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-
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.

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 m³), a biomass of copepod per unit filtered volume (m³) 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

<table>
<thead>
<tr>
<th>Depth</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 m</td>
<td>20.1±1.8</td>
<td>26.0±1.7</td>
<td>26.7±1.0</td>
<td>23.5±0.8</td>
<td>18.5±2.7</td>
</tr>
<tr>
<td>10 m</td>
<td>19.3±1.8</td>
<td>23.2±1.0</td>
<td>24.6±1.8</td>
<td>23.1±0.9</td>
<td>18.3±2.9</td>
</tr>
<tr>
<td>Aver.</td>
<td>19.7±1.8</td>
<td>24.6±1.4</td>
<td>25.7±1.4</td>
<td>23.3±0.9</td>
<td>18.4±2.8</td>
</tr>
<tr>
<td>Salinity (psu)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 m</td>
<td>32.3±0.5</td>
<td>31.3±0.7</td>
<td>30.3±0.6</td>
<td>31.1±0.3</td>
<td>32.5±0.5</td>
</tr>
<tr>
<td>10 m</td>
<td>32.6±0.3</td>
<td>31.8±0.3</td>
<td>31.2±0.5</td>
<td>31.3±0.2</td>
<td>32.8±0.6</td>
</tr>
<tr>
<td>Aver.</td>
<td>32.5±0.4</td>
<td>31.6±0.5</td>
<td>30.8±0.6</td>
<td>31.2±0.3</td>
<td>32.7±0.6</td>
</tr>
<tr>
<td>Chlorophyll a (µg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 m</td>
<td>1.168±0.364</td>
<td>1.063±0.272</td>
<td>1.258±0.768</td>
<td>1.878±1.028</td>
<td>1.612±0.495</td>
</tr>
<tr>
<td>10 m</td>
<td>1.222±0.383</td>
<td>1.293±0.415</td>
<td>1.373±0.839</td>
<td>1.691±0.871</td>
<td>1.755±0.649</td>
</tr>
<tr>
<td>Aver.</td>
<td>1.195±0.374</td>
<td>1.178±0.344</td>
<td>1.316±0.804</td>
<td>1.785±0.950</td>
<td>1.684±0.572</td>
</tr>
<tr>
<td>Copepod (ind./m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 m</td>
<td>35.8±117.1</td>
<td>4.4±5.5</td>
<td>45.7±40.5</td>
<td>41.9±36.6</td>
<td>155.2±418.8</td>
</tr>
<tr>
<td>10 m</td>
<td>58.7±132.4</td>
<td>46.5±71.5</td>
<td>31.5±29.8</td>
<td>108.8±132.0</td>
<td>169.5±204.1</td>
</tr>
<tr>
<td>Aver.</td>
<td>47.3±124.8</td>
<td>25.5±38.5</td>
<td>38.6±35.2</td>
<td>75.4±84.3</td>
<td>162.4±311.5</td>
</tr>
</tbody>
</table>
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./m³ (July) to 155.2 ind./m³ (October) at the surface and from 31.5 ind./m³ (August) to 169.5 ind./m³ (October) at 10 m depth.

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

Fig. 3. Variation of the hourly average wind condition at Keumun 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 m³ and mean larval abundance ranged from 1 (±3) to 262 (±457) ind./1,000 m³, and the mean egg abundance ranged from 10 (±21) to 220 (±522) No./1,000 m³ and the mean larval abundance ranged from 6 (±21) to 1,033 (±1,875) ind./1,000 m³ 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

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg (No./10³ m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 m</td>
<td>153±561</td>
<td>305±721</td>
<td>122±440</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10 m</td>
<td>10±21</td>
<td>220±522</td>
<td>130±367</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>82±291</td>
<td>263±622</td>
<td>126±404</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Larvae (ind./10³ m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 m</td>
<td>18±34</td>
<td>2±9</td>
<td>262±457</td>
<td>4±16</td>
<td>1±3</td>
</tr>
<tr>
<td>10 m</td>
<td>6±21</td>
<td>31±93</td>
<td>1,033±1,875</td>
<td>14±46</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>12±28</td>
<td>17±51</td>
<td>648±1,166</td>
<td>9±31</td>
<td>0.5±1.5</td>
</tr>
</tbody>
</table>

Fig. 4. Distribution of anchovy eggs (No./10³ m³) 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 m³) 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
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 lar-
vaes, 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 J uly to August during the sampling periods indicating that the adult anchovy spawned over a summer season around J eju Strait. However, about 86% of total egg abundance occurred in only two months from J uly to August when the mean water temperature over 25°C, which suggests that the main anchovy spawning period around J eju 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 these areas are major spawning grounds of the anchovy in summer.

Basically, in the J eju 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 J uly 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 lead 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


제주해협 동부해역에 있어서 멸치 낫·자치어의 분포패턴과 환경 특성
이 승종*·고 유봉1

제주대학교 해양과환경연구소, 1제주대학교 해양과학부 해양생산과학전공

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