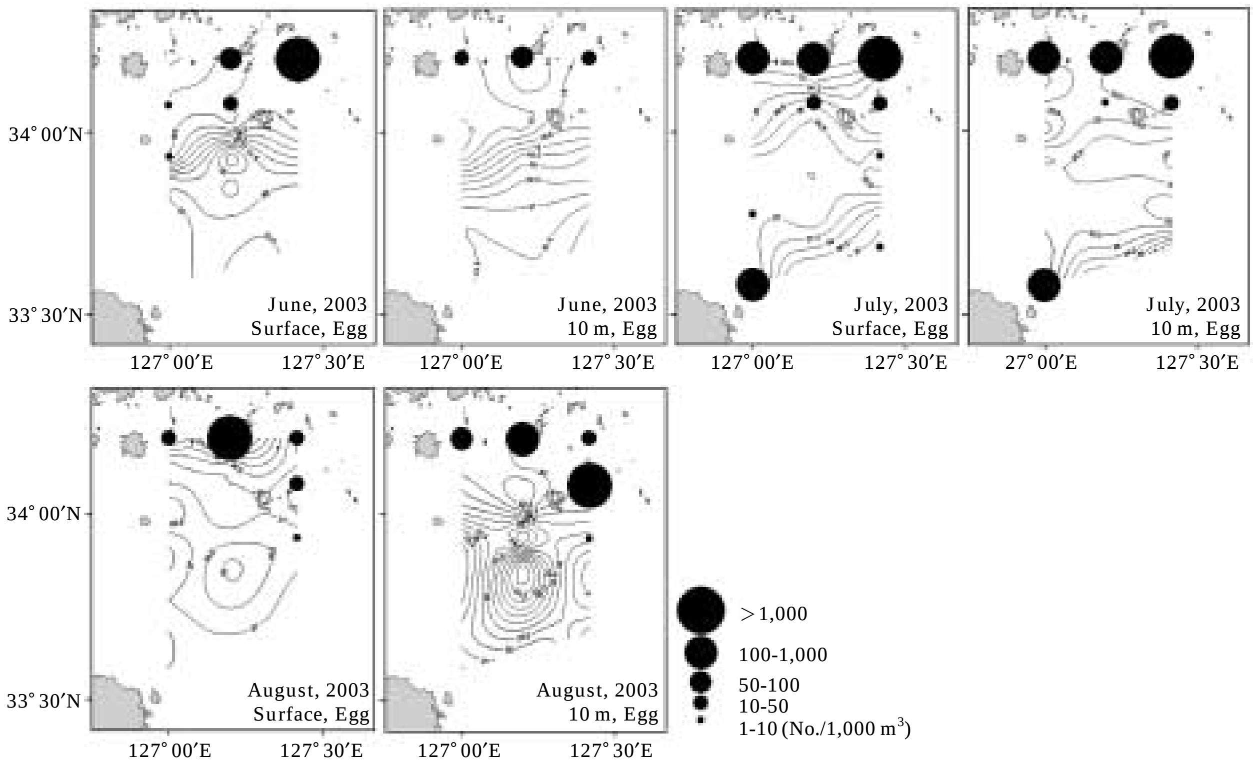

Fig. 4. Distribution of anchovy eggs (No./10^3 m^3) during the survey period.

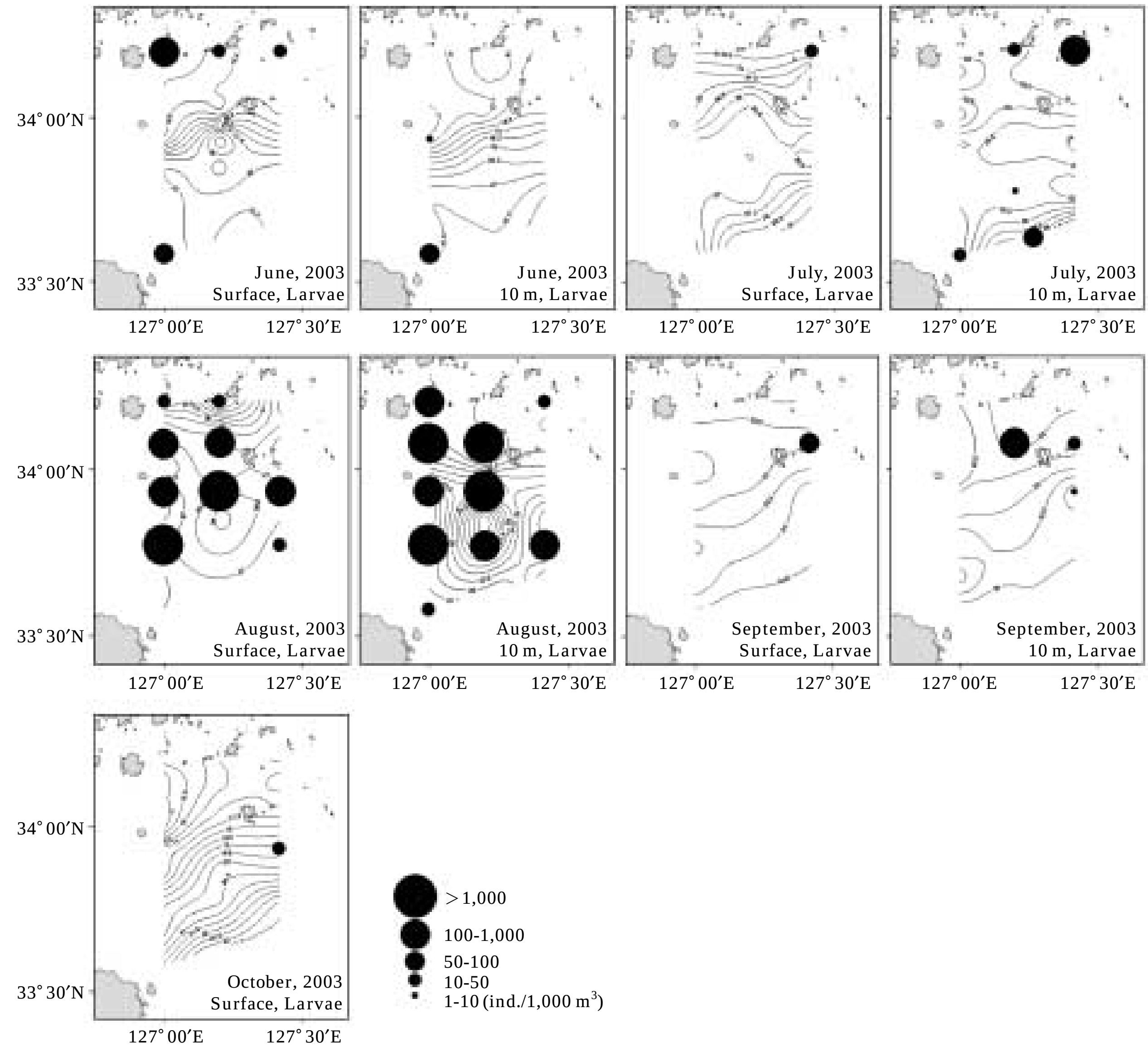

Fig. 5. Distribution of anchovy larvae (ind./10^3 m^3) during the survey period.

Island and Cho Island, the northern part of the study area in June. In July and August, moreover, the high densities (more than 100 No./1,000 m^3) of eggs were found in stations adjacent to the Islands at all depths, whereas eggs were scarcely distributed in the central part of survey area. Anchovy larvae were also appeared on the northern part of study area in June when the eggs occurred abundantly (Fig. 5). In August, however, the larvae seemed to be mainly in the central part of the survey area at all depths, where eggs were almost not collected.

Spatial distributions of anchovy larvae by developmental stages

Fig. 6 shows the monthly and spatial changes of length-frequency distribution of anchovy larvae collected during the survey period. In June, larvae ranged from 10.0～13.9 mm TL occurred in the northeastern part station of Jeju Island, but most of the collected specimens in the other stations were less than 10.0 mm TL. Also, the larvae with less than 10.0 mm TL predominated in July, though specimens ranged from 18.0～21.9 mm TL occurred from one station located in southern part of the survey area. In

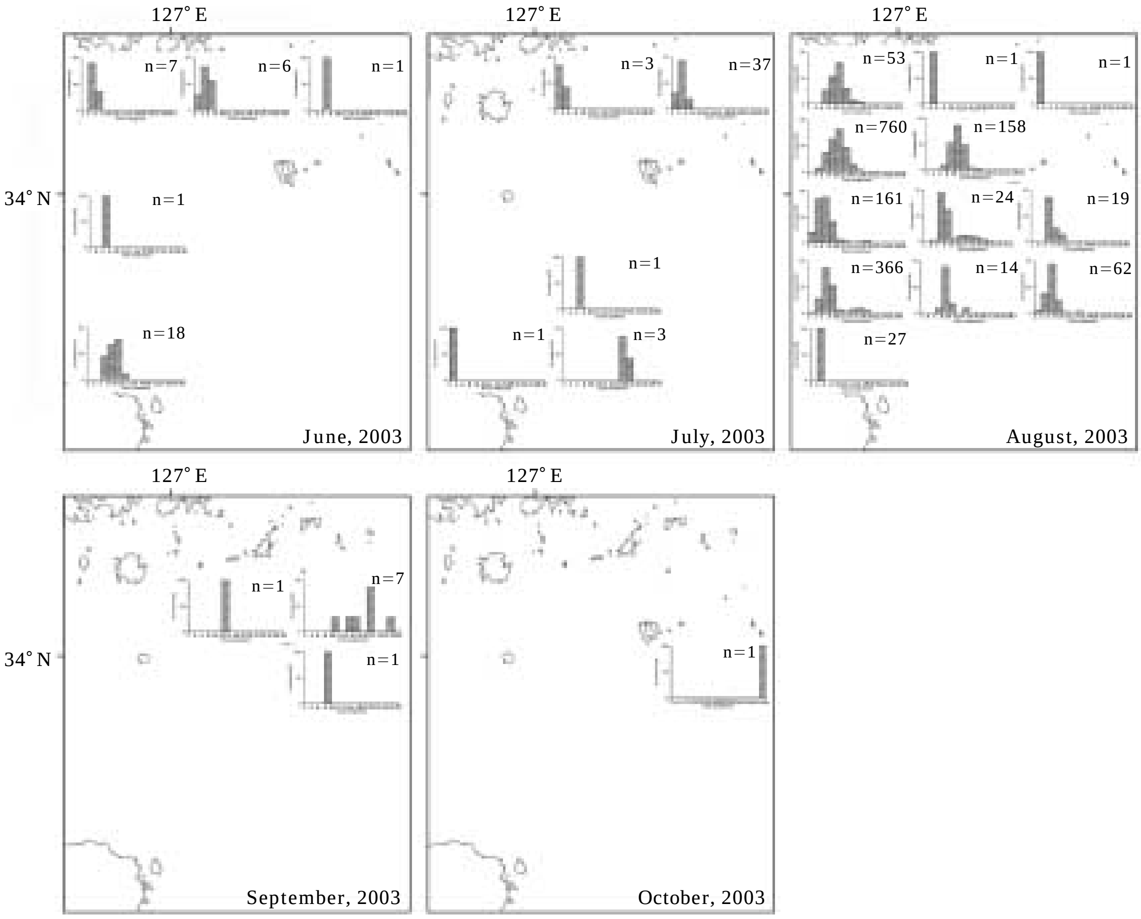

Fig. 6. Length-frequency distribution of anchovy larvae in the eastern part of Jeju Strait.

Table 3. Correlation coefficients between the anchovy eggs abundances and environmental factors during the survey period

	Y_1	X_1	X_2	X_3
X_1	+0.374			
X_2	+0.265	−0.908**		
X_3	+0.458*	−0.190	+0.109	
X_4	+0.484*	+0.273	−0.046	+0.402*

Y_1, egg abundance; X_1, water temperature; X_2, salinity; X_3, chlorophyll *a* concentration; X_4, copepod biomass. *, significant at 5% level; **, significant at 1% level

Table 4. Correlation coefficients between the anchovy larval abundances and environmental factors during the survey period

	Y_2	X_1	X_2	X_3
X_1	+0.474*			
X_2	−0.577**	−0.904**		
X_3	−0.340	−0.239	+0.125	
X_4	+0.329	+0.107	−0.161	+0.335

Y_2, larval abundance; X_1, water temperature; X_2, salinity; X_3, chlorophyll *a* concentration; X_4, copepod biomass. *, significant at 5% level; **, significant at 1% level

August, which shows a maximum in larval abundance, the appearance rate of specimens larger than 20.0 mm TL increased in the stations of central part and southern part of the survey area. Moreover, juveniles as large as 26.0 mm TL also occurred in the eastern part of the study area in September and October. Accordingly, the size frequency histograms of anchovy larvae collected in this study revealed that the modal size shifted to larger size per month, and the larvae size tended to be larger in the southern and eastern part than the western and northern part of the study area with time.

Results of correlation analysis

Table 3 and 4 gives the correlation coefficients between the abundance of anchovy eggs and larvae, and environmental factors. The eggs abundance correlated significantly with chlorophyll *a* concentration ($r=0.458$, $P<0.05$) and copepod biomass ($r=0.484$, $P<0.05$). The larval abundance showed significant correlation with water temperature ($r=0.474$, $P<0.05$) and salinity ($r=-0.577$, $P<0.01$). In addition, chlorophyll *a* concentration correlated significantly with copepod biomass ($r=0.402$, $P<0.05$) at the surface.

Discussion

It is generally well known that adult anchovy are relatively widely distributed in Korean waters (Chang *et al*., 1980) and that they adapt well to the variation of hydrographic conditions such as water temperature and salinity (Mio and Tsujino, 1995; Goto and Hirai, 1999). And most of anchovy spawned at over 14~15°C in the coastal area (Kawaguchi *et al*., 1990; Kim and Lo, 2001). In this study, the anchovy eggs occurred from June to August during the sampling periods indicating that the adult anchovy spawned over a summer season around Jeju Strait. However, about 86% of total egg abundance occurred in only two months from July to August when the mean water temperature over 25°C, which suggests that the main anchovy spawning period around Jeju Strait was closely restricted to summer. In addition, the anchovy eggs were considered to be more concentrated in the coastal area such as in the vicinity of Chongsan Island and Cho Island than other sites from the results in this study. Therefore, this suggests that theses areas are major spawning grounds of the anchovy in summer.

Basically, in the Jeju Strait included the study area, there was a predominance eastward flow pattern by Tsushima Warm Current through the year (Pang *et al*., 1992; Kim and Rho, 1997). During the sampling periods, the proportions of anchovy larvae larger than 20 mm TL were high in the southern and eastern part of the study area. It is well known that most of fish larvae nearly hatched have lack of ability to swim. In this regard, Lee and Go (2003) founded out that anchovy larvae larger than about 15.0 mm TL have increased sustained and burst a swimming ability after an examination of fins and trunk musculature using a histological method. Consequently, anchovy larvae smaller than 10.0 mm TL in our samples may originated in the coastal spawning grounds, and these facts suggest that hatched anchovy larvae grew continuously in the coastal area until the size reached over 15.0 mm TL, and then larger specimens (>16.0 mm TL) moved out to the eastern part of study area by improvement of swimming ability and the existence of eastward flow pattern in the study area.

Many environmental factors commonly affect the spawning of fishes and the formation of spawning ground and nursery ground (Lasker, 1975; Smith and Lasker, 1978). Lasker (1975, 1981) proposed that wind-driven turbulent mixing of the upper ocean could cause high mortality of first-feeding fish larvae through dissipation and dilution of patches of larval food. Peterman and Bradford (1987) found that, indeed, high mortality rates of young northern anchovy (*Engraulis mordax*) larvae (up to age 19 days) occurred in years when spawning seasons had period of high wind speed. Furthermore, Nakata *et al*. (2000) suggested that anchovy larvae could benefit from potentially high food availability associated with high chlorophyll *a* concentration, which is related to copepod production. In the present study, results in correlation analysis showed that the positive relationship between the anchovy eggs and chlorophyll *a* concentrations and copepod biomass (Table 3). These facts indicated that the eggs appeared abundantly to the sea area where the chlorophyll *a* and copepod biomass was high in spite of the chlorophyll *a* and copepod biomass displayed low values in summer compared with autumn. In addition, most wind speeds were markedly reduced to below 10 m/s from July to August when the anchovy eggs and larvae occurred abundantly during the observation period in this study. These facts suggested that the feeding success and survival of anchovy larvae would be maximized by windless conditions when the ocean's stratification structure would be stronger, suggesting a possible connection with food availability. And, it can be assumed that an abundant chlorophyll *a* and copepod in the spawning area may led to quantitatively high level of food organism for anchovy larvae hatched during summer. Therefore, it may be that the beginning of anchovy spawning activity in summer when spawning seasons showed periods of low wind speed with the increasing water temperature is one of the reproductive strategy for the reducing a mortality rate of the hatched anchovy larvae due to lack of food organism.

Generally, it is well known that the variations of salinity are closely connected with precipitation in the sea area. Lee *et al*. (1990) reported that larval anchovy schools usually inhabit areas close to the mixing areas of ocean currents and river water. In Japan, catches of larval anchovy were found to be directly (Uehara, 1962) or inversely (Nojima and Nakamura, 1988; Mitani, 1990) related to precipitation. Moreover, Mitani and Hasegawa (1988) pointed out that the larval anchovy disappeared from the fishing ground when the salinity falls less than 28 psu or increase more than 33 psu in Sagami bay. In this investigation, the anchovy larvae were abundant from July to August when the salinity was low and 37% of total precipitation was concentrated. Also, results in correlation analysis showed that the negative relationship between the anchovy larval abundance and salinity (Table 4). These facts indicated that the anchovy larvae appeared abundantly to the sea area where the salinity was low. Therefore, this is suggested that the decreasing salinity by increasing precipitation would have significant effects on the distribution of anchovy larvae.

References

Chang, S.D., S.Y. Hong, C.K. Park, P. Chin, B.G. Lee, T.Y. Lee, Y.J. Kang and Y. Gong. 1980. Studies on the migration of anchovy *Engraulis japonica* in Korean waters. Publ. Inst. Mar. Sci. Nat. Fish. Univ. Busan, 12 : 1～38.

Goto, T. and M. Hirai. 1999. Horizontal distribution of clupeoid eggs in relation to the distribution of water masses in the vicinity of Noto Peninsula in the Japan Sea, May 1989-1993. Bull. Japan Sea Natl. Fish. Res. Inst., 49 : 81～96.

Hayashi, S. 1966. A note on the biology and fishery of the Japanese anchovy *Engraulis japonica* (Houttuyn). CalCOFI Rep., 11 : 44～57.

Kawaguchi, K., Y. Yamashita and A. Hayashi. 1990. Some aspects of spawning of the reared Japanese anchovy (*Engraulis japonicus*, H.) in relation to the photoperiod, water temperature and starvation. Bull. Japan. Soc. Fish. Oceanogr., 54 : 364～372.

Kim, J.Y. 1992. Relationship between anchovy, *Engraulis japonica*, egg and larval density and environmental factors in the eastern waters of Korea. Bull. Kor. Fish. Soc., 25 : 495～500.

Kim, J.Y. and N.C.H. Lo. 2001. Temporal variation of seasonality of egg production and the spawning biomass of Pacific anchovy, *Engraulis japonicus*, in the southern waters of Korea in 1983-1994. Fish. Oceanogr., 10 : 297～310.

Kim, K. and S.H. Lee. 1991. Vertical homogeneous water along the west coast of Jeju Island. J. Kor. Soc. Oceanogr., 17 : 59～68.

Kim, S.H. and H.K. Rho. 1997. A study on the residual current in the Cheju Strait. J. Korean Fish. Soc., 30 : 759～770.

Lasker, R. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull. U. S., 73 : 453～462.

Lasker, R. 1981. Factors contributing to variable recruitment of the northern anchovy (*Engraulis mordax*) in the California current : contrasting years, 1975 through 1978. Rapp. P.-V. Reun. Cons. int. Explor. Mer, 178 : 375～388.

Lee, M.A., K.T. Lee and H.C. Ou. 1990. The larval anchovy fishing ground formation in relation to osmotic pressure changes of the coastal waters along southern Taiwan. J. Fish. Soc. Taiwan, 17 : 233～245.

Lee, S.J. and Y.B. Go. 2003. Development of trunk musculature and fins in the early growth of anchovy, *Engraulis japonica*. Kor. J. Ichthyol., 15 : 45～52.

Lim, J.Y. and I.S. Ok. 1977. Studies on the occurrence and distribution of eggs and larvae of anchovy in the Korean waters. Bull. Nat. Fish. Res. Dev. Agency, 16 : 73～86.

Mio, S. and K. Tsujino. 1995. Effects of hydrographic condition on fishing condition of sardine and anchovy in the Osaka Bay. Bull. Japan. Soc. Fish. Oceanogr., 59 : 115～122.

Mitani, I. 1990. Biological studies on the larvae of Japanese anchovy, *Engraulis japonica* Houttuyn, in Sagami Bay. Ph. D. Thesis, University of Hokkaido, 213 pp.

Mitani, I. and T. Hasegawa. 1988. The shirasu fishing ground formations and sea surface salinity change in Sagami Bay. Bull. Japan. Soc. Fish. Oceanogr., 52 : 297～303.

Nakata, H., S. Kimura, Y. Okazaki and A. Kasai, 2000. Implications of meso-scale eddies caused by frontal disturbances of the Kuroshio Current for anchovy recruitment. ICES J. Mar. Sci., 57 : 143～152.

Nojima, M. and Y. Nakamura. 1988. Biological study on the shirasu in the adjacent waters to Satsunan sea region. Bull. Japan. Soc. Fish. Oceanogr., 52 : 248～252.

Odate, S. 1957. Studies on the larval fish of the Japanese anchovy, *Engraulis japonica* (Houttuyn), in the northeastern sea area of Japan. Bull. Tohoku Reg. Fish. Res. Lab., 9 : 111～128.

Pang, I.C. and K.H. Hyun. 1998. Seasonal variation of water mass distributions in the Eastern Yellow Sea and the Yellow Sea Warm Current. J. Kor. Soc. Oceanogr., 33 : 41～52.

Pang, I.C., H.K. Rho and T.H. Kim. 1992. Seasonal variations of water mass distributions and their cause in the Yellow Sea, the East China Sea and the adjacent seas of Cheju Island. Bull. Kor. Fish. Soc., 25 : 151～163.

Park, Y.H. 1985. Some important summer oceanographic phenomena in the East China Sea. J. Kor. Soc. Oceanogr., 20 : 12～21.

Parsons, T.R., Y. Maita and C.M. Lalli. 1984. A manual of chemical and biological methods for seawater analysis. Pergamon Press, Oxford, 173 pp.
Peterman, I. and M.J. Bradford. 1987. Wind speed and mortality rate of a marine fish, the northern anchovy, *Engraulis mordax*. Science, 235 : 354～356.
Smith, P.E. and R. Lasker. 1978. Position of larval fish in an ecosystem. Rapp. P.-V. Reun. Cons. Int. Explor. Mer., 173 : 77～84.
Uehara, S. 1962. Fishery oceanography around Enshu Nada off the central Pacific coast of Honshu-I. Oceanographic condition for skipjack and *shirasu* fisheries. Bull. Tokai Reg. Fish. Res. Lab., 34 : 55～66.

Received: November 30, 2005
Accepted: February 27, 2006

제주해협 동부해역에 있어서 멸치 난 · 자치어의 분포패턴과 환경 특성

이 승 종* · 고 유 봉[1]

제주대학교 해양과환경연구소, [1]제주대학교 해양과학부 해양생산과학전공

2003년 6월부터 10월에 걸쳐 제주해협 동부해역에서의 멸치 난 · 자치어 분포패턴과 기상요인을 포함한 해양환경의 특성들에 대해 조사하였다. 조사기간 동안 멸치 난들은 주로 연안에 근접한 해역에서 풍부하게 출현하고 있었고, 전체 난 출현량의 약 85% 정도가 7월과 8월에 발생하고 있어서 이번 연구해역에서 멸치의 주산란기는 여름철로 추정되었다. 크기별 멸치 자치어의 분포현황을 살펴본 결과, 비교적 20 mm TL 이상의 자치어들은 연구해역의 동쪽에서 상대적으로 높은 비율로 출현하고 있었다. 멸치의 주산란기인 여름철 연구해역 내 기상현황을 보면 바람인 경우 대부분 10 m/s 미만의 약한 풍속의 바람이 지속적으로 불고 있었고, 연간 강수량 중 37% 정도가 7월과 8월에 집중되고 있었다. 멸치 난 · 자치어 출현량과 해양 환경요인들과의 상관관계 분석결과, 난 출현량은 클로로필 *a* 농도와 요각류 생물량과 유의한 양의 상관관계를 보인 반면 자치어 출현량은 수온과는 유의한 양의 상관관계, 염분과는 유의한 음의 상관관계를 보여주고 있었다.