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ANCHOVY DISTRIBUTIONAL PROPERTIES BY TIME AND LOCATION: USING ACOUSTIC DATA FROM A PRIMARY TRAWL SURVEY IN THE SOUTH SEA OF SOUTH KOREA

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ANCHOVY DISTRIBUTIONAL PROPERTIES BY TIME AND LOCATION: USING ACOUSTIC DATA FROM A PRIMARY TRAWL SURVEY IN THE SOUTH SEA OF SOUTH KOREA

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Key words: echosounder, anchovy, acoustic data, trawl survey.

ABSTRACT

In South Korea, acoustic data from primary trawl surveys are not exploited. Thus, the objective of this study was to present the availability of acoustic data from a primary trawl survey by examining the distributional properties of anchovy schools by time (morning and afternoon) and location (inshore and offshore). Echosounder data were collected while conducting a trawl survey in the South Sea of South Korea on April 14-18, 2014. In six of eight trawl shots, the major species was anchovy *Engraulis japonicus* (> 95% of total catch weight). Consequently, the length, thickness, area, and volume backscattering strength (S_V) of morning and afternoon anchovy schools were similar; however, some afternoon schools were very long or thick. Morning schools were distributed in a wider depth range than were afternoon schools. All distributional properties, other than the length and area, differed significantly by time (Mann-Whitney U test, $p < 0.05$). A comparison between anchovies in inshore waters and mixed species schools in offshore waters, the average length of the inshore anchovy schools was longer than that of the offshore schools, whereas the average thickness, area, and S_V of both schools were similar. Long or large schools were observed only in inshore waters. Inshore schools were distributed at a deeper depth than offshore schools. Every property, except S_V, differed significantly between inshore and offshore waters. Finally, a conceptual diagram is presented to illustrate the distributional properties of anchovy schools according to time and location.

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I. INTRODUCTION

The South Sea of South Korea is a critical habitat for numerous marine organisms because it comprises various water masses such as the Tsushima Warm Current, Yellow Sea Warm Current, coastal waters of the China Continent, and southern coastal waters of Korea; thus, it is a nourishing environment (Choo and Kim, 1998). Specifically, it plays a role as a spawning ground and habitat for numerous fish species such as croaker, hairtail, anchovy, mackerel, horse mackerel, and squid (Kim and Pang, 2005). Among them, the most frequently caught fish species in the marine fisheries of South Korea is anchovy (*Engraulis japonicus*). Eighty percent of anchovy catches in the South Sea of South Korea are caught using various types of fishing gear such as anchovy trawlers, gill nets, and set nets. Sixty percent of anchovy catches are harvested by anchovy trawlers. The annual yield of anchovy in South Korea has been more than 200,000 tons since 2009 (Statistics Korea, 2015). Accordingly, anchovies are a crucial species in the ecology and fisheries of South Korea. In general, anchovies are small-sized species with a maximum body length of approximately 15 cm. It distributes mainly in the coastal regions of temperate waters around the world (Shelton et al., 1993). In South Korea, it migrates to southern coastal waters with the extension of the Tsushima Warm Current; thus, it is distributed across the South Sea of South Korea, particularly from Yeosu to Geoje Island and from Tongyeong to Yokji Island (Choo, 2002). Anchovies play a critical role in the food chain of the coastal marine ecosystems as a predator for zooplankton and a prey for other fish (Shelton et al., 1993). Research on anchovies in South Korea has examined the horizontal and vertical distributions on the basis of oceanographic factors such as water temperature, salinity, and chlorophyll

(Seo and Kim, 1999; Ko et al., 2007; Ko et al., 2010), catch, and the catch per unit effort (CPUE, Park et al., 2004). Previous studies have adopted the hydroacoustic method to estimate the anchovy biomasses in different areas, such as the coastal waters off Tongyeong and the South Sea of South Korea (Kim et al., 2008; Kang et al., 2015), and to identify anchovy species (Kim et al., 1998). However, the temporospatial distribution of anchovy schools in the South Sea of South Korea has not yet been studied.

For the sustainable and efficient utilization of critical fish species in the coastal waters of South Korea, scientific surveys must be conducted to estimate the biomass of such species and to understand their distributional characteristics. Trawl surveys have long been used to perform such estimation. In the South Sea of South Korea, bottom trawl nets have been used to investigate the species composition and body length distribution from catches (Lee et al., 1998; Jeong et al., 2005), and in the northeastern sea of Jeju Island, they have been used to examine the species composition and body length distribution of commonly caught fish species (Kim et al., 2013). In addition, trawlers were used to elucidate the species composition of demersal fish and the change in catches by month and season in the coastal waters of Geumo Island, Yeosu, and in the South Sea of South Korea (Han and Oh, 2007). Bottom trawlers have been used to observe the species composition of demersal fish as well as seasonal and regional quantitative changes in the eastern sea (Yoon et al., 2008), and to determine the species composition and distributional density of demersal fish in the Yellow Sea (Shin et al., 2002). Moreover, the seasonal and positional species composition, and CPUE were investigated by trawl surveys for the efficient utilization and management of fishery resources in the boundary waters between South Korea and Japan, and South Korea and China (Kim et al., 2010; Kim et al., 2011). The trawl surveys aforementioned could be beneficial to recognize the species composition and distribution of fish in the survey areas. However, trawl surveys have several disadvantages; for instance, the considerable survey time and effort involved, as well as the limited information that can be obtained from only the depth layer of a net mouth.

To investigate the distribution and abundance of fishery resources, scientific echo sounders have long been used for conducting hydroacoustic surveys in many countries. Some difficulties are involved in using the hydroacoustic method to extract acoustical information on species composition. However, this method has successfully been used in identifying certain fish species in various waters (Kloser and Horne, 2003; Kang et al., 2006; Fassler et al., 2007). Furthermore, using the hydroacoustic method has numerous advantages. For example, a wide area can be covered in a relatively short time, and information on fish distribution and abundance is attainable throughout water columns (Simmonds and MacLennan, 2005). In general, hydroacoustic surveys are conducted in areas occupied by only a few fish species. In South Korea, hydroacoustic research can be categorized into three categories. First, the acoustic reflected intensity from a single fish (i.e., the target strength, TS) has been measured in natural environments (*in situ* TS, Yoon et al., 1996) and experimental environments (*ex situ* TS) such as tanks (Yoon and Ha, 1998; Lee and Shin, 2005; Lee, 2010; Lee, 2012). The TS is an essential element for calculating the fish abundance, and it fluctuates substantially according to the swimming angle and fish length (Lee and Shin, 2005). Second, the distribution and abundance of fish have been estimated by analyzing echograms derived from acoustic data (Kang et al., 1996; Hwang et al., 2002; Kim et al., 2008; Lee et al., 2012). Finally, using acoustical information to identify fish species has been attempted with various elements such as the morphometric properties (Kim et al., 1998), distributional depth (Lee et al., 2012), and mean volume backscattering strength (S_V) difference between multiple frequencies (e.g., 38 and 120 kHz, Kang et al., 2002).

In South Korea, during a trawl survey, only catch data have been used to elucidate the species composition or distribution of marine creatures. However, hydroacoustic surveys can provide substantial information on marine organisms and can be conducted concurrently with a trawl survey. Therefore, the objective of this study was to present the availability of acoustic data collected during a primary trawl survey by examining the distributional properties of anchovy schools on the basis of time and location. Through this study, the application of acoustic data collected during primary trawl surveys is clearly demonstrated and could eventually improve the efficiency and sustainability of fishery resource management.

II. MATERIALS AND METHODS

1. Data Collection

A midbottom trawl survey was conducted from April 14 to 18, 2014, in the coastal waters of Tongyeong and Geoje Island of South Korea (Fig. 1(a)). The original purpose of the trawl survey was to modify a permissible fishing area for a fishing method to target anchovy *E. japonicus* species. Before the current trawl survey, four scientific surveys were conducted in 2013 in a wider area than that investigated in this study. Thus, anchovy was confirmed to be the dominant species in that area around this time. The random stations survey was adopted because it was derived from the fishing method for targeting anchovies. The research vessel Tamgu 20 of the National Institute of Fisheries Science (NIFS) was used in this survey. The vessel speed was maintained at less than 4 knots during trawl operations. Eight trawl shots were conducted. The trawl operations were performed between 07:34 and 18:11. The periods of the trawl tows were from 1 to 3 hours, and the average towing time was 2 hours and 16 minutes. The total length and circumference of the trawl net were 163.8 m and 504 m, respectively. The mesh size of a cod end was 50 mm. The heights of the net mouth differed among the trawl operations, and the average height was 25.2 m (Table 1). The fish samples in the catch were identified to the lowest taxonomic levels possible. Then, by species, the total number of fish samples was counted

Table 1. Information and results of the midbottom trawl surveys. Trawling was conducted eight times (T1 refers to the first trawl shot).

Trawl no.	Date	Hauling time	Duration	Net mouth height (m)	Species composition	Average body length (cm)	Average body weight (g)	Catch ratio (%)	Total catch (kg)
T1	Apr 14	14:25-17:27	3:02	26.3	Anchovy	10.4	8.7	95.7	297.6
T2	Apr 15	08:42-10:46	2:04	30.3	Anchovy	9.4	6.8	98.7	229.2
T3	Apr 15	12:08-15:07	2:59	22.5	Anchovy	9.9	7.9	95.5	479.3
T4	Apr 15	16:10-18:11	2:01	32.4	Gizzard shad	13.6	31.0	35.7	68.0
					Anchovy	10.0	8.3	24.0	
					Japanese common squid	11.5	31.1	23.9	
					Large-eyed herring	11.1	16.1	11.0	
T5	Apr 16	07:34-10:34	3:00	28.7	Anchovy	9.3	6.4	94.6	106.6
T6	Apr 16	11:27-12:27	1:00	23.8	Anchovy	9.6	7.4	77.5	255.9
					Large-eyed herring	11.6	16.7	20.3	
T7	Apr 16	13:54-16:55	3:01	25.8	Anchovy	9.9	8.1	96.4	243.9
T8	Apr 18	11:00-12:01	1:01	11.7	Anchovy	10.0	7.9	93.8	70.0

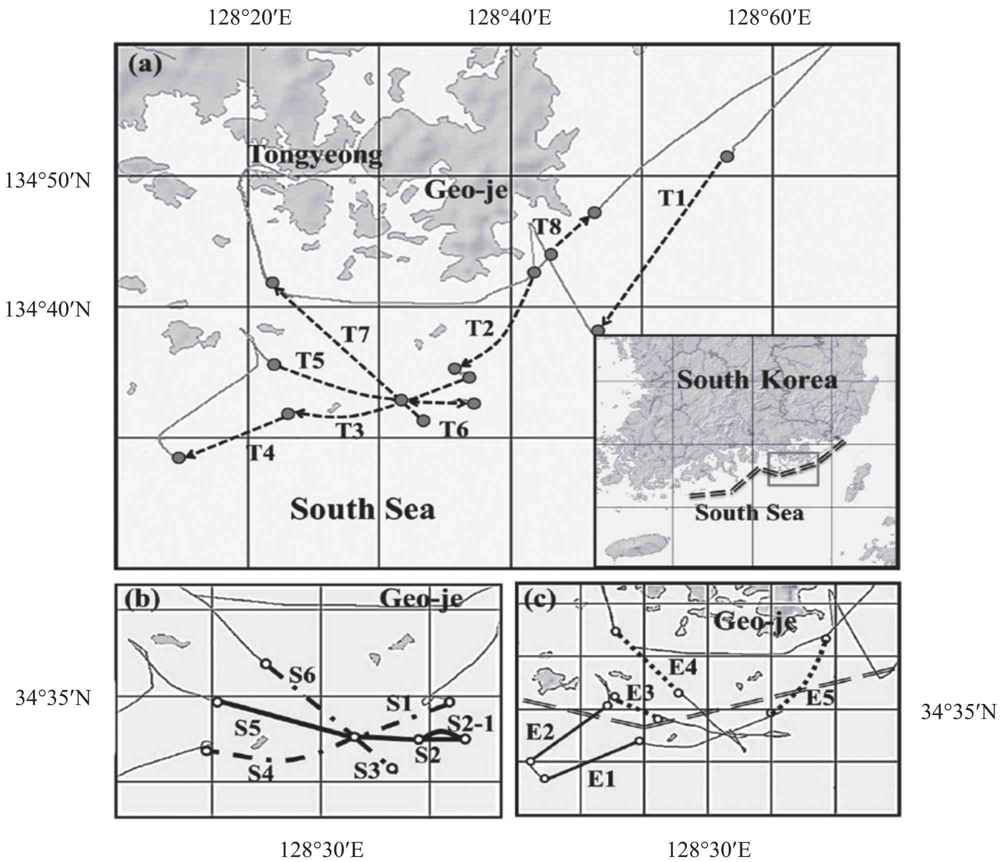

Fig. 1. Study area. The exact location of the study area is shown in the embedded figure in (a). The line represents the cruise line of the research vessel. T1 indicates the first trawl station. The length and direction of the dashed arrow indicates the towing time and its direction. Gray closed circles represent the first and last points of a trawl station. (b) Star-shaped survey line for examining the distributional properties of anchovy schools on the basis of time, namely the morning (08:00-12:00, thick lines) and afternoon (12:00-15:30, dash-dot lines). (c) Five extended lines for investigating the distributional properties of the anchovy schools and mixed schools according to location. The double lines in (a) and (c) are drawn as a baseline dividing the inshore and offshore waters.

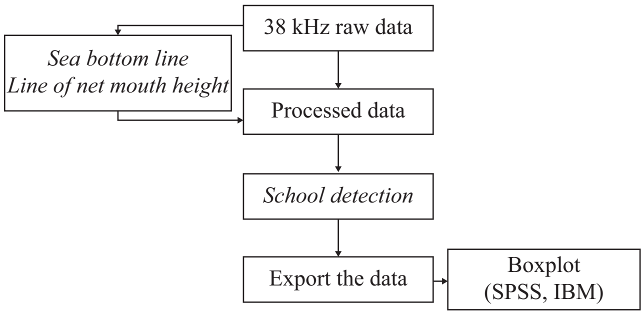

Fig. 2. Acoustic data analyzing flowchart. A detailed illustration shown in the text.

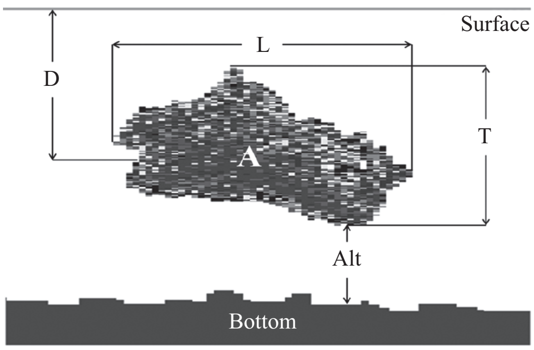

Fig. 3. Fish school descriptors. The morphometric properties are the length (L), thickness (T), and area (A). The positional properties are the distributional depth (D), which is the distance from the sea surface to the middle of the school, and the altitude (Alt), which is the distance between the sea bottom and the lower part of the school.

and their total weight was measured. The body length (cm) and weight (g) of 200 samples of anchovy and of 30 samples of other species were precisely measured. Acoustic data was collected using a 38-kHz echosounder (Simrad, EK60) that was calibrated through the standard calibration method (Foote et al., 1987) before the survey. Positional information, such as latitude and longitude (GPS fixes), was imbedded in the acoustic data.

2. Acoustic Data Analysis

Echoview version 6.0 (Echoview) was used to analyze acoustic data. A flowchart showing the data analysis process is presented in Fig. 2. In the figure, "38 kHz raw data" refers to the raw data collected using the echosounder and is displayed as an S_V echogram, which was obtained using Echoview. To directly compare the catch and acoustic data, fish schools from the sea bottom line to the line of the net mouth height were selected from the S_V echogram. The sea bottom line was determined using the best bottom candidate line pick algorithm in the virtual echogram module of Echoview. The line of the net mouth height was determined by adding the net mouth height to the sea bottom line made. The net mouth height differed for each trawl station (Table 1); thus, the exact net mouth height per station was used to plot the line of net mouth height. To reduce the number of data points to speed up the data processing, the processed data were created after removing data points above the line of net mouth height and below the sea bottom line. The SHAPES school detection algorithm was employed to detect fish schools and define them as polygons in order to calculate their morphometric and positional properties (Coetzee, 2000). In detail, setting a minimum data threshold is crucial because subthreshold data points surrounding the school will be excluded. Any school candidate should be longer and taller than a minimum candidate length and height, respectively. The maximum vertical and horizontal linking distances form the semiaxes of an ellipse that is moving around the boundary of a school candidate. If any part of the other candidates falls within the ellipse, a link is created between the candidates contributing to a larger school candidate. Finally, linked schools shorter than the minimum school length or height are rejected. The detection parameters were set to detect even a small anchovy school because anchovy schools vary in size (Table 2). The descriptors depicting the morphometric and positional properties of the detected fish schools (Fig. 3) were exported in comma separated values (CSV) format and were illustrated as boxplots by using SPSS version 10 (IBM, USA). To observe the whole voyage line at a glance, a resample operator of the virtual echogram module was used. Here, resampling means averaging the S_V values in a given range in a cell. The size of a cell can be selected by time, distance, or ping (horizontally) and depth (vertically). Two cell sizes (5 pings × 1 m and 6 pings × 1 m) were employed to visualize the entire voyage line as an echogram.

Table 2. Parameters settings for detecting the fish schools.

Parameter	Value
Minimum data threshold	-70 dB
Minimum total school length	3 m
Minimum total school height	1.6 m
Minimum candidate length	3 m
Minimum candidate height	1.6 m
Maximum vertical linking distance	2 m
Maximum horizontal linking distance	5 m

3. Statistical Analysis

Differences in the distributional properties of anchovy school between times (morning and afternoon) and locations (inshore and offshore waters) were tested using the Mann-Whitney U test in SPSS.

4. Defining Anchovy Schools by Time and Location

The survey lines off Geo-je Island were located close to each other, forming a star shape centered on the location (34°32.67'N and 128°31.66'E; Fig. 1(b)). The length of the survey lines was approximately 9,800 m, except for S2-1 and S3. Anchovy was the dominant species in most of the survey lines, as confirmed by the trawl results (Table 3), although the

Table 3. Seven survey lines (S1-S6) and five extended lines (E1-E5) for examining the distributional properties of the anchovy schools on the basis of time and location. Three survey lines (S2, S2-1, and S5) were for the morning anchovy schools, four survey lines (S1, S3, S4, and S6) were for the afternoon anchovy schools, two extended lines (E1 and E2) were for the offshore mixed schools, and three extended lines (E3-E5) were for the inshore anchovy schools.

Line	Date	Hour	Duration	Trawl	Species composition in catch
S5	16	08:13-09:33	1:20	T5	Anchovy 95%
S2	16	09:33-10:51	1:18	T5	Anchovy 95%
S2-1	16	11:12-12:00	0:48	T6	Anchovy78% Large-eyed herring 20%
S1	15	12:00-13:18	1:18	T3	Anchovy 96%
S3	16	13:44-14:13	0:29	T7	Anchovy 96%
S4	15	13:18-14:38	1:20	T3	Anchovy 96%
S6	16	14:13-15:23	1:20	T7	Anchovy 96%
E1	15	16:07-17:50	1:43	T4	Gizzard shad 36% Anchovy 24% Japanese common squid 24% Large-eyed herring 11%
E2	15	18:22-19:25	1:03	-	-
E3	16	07:28-08:03	0:35	T5	Anchovy 95%
E4	16	15:33-17:13	1:40	T7	Anchovy 96%
E5	15	09:06-10:46	1:40	T2	Anchovy 99%

survey line S2-1 contained 77.5% anchovies. The time taken to collect the acoustic data differed for each survey line. Three thick lines (S2, S2-1, and S5) were surveyed between 08:00 and 12:00; accordingly, the fish schools that were observed in these lines were defined as morning anchovy schools. Other four dash-dot lines (S1, S3, S4, and S6) were collected between 12:00 and 15:30, and the fish schools in the lines were defined as afternoon anchovy schools. The distributional properties of the morning and afternoon anchovy schools were accordingly examined relative to time.

Five extended lines centering on the star-like lines were created (Fig. 1(c)). The length of an extended line was approximately 12,300 m, except for E3. For the lines drawn along the coastline of the South Sea (the double line in the inset of Fig. 1(a)), the thick lines (E1 and E2) were located in offshore waters, and the dotted lines (E3, E4, and E5) were located in inshore waters. Anchovies were mainly caught in inshore waters; however, multiple species were found in E1, and no trawling was performed in E2 (Table 3). Therefore, fish schools in the dotted lines were defined as offshore mixed schools and those in thick lines were defined as inshore anchovy schools. The distributional properties of the fish schools were examined considering coastal proximity.

III. RESULTS

1. Trawl Results

During the trawl survey, eight shots were performed, and anchovy (*E. japonicus*, > 95%) was the major species of the trawl catch, except for T4, which contained various species such as gizzard shad (*Konosirus punctatus*, 35.7%), anchovy (24.0%), Japanese common squid (*Todarodes pacificus*, 23.9%), and others; and T6, which included anchovy (77.5%) and large-eyed herring (*Sardinella zunas*, 20.3%). The average fork length, weight, and total catch of anchovy were 9.8 cm, 7.7 g, and 198.1 kg, respectively (Table 1). The echo signals in the echograms, which were confirmed by the trawl results, could indicate that the signals were from anchovies.

2. Distributional Properties of the Anchovy Schools (by Time) and Statistical Test Results

Detailed information, such as trawl duration and species caught, from seven trawl survey lines is shown in Table 3 for examining the distributional properties of anchovy schools on the basis of time and location. Anchovies (> 95%) occupied most survey lines other than S2-1, which included anchovy (77.5%) and large-eyed herring (20.3%). Echograms of six survey lines arranged in order of survey time are shown in Fig. 4. The echogram of S3 is omitted because its time overlapped with S4, although the survey dates of S3 and S4 differed. Each survey line is presented in two echograms; the upper panels are S_V echograms, and the lower panels are resampled echograms that were obtained by averaging S_V within a cell (6 pings × 1 m). To compare the catch data and acoustic data directly, acoustic data between the line of the net mouth height and the bottom line were used. In the morning, most of the anchovy schools were very small and were distributed in all depths inside the net mouth (Fig. 4(a)-(c)); in the afternoon, some large anchovy schools were observed (Fig. 4(d)-(f)).

The fish school descriptors explaining the morphometric and positional properties of the morning and afternoon anchovy schools are described using boxplots (Fig. 5). The first quartiles (Q1), median, and third quartiles (Q3) for the S_V of morning anchovy schools were -55.0, -51.3, and -47.6 dB, respectively, and those of afternoon schools were -51.7, -48.2, and -44.9 dB. That means that stronger acoustic reflections were observed for the afternoon anchovy schools (average and standard deviation S_V of -48.4 ± 4.9 dB) than for the morning schools (average S_V of -51.3 ± 5.3 dB). Regarding the length of the anchovy schools, the Q1, median, and Q3 for the morning were 6.0, 11.4, and 20.1 m (average length of 16.8 ± 18.4 m) respectively, and those for the afternoon were 7.2, 11.7, and 20.9 m (average length of 18.9 ± 25.6 m). The lengths were similar for both times; however, anchovy schools longer than 63 m (outliers) were observed in the afternoon rather than in the morning. This indicates that several anchovy schools appeared to be extremely long in the afternoon. The Q1, median, and Q3 for the thickness of schools were also similar between the morning (8.3, 9.5, and 10.8 m, average

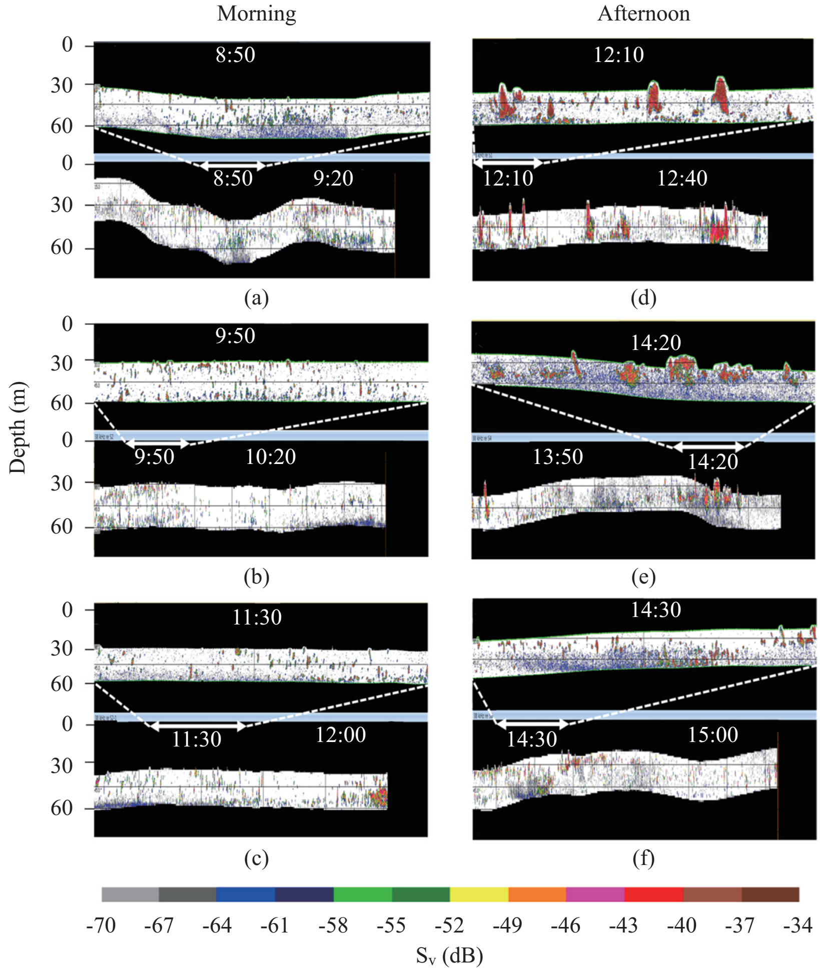

Fig. 4. Echograms of six survey lines for the morning anchovy schools (a)-(c) and afternoon anchovy schools (d)-(f). In each figure panel, the upper panel is an S_V echogram and the lower one is a resampled echogram. The time range of the S_V echogram is indicated by the white left-right arrows on the top of the resampled echogram. Acoustic data above the net height line and below the bottom line were excluded from the data analysis (these are shown in black to indicate "no data").

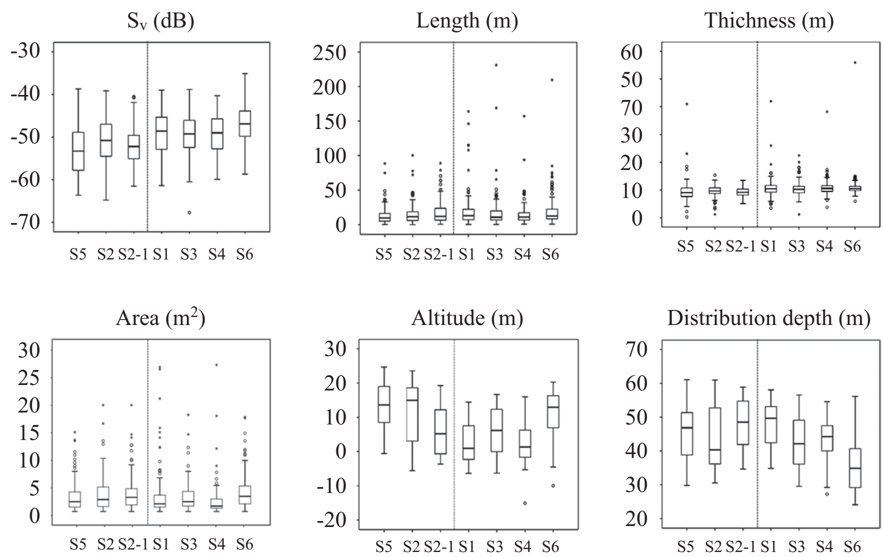

Fig. 5. Distributional properties of the morning anchovy schools (S2, S2-1, and S5) and afternoon anchovy schools (S1, S3, S4, and S6). The circles and asterisks denote outliers.

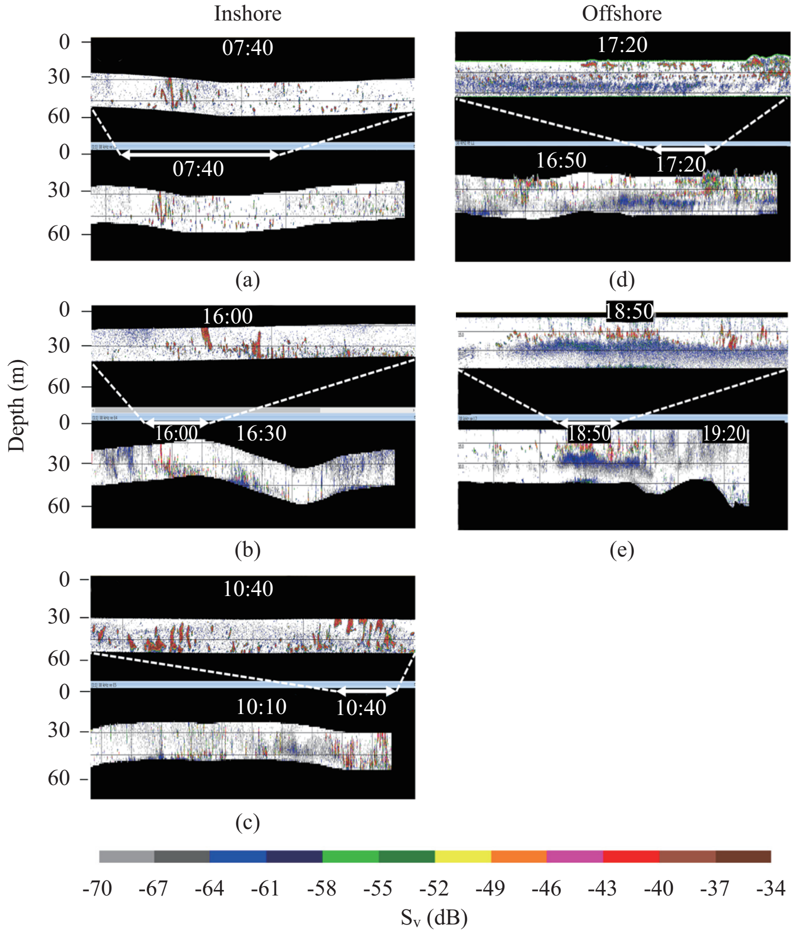

Fig. 6. Echograms of the five extended lines for the inshore anchovy schools (a)-(c) and offshore mixed schools (d) and (e). The time range of the S_V echogram is indicated by the white left-right arrows on the top of the resampled echogram. Acoustic data above the net height line and below the bottom line were excluded from the data analysis (these are shown in black to indicate "no data").

thickness of 9.7 ± 2.7 m) and afternoon (9.4, 10.5, and 11.5 m, average thickness of 10.8 ± 3.1 m); however, more outliers were observed in the afternoon than in the morning. Specifically, anchovy schools with a thickness of 19-56 m appeared in the afternoon. Regarding the anchovy school area, the difference in the Q1, median, and Q3 between the morning (1.7, 2.9, and 4.8 m^2, average area of 3.9 ± 3.0 m^2) and afternoon (1.7, 2.5, and 4.6 m^2, average area of 3.9 ± 3.8 m^2) was negligible. However, anchovy schools larger than 12 m^2 (outliers) were observed in the afternoon. The median and average altitudes of the morning anchovy schools were 9.5 and 9.5 ± 7.8 m, and those of afternoon schools were 5.8 and 6.2 ± 6.9 m, indicating that the morning anchovy schools were located closer to the water surface than were the afternoon schools. Regarding the distributional depth, the range between Q1 and Q3 was 15.8 m (37.4-53.2 m) in the morning and 12.7 m (36.0-48.7 m) in the afternoon, showing that the morning anchovy schools were distributed over a wider depth range than were the afternoon schools.

In the statistical results, the S_V (Mann-Whitney U test, z = -11.30, $p < 0.05$), thickness (Mann-Whitney U test, z = -10.20, $p < 0.05$), distributional depth (Mann-Whitney U test, z = -6.23, $p < 0.05$), and altitude (Mann-Whitney U test, z = -6.23, $p < 0.05$) of anchovy schools differed significantly between the morning and afternoon. However, the difference in length (Mann-Whitney U test, z = -1.91, $p > 0.05$) and area (Mann-Whitney U test, z = -1.68, $p > 0.05$) between the morning and afternoon was nonsignificant. This indicates that the anchovy schools had similar lengths and areas regardless of time.

3. Distributional Properties of the Anchovy Schools (by Location) and Statistical Test Results

The trawl station, species composition, and trawl time of five extended lines are noted in Table 3. Three lines defined as inshore anchovy schools contained nearly all anchovies (> 95%). However, the E1 line, defined as offshore mixed schools, comprised 24% anchovy mixed with other species such as gizzard shad; no trawling was conducted in E2. The representative echograms of five lines are shown in Fig. 6. The inshore anchovy schools and offshore mixed schools were compared to elucidate their distributional properties. In the inshore waters, the anchovy schools showed relatively large aggre-

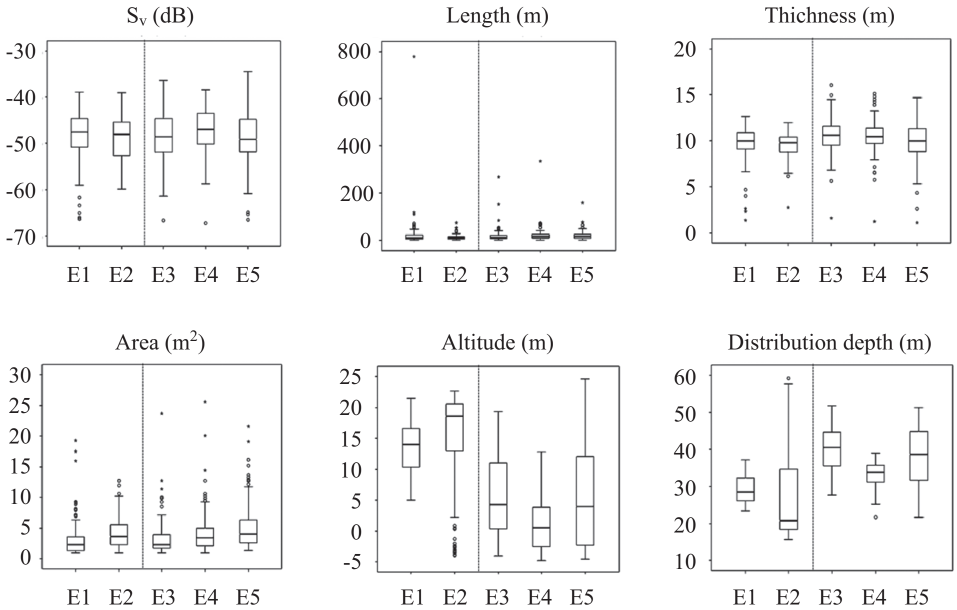

Fig. 7. Distributional properties of the offshore mixed schools (E1 and E2) and inshore anchovy schools (E3-E5). The circles and asterisks denote outliers.

gated forms and appeared relatively close to the sea bottom (Fig. 6(a)-(c)). By contrast, the offshore mixed schools varied in size, with very dense aggregations on the top of the scattered echoes distributed in midwater depth (Fig. 6(d) and (e)).

Boxplots on the properties of the inshore and offshore fish schools are shown in Fig. 7. For the S_V of the fish schools, the Q1, median, and Q3 of the offshore mixed schools were -51.3, -47.6, and -44.7 dB (average S_V of -48.2 ± 5.0 dB), respectively, and those of the inshore anchovy schools were -51.3, -47.6, and -43.4 dB (average S_V of -47.7 ± 5.6 dB), showing similar values. The Q1, median, and Q3 for the length of the offshore mixed schools were 5.8, 10.5, and 18.6 m (average length of 17.8 ± 41.6 m), and those for the inshore anchovy schools were 8.3, 15.3, and 27.7 m (average length of 23.7 ± 30.3 m). This indicates that the inshore anchovy schools were longer than the offshore mixed schools, and that schools of 73-780 m in length (outliers) were observed in the inshore waters rather than in the offshore waters. The difference in fish school thickness between the inshore and offshore schools was marginal, and the Q1, median, and Q3 values were 9.0, 10.1, and 10.9 m for the offshore mixed schools (average thickness of 9.9 ± 1.8 m) and 9.4, 10.4, and 11.5 m for the inshore anchovy schools (average thickness of 10.4 ± 2.4 m), respectively. In addition, the difference in fish school area between the inshore and offshore schools was also marginal, with Q1, median, and Q3 values of 1.5, 2.5, and 4.4 m^2 for the offshore schools (average area of 3.5 ± 3.1 m^2) and 2.1, 3.7, and 5.6 m^2 for the inshore schools (average area of 4.9 ± 4.3 m^2); however, extremely large schools (15-29 m^2) were observed in the inshore waters. The Q1, median, and Q3 for altitude in the offshore schools were 8.5, 12.7, and 17.3 m, respectively (average altitude of 13.1 ± 8.0 m), and those in the inshore anchovy schools were -1.7, 1.9, and 8.1 m (average altitude of 3.8 ± 7.0 m). This means that, in general, the inshore anchovy schools were closer to the sea bottom than were the offshore mixed schools. Regarding the distributional depth, the Q1, median, and Q3 for the offshore schools were 25.1, 30.0, and 34.1 m (average depth of 30.0 ± 7.4 m) and those for the inshore schools were 33.1, 37.9, and 44.3 m (average depth of 38.7 ± 7.2 m), respectively. This indicates that the inshore anchovy schools were distributed over deeper depths than were the offshore mixed schools.

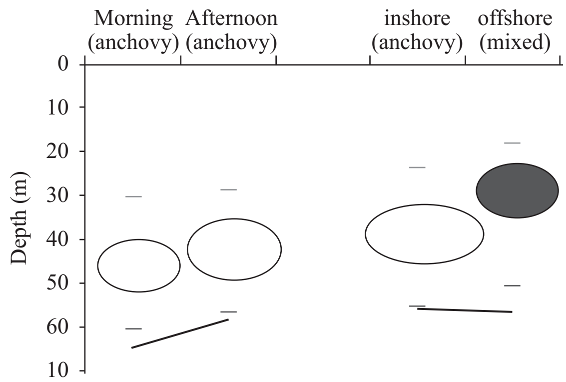

Fig. 8. Conceptual diagram showing the distributional properties of the anchovy schools relative to time and location. The white circles indicate the anchovy schools and the gray closed circle indicates the mixed school. The circle size corresponds to the average size of the fish schools. The circle location indicates the average distributional depth of the fish schools. The light gray bar above the circles denotes the minimum distributional depth, and the dark gray bar below the circles denotes the maximum distributional depth. The black line represents the sea bottom.

In the statistical results, other than S_v (Mann-Whitney U test, $z = -1.13, p > 0.05$), significant differences were observed in the length (Mann-Whitney U test, $z = -5.91$, $p < 0.05$), thickness (Mann-Whitney U test, $z = -4.40$, $p < 0.05$), area (Mann-Whitney U test, $z = -6.97$, $p < 0.05$), distributional depth (Mann-Whitney U test, $z = -15.32$, $p < 0.05$), and altitude (Mann-Whitney U test, $z = -16.69$, $p < 0.05$) of the fish schools between the inshore and offshore waters. This means that the differences in the fish school descriptors, other than the S_V, between the inshore and offshore waters, can be distinguished.

A simplified conceptual diagram showing the distributional properties of the anchovy schools by time (morning and afternoon) and location (inshore) and those of the mixed schools in the offshore waters is shown in Fig. 8. The afternoon anchovy school tended to be longer and closer to the sea bottom compared with the morning school, and the inshore anchovy schools seemed to be longer and closer to the sea bottom compared with the offshore mixed schools.

IV. DISCUSSION

1. Acoustic Surveys Combined with Trawl Surveys

Trawl surveys conducted in South Korea have mainly used catch data to elucidate the species composition, distributional properties, and abundance estimation of sampled fish, as mentioned in the Introduction. In other countries, trawl and acoustic surveys are generally conducted concurrently. However in several studies, bottom trawl surveys have been conducted only once every 3 years, as in Norton Sound and Alaska from 1976 to 2002, to elucidate the presence of regime shifts (Hamazaki et al., 2005). Surface trawl surveys have also been conducted in Penobscot Bay, Maine, USA, and the nearshore Gulf of Maine waters from May to June between 2001 and 2005, the objective was to investigate the early marine dynamics of the Atlantic postsmolts (Sheehan et al., 2011). Seasonal bottom trawl surveys have also been conducted in the East China Sea and Yellow Sea to investigate the horizontal distribution patterns according to the growth of age-0 jack mackerel (Sassa et al., 2009). Acoustic surveys have several limitations; for example, areas near the water surface and sea bottom cannot be observed using an echosounder. Therefore, studies have naturally focused on those areas to use appropriate gear, such as bottom and surface trawl nets, other than an echosouner. Regarding research combining trawl and acoustic surveys to determine species compositions and size distributions, a trawl survey was carried out in the North Patagonian shelf between 2011 and 2013 to understand the behavior and vertical distribution of young-of-the-year Argentine hake by examining acoustic data collected along transect lines (Álvarez-Colombo et al., 2014). From 1991 to 2010 in the Puget Sound, USA, the diel pattern of spotted ratfish was estimated using acoustic tags, and their precaudal length and sex were elucidated through a trawl survey (Andrews and Quinn, 2012). Makarov et al. (2012) used a hydroacoustic system to estimate the abundance of Omul in Lake Baikal, the population distribution and length-to-weight ratio were obtained through a trawl survey. Moreover, Ehrlich et al. (2013) analyzed the acoustic data from an echosounder to understand the vertical distribution of hake, and investigated the species composition, length, and sex of the catch by conducting a trawl survey. Thus, acoustic data in other countries have been commonly collected while conducting a trawl survey; however, in South Korea, the present study is the first where acoustic data were recorded during a primary trawl survey. Quantitative and qualitative information of a target species can be obtained by simply turning on an echosounder during a trawl survey, especially for midwater and midbottom trawls. It is crucial for fishery oceanographers and managers to be aware of the availability of acoustic data in South Korea. Accordingly, reliable results from hydroacoustic surveys concurrently conducted with trawl surveys can be utilized more effectively and for a greater variety of purposes. For example, the total allowable catch system is set annual quotas for pelagic fish species, such as mackerel, horse mackerel, and squid. An acoustic and trawl survey in parallel can be very effective for the sustainable management of these species.

2. Acoustic Research by Time and Location

Regarding the temporal distribution of fish species, a study conducted in the Straits of Korea used a Bongo net and WP-2 net at depths of 0, 30, 50, 70, 100, and 150 m in April, July, October, and January from 1992 to 1993, reporting that anchovy larvae were distributed between the sea surface and 50 m and appeared during the daytime in the spring and at night in the summer and autumn (Lee et al., 1996). Between 2005 and 2006, a series of acoustic surveys was conducted to elucidate the diel behavior of sardines and anchovies in Monterey Bay and on the Oregon coast; schools of these species were observed during the daytime (approximately 06:00-20:00) at a depth of 20 m on the Oregon coast and across the entire depth regardless of time in Monterey Bay. Additionally, the Oregon coast is deeper and has a lower plankton density, whereas Monterey Bay is relatively shallow and has more plankton (Kaltenberg and Benoit-Bird, 2009). Another study showed that anchovies in the Aegean Sea followed diurnal vertical migration. Specifically, the anchovy schools descended suddenly to the sea bottom at approximately 09:00 and ascended rapidly to the sea surface at approximately 20:00 in July from 2004 to 2006 (Tsagarakis et al., 2012). In the present study, the anchovy schools tended to be distributed relatively evenly throughout the entire water column in the morning and close to the sea bottom in the afternoon. This pattern of traveling toward the sea bottom from morning to afternoon is similar to that of diel behavior. Understanding the distributional properties of anchovy schools relative to time could facilitate designing survey lines and enable determining an appropriate time for sailing on the transect line.

Relatively higher nautical area scattering coefficients, the acoustic intensity called referred to as the acoustic abundance

Table 4. Comparison with other studies regarding the distributional properties of anchovy schools in South Korea.

	This study		Kang et al. 1996		Kim et al. 1998	
Surveyed date	Apr.14-18, 2014		Jul.22-28, 1994		Mar.15-30, 1994	Mar.15-Apr. 2, 1995
Surveyed area	Inshore	Offshore	Pohang	Ulsan	East China Sea	Eastern South Sea
S_V (dB)	-47.7	-48.2	-38.0	-36.6	-53.4	-50.0
Length (m)	23.7	17.8	32.4	23.3	13.8	22.7
Thickness (m)	10.4	9.9	6.1	10.1	3.4	4.4
Area (m^2)	4.9	3.5	53.7	50.1	29.5	69.4
Altitude (m)	3.8	13.1	-	-	12.0	23.3
Distributional depth (m)	38.7	30.0	50-100	50-100	52.0	14.3
Anchovy fork length (cm)	10.0	9.5	9.2	11.8	-	-
Anchovy caught proportion (%)	24.0	96.6	92.2	93.7	84.0	95.3

index, of anchovies were observed near the coastal waters off Tongyeong and Yeosu of South Korea than offshore in the spring and winter (Kang et al., 2015). Two studies regarding the distributional characteristics of anchovy schools were conducted in South Korea in late 1990, the results of which were compared with the results from the present study (Table 4). Anchovy schools off the coast of Pohang and Ulsan (East Sea of South Korea) had higher S_V, larger area, and deeper distributional depth than those in the present study area (Kang et al., 1996). Anchovy schools in the East China Sea had a lower S_V yet a larger area, and those in the eastern South Sea of South Korea had a larger area and lower distributional depth compared with those in this study area (Kim et al., 1998). Tugores et al. (2010) conducted an acoustic survey along transect lines in two coastal areas of the eastern sea off Spain, namely in the North region (42°26'-41°55'N) and South region (41°01'-40°17'N) from November to early December between 2003 and 2006, showing that anchovies were more abundant in the upper parts of both regions. According to a study conducted in Biscay Bay from 2003 to 2010, small juvenile anchovies (*Engraulis encrasicolus*) were distributed on the sea surface on the continental shelf, whereas fish schools composed of relatively large juvenile and adult anchovies were located in the deep sea near the coast (Boyra et al., 2013). Accordingly, the distribution of anchovies varies with location; however, no specific regular pattern based on the location was identified. The current study showed that anchovy schools in the inshore waters were distributed deeper than the mixed schools in the offshore waters, which is similar to the results of the Biscay Bay research. In addition, some of the anchovy schools in the afternoon, which were at the extremes in length, thickness, and area (outliers of Fig. 5), differed from the morning anchovy schools. In particular, the schools with extreme thickness resulted in a significant difference between the morning and afternoon anchovy schools, although their mean values were similar. Very tall and large anchovy schools in the inshore waters (outliers of Fig. 7) were statistically distinguished from the mixed schools in the offshore waters. Additionally, accurate geological information on the anchovy schools from this study can contribute to solving territory issues among fishing companies that use different fishing gear.

3. Oceanographic Condition and Future Study

Overall, the distributional properties of the anchovy schools change according to time and location in numerous waters, and it is assumed that factors affecting distributional properties are quite diverse. Numerous studies have been conducted to clarify the distributional change in anchovy eggs and larvae relative to marine environmental information, such as sea temperature, salinity, chlorophyll, suspended solids, and dissolved oxygen, the stream of coastal waters, and the prey along the southern coast of South Korea, particularly from Yeosu to Tongyeong and the Jeju Strait (Cha, 1990; Park and Cha, 1995; Choo and Kim, 1998; Choo, 2002; Ko et al., 2007, 2010). In addition, for adult anchovies, the relationship between the vertical distribution of the schools and sea temperature and salinity was observed in two small areas near Pohang and Ulsan (Kang et al., 1996). Between June and August 1997, in Gamak Bay along the southern coast, the anchovy schools migrated toward waters with a sea temperature of approximately 21°C-24°C and salinity of 30‰-34‰ salinity, showing that the location of anchovy schools varies monthly (Seo and Kim, 1999). In other words, anchovies have different distributional patterns with diurnal rhythm and monthly and seasonal changes that are affected by various environmental factors. A conductivity, temperature, and depth (CTD) probe was used to investigate the oceanographic conditions while the trawl survey was conducted. Specifically, CTD experiments were conducted once per trawl station, and the data were selected from the sea bottom to the line of the net mouth height to examine the water temperature and salinity while considering the distribution of anchovy schools by time and location, respectively. The average water temperature and salinity in the net were respectively 13.5°C ± 0.2°C and 34.4‰ ± 0.0‰ in the morning and 13.1°C ± 0.2°C and 34.3‰ ± 0.0‰ in the afternoon. The average water temperature and salinity in the net were 12.6°C ± 0.3°C and 34.3‰ ± 0.0‰ in the offshore waters and 13.5°C ± 0.3°C and 34.4‰ ± 0.1‰ in the inshore waters, respectively. The difference in the average water temperature and salinity in the study area was very minor (below 1.1°C and 0.1‰). One could assume that the oceanographic conditions did not significantly affect the distributional patterns of anchovies in the study. Other oceanographic elements should be considered in order to investigate causes of the dynamic change of the distribution of the schools.

The major objective of this study was to present the availability of acoustic data recorded from a primary trawl survey.

The acoustic data were analyzed in a limited condition; hence, the factors that contributed largely to the diverse changes in the anchovy distribution could not be explained, although it was confirmed that the water temperature and salinity might not play a key role. In the study, the distributional properties of anchovy schools were examined only from 8:30 to 15:30. In the future, distributional differences over 24 hours will be investigated to determine the ecological characteristics of anchovies and provide information on the optimal time for acoustic abundance surveys. A high-frequency echosounder can be employed to target anchovy eggs and larvae to realize the dynamic structure of the entire life stages of anchovies.

V. CONCLUSION

In South Korea, trawl surveys have been conducted to elucidate the species composition and/or distributional properties of marine organisms by using only catch data. When trawl surveys are conducted, acoustic data can be collected simultaneously to provide useful information on marine creatures. In this study, acoustic data were first collected and analyzed to understand the distributional properties of anchovy schools on the basis of time and location, through a primary trawl survey conducted in the South Sea of South Korea from April 14 to 18, 2014. According to the trawl results, the fish schools detected in the seven survey lines near Geoje Island were confirmed as being comprised almost entirely of anchovy species. Their distributional properties were examined on the basis of time (morning and afternoon), because the time of seven lines was recorded from 8:00 to 15:30. Consequently, the acoustic-reflected intensity (S_V) of the afternoon anchovy schools was higher than that of the morning schools, although the average length, thickness, and area of both schools were similar. The average altitude of the afternoon schools was closer to the seabed than that of the morning schools, and altitude range of the afternoon schools was narrower than that of the morning ones. All distributional properties other than the length and area differed significantly by time. To understand the distributional properties of anchovy schools according to location (inshore and offshore), five extended lines based on the seven aforementioned lines were created; anchovy schools were dominant in the three extended lines located in the inshore waters, and multiple species were distributed in the other two lines in the offshore waters. The average S_V, thickness, and area of the inshore anchovy schools and offshore mixed schools were similar; however, the average length of the inshore anchovy schools was longer than that of the offshore mixed schools. Notably, considerably long or thick schools appeared in the inshore waters. The inshore anchovy schools were distributed over deeper depths than were the offshore schools. Every property except S_V differed significantly between the inshore and offshore waters. A conceptual diagram is presented to illustrate the distributional properties of the anchovy schools by time and location.

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