Thalassas (2016) 32:91–100
DOI 10.1007/s41208-016-0013-y

Exploratory Study for Acoustical Species Identification of Anchovies in the South Sea of South Korea

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Published online: 15 August 2016

Abstract We conducted a hydroacoustic-trawl survey from April 16–19, 2013, for acoustical identification of anchovies in the South Sea of South Korea. Three types of fish schools were defined on the basis of the trawl results: L7 (schools mixed with 57 % hairtail and 37 % anchovy), L8 (schools with 95 % anchovy), and L1 (schools with unknown species). According to the results, the bathymetric characteristics (school depth, water depth, and altitude) of L1 were similar to those of L7; however, the morphometric characteristics (length, height, area, and image compactness) of L1 were similar to those of L8. To confirm whether L1 was more similar to L8 or L7, we used the ΔMVBS method [where ΔMVBS is difference of mean volume backscattering strength (MVBS) at 38 and 120 kHz] with three cell sizes, 0.1 nmi × 2 m, 0.25 nmi × 4 m, and 0.5 nmi × 5 m; the ΔMVBS pattern of L1 seemed similar to that of L8, but not that of L7. By using one-way analysis of variance, we noted significant differences of frequency characteristics between L7 and L8 and L7 and L1, supporting the results of the ΔMVBS method. Moreover, only 0.1 nmi × 2 m and 0.25 nmi × 4 m were the appropriate cell sizes for anchovy species identification. This exploratory study may form the basis for other species identification.

Keywords Species identification · Anchovy · Echosounder · South Korea

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Introduction

The anchovy (*Engraulis japonicus*) is one of the most commercially and ecologically valuable species in the South Sea of South Korea. Between 2006 and 2014, the annual yield of anchovy in South Korea was approximately 100,000 M/T (Statistics Korea 2015). Anchovies are small shiny silver fish, with a maximum body length of approximately 15 cm. The average lifespan of an anchovy is approximately 1.5 years (Kim et al. 2004). These fish form schools and typically migrate to the coastline, particularly between Yeosu to Geoje Island and Tongyeong (Choo and Kim 1998). Eight species belonging to the genus *Engraulis* have been reported worldwide, with most of them distributed in coastal waters (Whitehead et al. 1988). Their major preys are copepods, small crustaceans, mollusk larvae, and fish eggs (Nizinski and Munroe 1988). Anchovies have a major role in sustaining the mean trophic level in the food web of marine ecosystem in coastal waters.

Several studies have estimated anchovy biomass by using scientific echosounders in the seas of South Korea (Choi et al. 2001; Kim et al. 2008; Oh et al. 2009). However, these studies were conducted over short periods. For understanding the morphological and positional characterisitcs of anchovy schools, two studies were conducted in small areas of the East China Sea and the East Sea of South Korea (Kang et al. 1996; Kim et al. 1998). Furthermore, Yoon et al. (1996) determined the ex situ target strength (TS) of the anchovy (average body length, 14.4 cm) at 38 kHz and obtained its length-TS conversion equation. Lee and Kang (2010) reported that TS on the side aspect of the anchovy (average body length, 9.3 cm) was 2 dB higher than that on the dorsal aspect at 120 kHz. In many areas in the seas of South Korea, other species coexist along with the anchovy species. Anchovy species are difficult to distinguish from other marine organisms by using acoustic approaches. To investigate the distributional characteristics of anchovy schools and estimate their biomass by using an echosounder, anchovy species identification is required. The determination of anchovy school characteristics differing from those of schools of other species or of fish aggregations mixed with anchovy and other species can aid in identifying anchovy as well as in identifying other species.

This study identified anchovies, and consequently, formed the basis for enabling identification of other species. Specifically, we formed two groups for examining the distinguishing characteristics of anchovy and other species: fish schools comprising anchovies almost exclusively and fish schools comprising anchovies along with other species. Moreover, we identified fish in fish schools comprising unknown species.

Materials and Methods

Data Collection

We conducted a hydroacoustic survey during April 16–19, 2013, by using an EK60 echosounder (Simrad, Norway) calibrated at 38 and 120 kHz in an area located in the middle of the South Sea of South Korea (Fig. 1). Cruise track consisted of eight transect lines. Throughout the survey, the daytime weather was extremely unfavorable on most days. Thus, only three transect lines—1, 7, and 8—were conducted during the daytime. During the survey, the vessel speed was maintained at approximately 10 kn. For setting the echosounder at 38 kHz, transmitted power and pulse length were adjusted to 1000 W and 1.024 ms, respectively; major and minor axis 3 dB beam angles were 7.06° and 6.93°, respectively. For setting the echosounder at 120 kHz, transmitted power and pulse length were adjusted to 500 W and 1.024 ms, respectively; major and minor axis 3 dB beam angles were 6.66° and 6.60°, respectively. Midwater trawls were concurrently conducted, and locations for trawling were determined on the basis of the echo signals of fish schools on the echogram. The circumference of the trawl net was 504 m, net length was 163.8 m, and mesh size of the cod-end was 4 cm. In total, four shots were conducted: the first two shots (T1 and T2) were performed during the day and the remaining (T3 and T4) during the night. At each trawl station, fish weight, length, and total catch weight per species were measured after classifying the catch by species on board.

Defining Fish Schools and Their Distributional Characteristics

Acoustic data were analyzed using Echoview (version 6; Echoview Software, Australia). First, echo signals at T1 and T2 were thoroughly examined on the basis of the catch results—an empirical training for understanding the echoes of the species. Echo signals of all transect lines were investigated according to the aforementioned findings. To determine the distributional characteristics of the fish schools, data from the 38 kHz analysis were used and the fish school detection module imbedded the SHAPES algorithm in the Echoview was applied (Coetzee 2000; Myriax 2015). First, the fish schools were determined by defining the boundaries of fish school-like regions. Properties of these regions were examined to extract diverse characteristics of the fish schools—morphometric, bathymetric, and energetic (hereafter, called distributional characteristics). The description and computation of the distributional characteristics are presented in Table 1 and Fig. 2, respectively. The morphometric characteristics comprised the length, height, area, and image compactness of a fish school. The bathymetric characteristics comprised the school depth, water depth and altitude. The energetic characteristics included volume backscattering strength (S_V).

Corrected length (L_c) denotes the length corrected for the effect of the beamwidth by using the term of 2D tan (θ/2, where θ indicates the attack angle, defined as the angle between an on-axis line and another line, toward the school edge, measured just at the beginning of school detection). Corrected height (H_c) compensates the effect of the pulse width [cτ/2, where τ denotes pulse duration (Diner 2001)]. Image compactness, defined as 1 divided by circularity, is commonly used for image analysis. If the shape of a fish school is completely round, image compactness value is 1; the value can range from 1 to infinity. Altitude refers to the distance between the bottom of a fish school and that of the sea.

Frequency Characteristics and Their Statistical Verification

The frequency characteristics of fish schools were examined using the ΔMVBS (i.e., the difference in mean S_V at two frequencies) method. This method uses the difference of mean

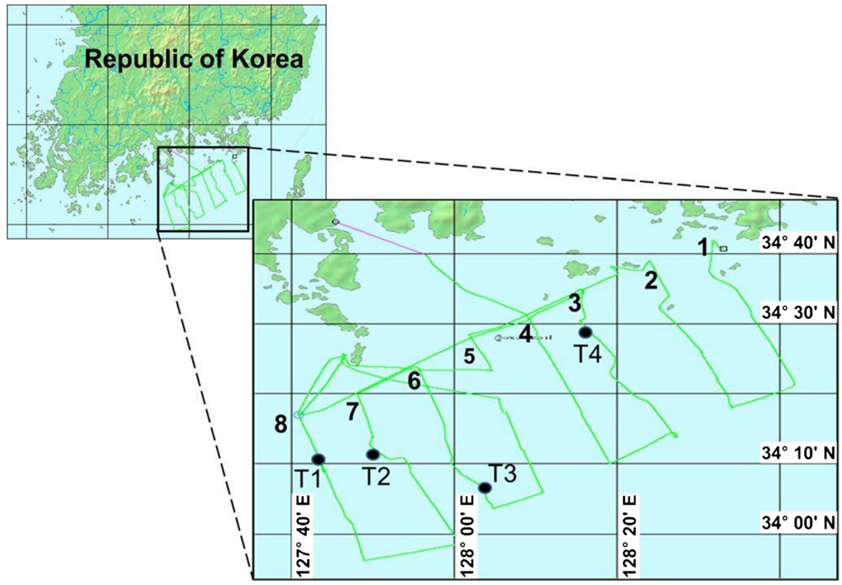

Fig. 1 Study area. The *green lines* represent the transect for the hydroacoustic survey. The eight transect lines are marked using numbers. The four trawl sites are indicated as T1–T4

volume backscattering strength at two frequencies, and the equation can be expressed as

$$\Delta S_V = \frac{S_{vf_2}}{S_{vf_1}} \quad (1)$$

where S_{Vf1} and S_{Vf2} are mean S_V in a cell at 38 and 120 kHz; a cell is the area comprising certain vertical and horizontal parameters (e.g., 2 m and 1 nmi, respectively). This method was developed using acoustic characteristic of organisms, considering their biological properties, and has been applied to various species in many areas worldwide. For example, krill was distinguished from walleye pollack, and the age groups of walleye pollack could be classified (Kang et al. 2002, 2006). Three fish species, namely orange roughy, whiptails, and myctophids, were discriminated using three colors (Kloser and Horne 2003). In the North Sea, Norway pout was differentiated from Atlantic herring (Fassler et al. 2007). The ΔMVBS method cannot be universally applied to all species because acoustic characteristics of several species are affected by their behaviors, the local oceanic environments and setting parameters of the acoustic systems. Nevertheless, the method has been widely used because it requires a simple mathematic equation and easy-to-handle application tools. In this study, three cell sizes—0.1 nmi × 2 m, 0.25 nmi × 4 m, and 0.5 nmi × 5 m (given as length × height)—were used.

Statistical analyses were performed using SPSS (version 19; IBM, USA) to verify the frequency characteristics results. In other words, for examining the statistical differences in the

Table 1 Descriptors of fish school characteristics and their computation

School descriptor	Symbol	Computations	Units
Energetic			
Volume-backscattering strength	S_V	-	dB
Morphometric			
Length	L_c	$L_c = [L - 2D \tan(\theta/2)]$	m
Thickness	H_c	$H_c = H - c\tau/2$	m
Area	A_c	$A_c = A\ (L_cH_c)/(LH)$	m^2
Image compactness	IC	$IC = P^2/(4\pi A_c)$	-
Bathymetric			
School depth	D	-	m
Water depth	WD	-	m
Altitude	Alt	$Alt = WD - (D + H_c/2)$	m

Subscript "c" denotes correction; θ, attack angle; τ, pulse duration (Diner 2001)

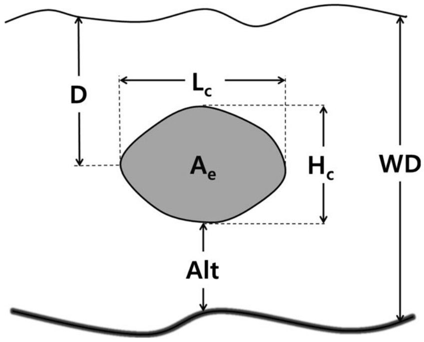

Fig. 2 Descriptors of fish school distributional characteristics. See Table 1 for a detailed explanation of each descriptor

frequency characteristics, the Student *t* test and one-way analysis of variance (ANOVA) were applied for two and three groups, respectively.

Results

Trawl Results and Echograms

Trawl results such as species and mean body weight and length are listed in Table 2. At trawl station 1 (T1) on transect line 8, 95 % of the catch included anchovies. At trawl station 2 (T2) on transect line 7, 57 % of the catch were hairtails and 37 % were anchovies. Echo signals at the trawl stations 3 and 4 were completely dispersed; thus, no aggregation could be observed. By using the T1 and T2 data, two groups were established: fish schools mainly comprising anchovy species (L8) and those comprising a mixture of hairtail and anchovy species (L7). By examining all echograms, fish aggregations were observed only at transect lines 1, 7, and 8, where the survey was conducted during daytime. In the transect line 1, echo signals located close to the coastal sea appeared to indicate small-sized aggregations. We analyzed the species observed in the transect line 1 and termed the fish schools at this line 1 as L1.

S_V echograms and resampled echograms at L7 and L8 are shown in Fig. 3. The resampled echograms were created by averaging all samples in the range of approximately 10 pings horizontally and 1 m vertically, so that it showed all echo signals of marine organisms on the entire transect line. L7 demonstrated relatively larger sizes with stronger echo signals, with distribution approximately in between 15 and 60 m. L8 was relatively small sized with weak signals and scattered. In Fig. 3, black portions below the line of sea bottom and above the straight line on the top present no data by deleting any data samples above the top line including ring-down noise and below the sea bottom including the sea bottom signals.

Distributional Characteristics

Distributional characteristics of L7, L8, and L1 are presented using a box plot in Fig. 4. For L7, the first, second, and third quartiles of the school depths were 29.5, 35.5, and 45 m, respectively, whereas they were 25, 28.7, and 34 m, respectively, for L8, indicating a relatively narrower range with several outliers. For L1, the first, second, and third quartiles of were 25.6, 29.6, and 34.1 m, respectively; these values were closer to those of L8. Average school depths and their standard deviation for L7, L8, and L1 were 36.0 ± 9.8, 29.6 ± 7.6, and 30.4 ± 5.7 m, respectively. L8 had a relatively shallow water depth (Fig. 3); the water depth of L1 was similar to that of L7. The first and third quartiles of the water depth of L7 were 49.8 and 69.8 m, respectively, and those of L1 were 52.9 and 65.7 m, respectively. However, the minimum and maximum water depths of L1 were closer to those of L8. The altitudes indicated that among the three fish schools, those at L8 were the closest to the sea bottom. Average altitudes of L7, L8, and L1 and their standard deviations were 21.6 ± 6.2, 14.6 ± 8, and 27.8 ± 10.3 m, respectively. The mean lengths of L7, L8, and L1 and their standard deviation were 14.7 ± 27.5, 9.3 ± 11.4, and 9.2 ± 8.4 m, respectively. The maximum lengths of L7 and L8 were 408.3 and 105.9 m, respectively. Therefore, L7 contained extremely long fish schools. The heights of L7, L8, and L1 were extremely similar, although L7 had more outliers; their average heights

Table 2 Results of four trawl shots

Trawl No.	Transect line	Total catch (kg)	Species	Percent (%)	Average body length (cm)
T-1	8	32.0	Anchovy	95	9.2
T-2	7	78.2	Hairtail	57	9.9
			Anchovy	37	9.6
T-3	6	17.3	Anchovy	60	11
			Korean pomfret	13	18.7
			Chefoo thryssa	11	11
T-4	3	103.9	Anchovy	39	10.4
			Japanese common squid	22	8.1

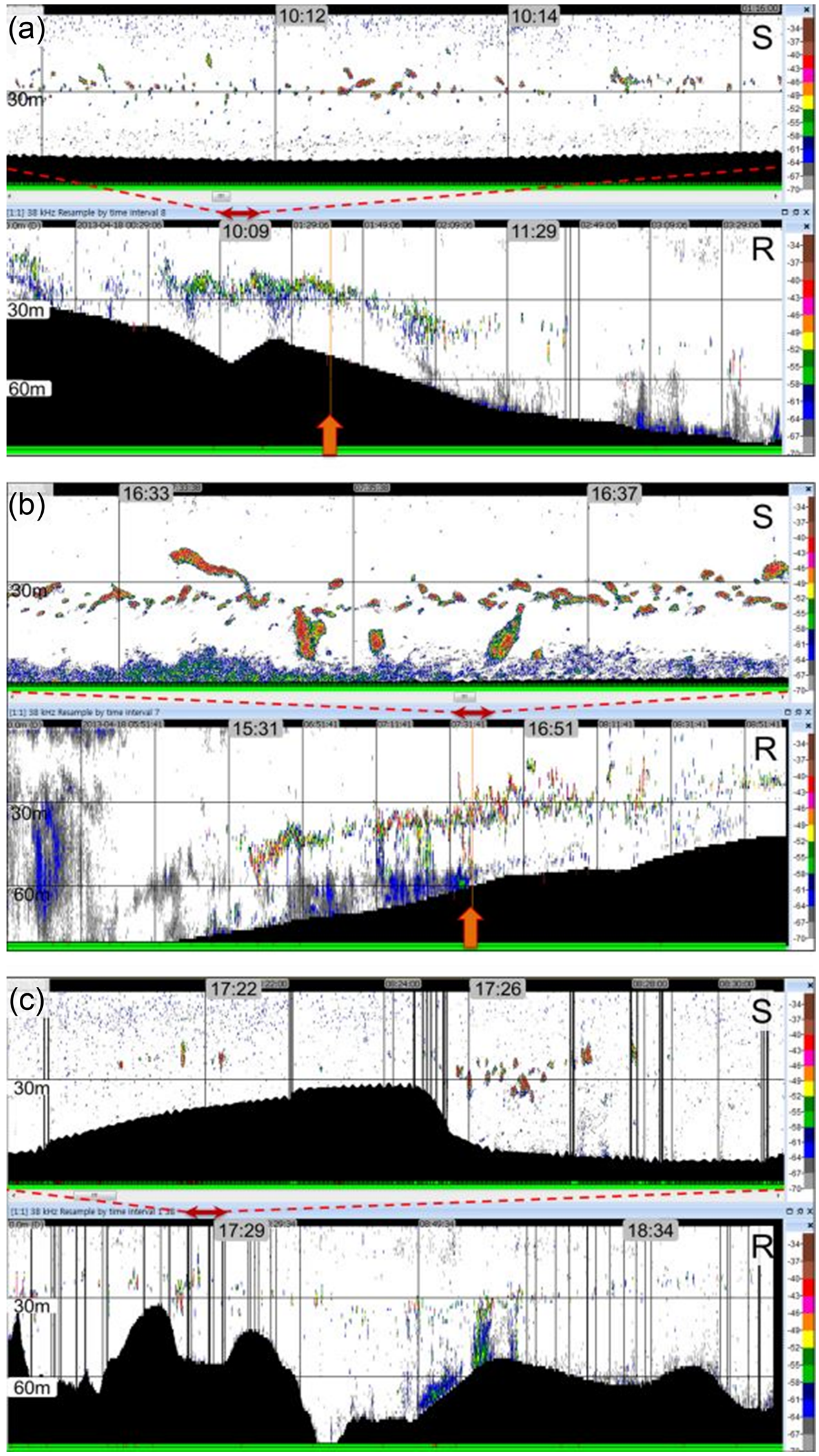

Fig. 3 Example echograms of L8 (**a**), L7 (**b**), and L1(**c**). "S" and "R" represent the original S_V echograms and resampled echograms, respectively. The horizontal interval is 30 m in all echograms, and the vertical interval is 2 min in the S_V echograms and 20 min in the resampled echograms. Pings contaminated with severe noise were omitted (indicated by *black lines*)

and their standard deviations were 2.4 ± 2.9, 2.5 ± 2, and 2.6 ± 2.4 m, respectively. The mean areas of L7, L8, and L1 and their standard deviation were 35.1 ± 160.5, 15.8 ± 32.6, and 17.6 ± 33.8 m^2, respectively; thus, the area of L7 was larger than that of the other two. The first, second, and third quartiles of image compactness for L7 were 4.9, 8.3, and 14.2, respectively, those for L8 were 3.9, 5.9, and 8.8, respectively, and those for L1 were 4.0, 6.8, and 10.4, respectively. The maximum image compactness in L7 was 246, indicating that the shape of the fish schools comprising a mixture of hairtails and anchovies was not round shaped. The range of Sv in all three regions was similar, particularly in the first and third quartiles for L7 and L1. The bathymetric characteristics of L1 were similar to those of L7, but its morphometric characteristics

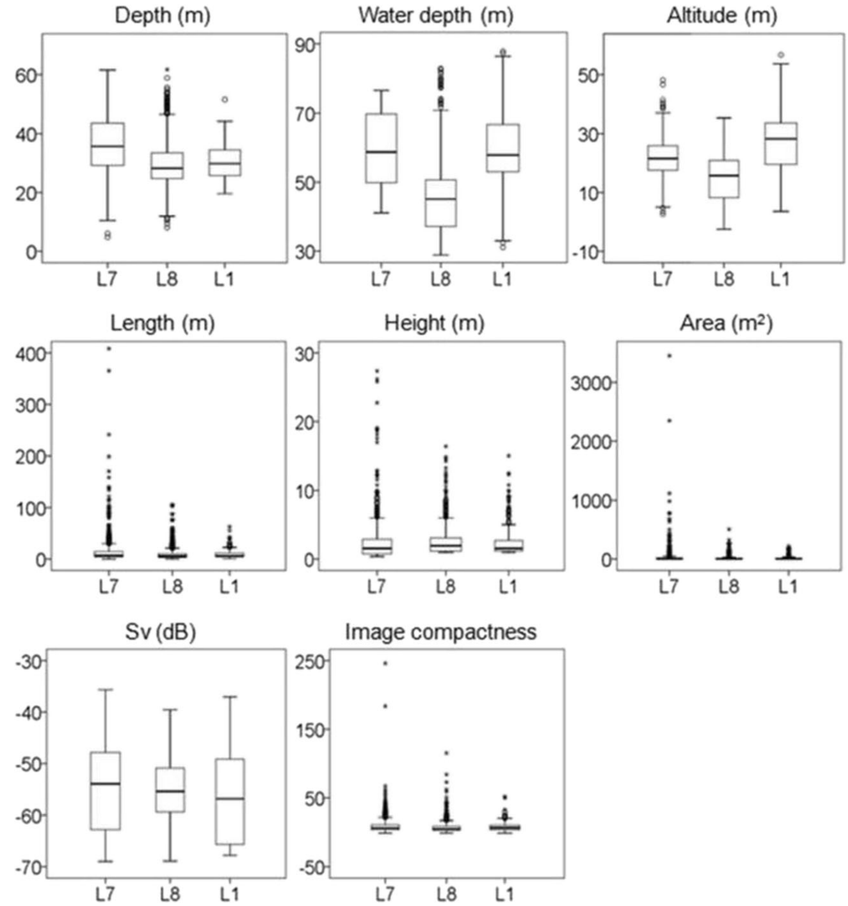

Fig. 4 Distributional characteristics of three fish school types. "L7" represents fish schools comprising a mixture of hairtails and anchovies, "L8" denotes fish schools majorly comprising of anchovies, and "L1" represents fish schools of unknown species

were similar to L8; nevertheless, the energetic characteristics of all three schools were similar. Therefore, it was difficult to conclude whether L1 was more similar to L8 or L7.

Frequency Characteristics

The ΔMVBS method results for L7, L8, and L1 by using three cell sizes—0.1 nmi × 2 m, 0.25 nmi × 4 m, and 0.5 nmi × 5 m—are shown in Fig. 5. ΔMVBS value was the highest in the range of −3 to 0 dB. As the cell size increased, ΔMVBS in the range of −3 to 0 dB increased. ΔMVBS can vary with the cell size. In the 0.1 nmi × 2 m cell, the average ΔMVBS and its standard deviation for L7, L8, and L1 were −1.9 ± 2.5, −1.2 ± 2.6, and −0.8 ± 3.3 dB, respectively. In L7, the second highest ΔMVBS value was observed in the range of −6 to −3 dB, regardless of the cell size; by contrast, in L8, the second highest ΔMVBS value was observed in the range of 0 to 3 dB, regardless of the cell size. Thus, L7 and L8 showed different ΔMVBS patterns. ΔMVBS patterns can aid in species identification. The ΔMVBS pattern for L1 appeared similar to that for L8. In other words, ΔMVBS values in the range of −6 to −3 dB were higher than those in the range of 0 to 3 dB, indicating that echo signals of L1 were higher at 120 kHz than at 38 kHz. Therefore, according to these frequency characteristics, L1 was more similar to L8 (mainly comprising anchovy species) than to L7 (comprising a mixture of hairtail and anchovy species).

Statistical Verification

For statistically verifying the result of the frequency characteristics (Fig. 5), the *t* test was first used to determine the differences between L7 and L8 for all three cell sizes. The frequency characteristics of L7 and L8 were significantly different for 0.1 nmi × 2 m and 0.25 nmi × 4 m cells (*t* test, $P < 0.001$); however, for 0.5 nmi × 5 m cells, no significant difference was noted. Based on the frequency characteristics, L1 probably contained anchovy species (Fig. 5). To determine statistical difference among L7, L8, and L1, we used the ANOVA. For 0.1 nmi × 2 m cells, because the variances in groups were not the same according to the Test of Homogeneity of Variances, we used the Welch F test; the results indicated a Welch's $F_{(2,\ 479.40)}$ of 16.02 ($P < 0.001$), implying that at least one group was different from the two. According to the Scheffe's post hoc test results, L7 and L1 and L7 and L8 were significantly different ($P < 0.001$), but not L1 and L8 ($P > 0.05$). In case of 0.25 nmi × 4 m cells, Welch's $F_{(2,\ 161.08)}$ was 9.03 ($P < 0.001$); in addition, L7 and L1 and L7 and

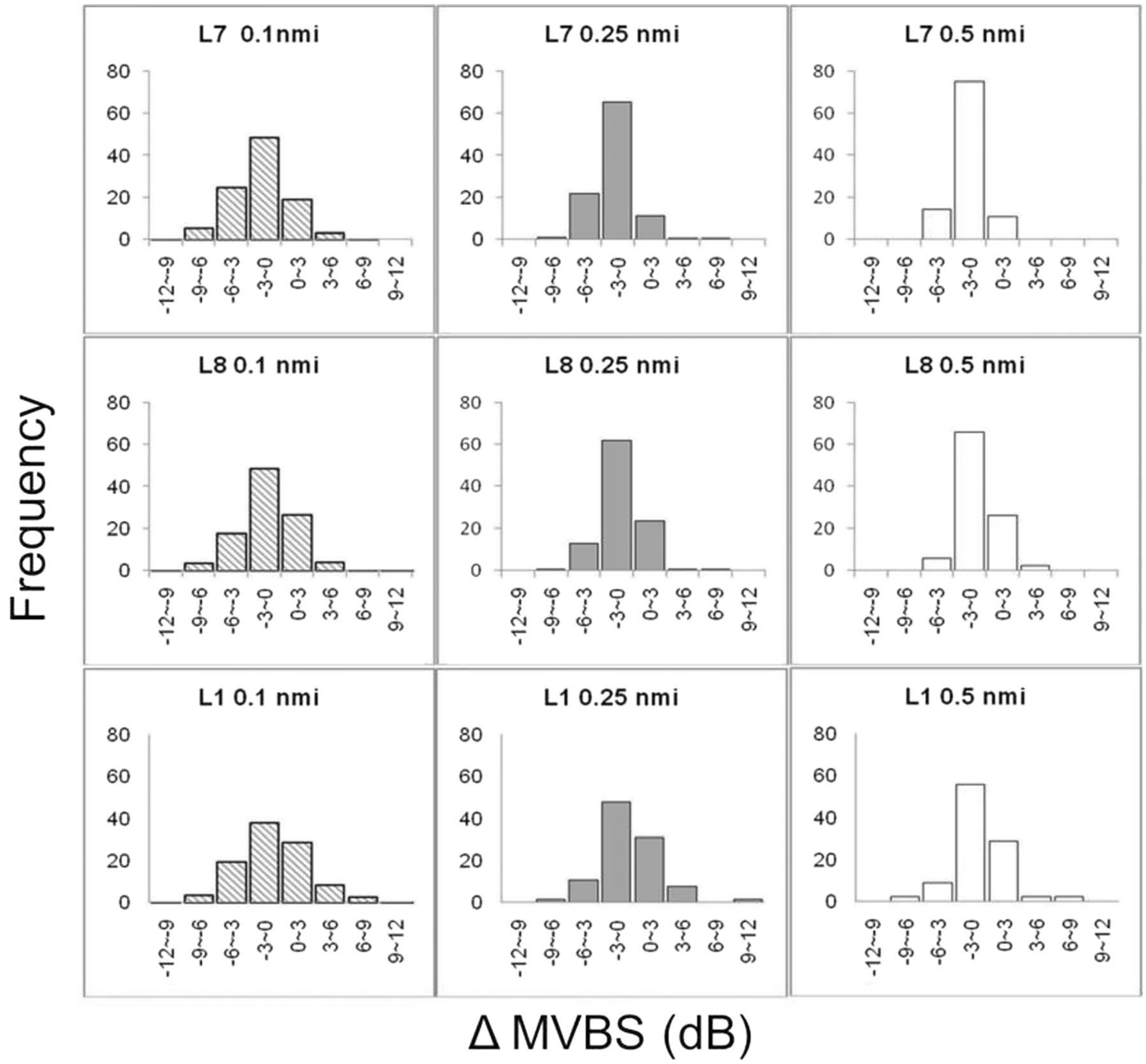

Fig. 5 Decibel difference of three fish school types. ΔMVBS in the three types of fish schools—L7, L8, and L1—and three different cell sizes—0.1 nmi × 2 m, 0.25 nmi × 4 m, and 0.5 nmi × 5 m—are depicted

L8 were significantly different ($P < 0.05$), but not L1 and L8 ($P > 0.05$). In case of 0.5 nmi × 5 m cells, Welch's $F_{(2, 103.68)} = 5.22$ ($P < 0.05$); furthermore, L1, L7, and L8 did not differ significantly ($P > 0.05$). Thus, the statistical analysis supported the result of the frequency characteristics. Considering the cell sizes, the ANOVA and *t* test indicated that cells measuring 0.1 nmi × 2 m and 0.25 nmi × 4 m were appropriate for anchovy species identification.

Discussion

Anchovy Geometrics

In 1996, Kang et al. measured the geospatial metrics of anchovy schools in two sites in the East Sea of South Korea—the mean length, height and area of anchovy schools were 26 m, 8 m, and 52 m^2, respectively and mean S_v was −37.2 dB. Kim et al. (1998) estimated the metrics of anchovy schools in the East China Sea in March 1994 and the east part of the South Sea in late March and early April 1995. The mean length, height and area of schools in the East China Sea were 13.8 m, 3.4 m, and 29.5 m^2, respectively, and those of schools in the eastern parts of the South Sea were 22.7 m, 4.4 m, and 69.4 m^2, respectively. Ohshimo (1996) also demonstrated the similarities in the anchovy shapes in the same area, with a mean length and height of 16.3 and 3.3 m, respectively, by using FQ 70 at 50 kHz (Furuno, Japan). Anchovies around South Korea migrate from East China Sea to the west side of the South Sea to the east side of the South Sea to the East Sea with seasons (Park et al. 1996). For example, around March (in spring), anchovies move from the East China Sea to Yeosu, Namhae, and Tongyeong with the Tsushima warm current. In June, anchovies migrate up to in the coastal waters of Kangwon province, i.e., the East Sea of South Korea. While migrating to the East Sea of South Korea from the East China

Sea, the size of an individual anchovy increases, assuming that the schooling pattern of anchovy schools differs. Thus, it can be assumed that the size of anchovy schools in the East Sea (Kang et al. 1996) is larger than that in the current study area.

ΔMVBS

Amakasu et al. (2010) used various swimming angles (−5° and 5°, 0° and 10°, 5° and 15°, −1.3° and 20.8°, as well as 10.2° and 20.3°) to reduce normalized TS of anchovy at four frequencies (38, 70, 120, and 200 kHz) by using the Kirchhoff ray mode (KRM) model. The TS at 38 and 120 kHz were slightly different, according to the swimming angle of anchovy. The largest range of ΔMVBS was approximately between −2 and 2 dB. Kang et al. (2009) measured ex situ TS of anchovies, with a mean body length of 8.54 cm, at 38, 120, and 200 kHz. TS at 38 kHz was approximately 2.6 dB larger than that at 120 kHz. The mean swimming angle and its standard deviation were $9.1 \pm 13.1°$. Murase et al. (2009) showed the ΔMVBS (at 38 and 120 kHz) of -1.1 ± 3.1 and -0.3 ± 5.6 dB for approximately 12 ± 8 cm of body length of anchovy at two adjacent locations in the western North Pacific. A few studies on the TS measurement of hairtail have been reported. Zhao (2006) measured in situ TS of hairtail at 38 kHz and expressed the relationship between TS and anal length. TS reported by these authors was 2.2 dB lower than that reported by Ona (1987). Hwangbo et al. (2009) determined the ex situ TS at 50, 75, 120, and 200 kHz and measured in situ TS at 120 kHz to obtain the TS-anal length equation. By using these equations at 38 and 120 kHz for 9.9 cm long hairtails, differences between TS values reported by Hwangbo et al. (2009) and Zhao (2006) was −1.5 dB and between those reported by Hwangbo et al. (2009) and Ona (1987) was −3.7 dB. Our study (Fig. 5) presented the ΔMVBS for L7 (comprising hairtails and anchovies) was stronger at 120 kHz than at 38 kHz, in agreement with the preceding studies.

Species Identification in South Korea

Primarily, three characteristics are available for acoustically identifying aquatic species: frequency characteristics (e.g., ΔMVBS), fish school geometric characteristics, and individual fish behavioral characteristics. In South Korea, little research has been conducted for species identification. Kang et al. (2003) applied the ΔMVBS method at 38 and 120 kHz to discriminate krill (ΔMVBS 2–16 dB) in the Antarctic sea and fish (>2 dB) and juvenile fish and plankton (7–18 dB) in the Yellow Sea; the authors removed the interference from a Doppler signal at 100 kHz by masking ΔMVBS values higher than 20 dB. In South Korean seas, studies on aquatic species identification are very limited because only a few hydroacoustic surveys targeting a single species have been performed; in other words, more research has focused on investigating the entire fish population in particular survey areas, and species identification was not performed. Nevertheless, species identification is imperative because it is necessary to analyze data collected in routine surveys for monitoring by fish species. Numerous species in the South Korean seas inhabit the same area or areas in close proximity of each other. Thus, acoustical identification of every species in the South Korean seas can be extremely difficult. However, the current preliminary study on anchovy species identification may form the foundation for developing a method for acoustic fish species identification.

Statistical Analyses

In our study, ANOVA was used to determine statistical differences, enabling anchovy species identification. ANOVA has been widely applied in fisheries science. For evaluating the contribution of environmental variables to the variability of the pelagic fish school sizes, a multiple ANOVA was performed on sonar (Seabat 6012, 455 kHz) and echosounder (Biosonics, 38 kHz) data in the Adriatic and Catalan Sea (Soria et al. 2003). When fish and invertebrates in Lake Paasivesi, Finland, were successfully discriminated at a single frequency, the ANOVA was applied to reveal the statistical significance of the differences in nautical area scattering coefficient at different frequencies (38, 120, and 200 kHz) and different depths (5–35 m with 5 m interval) (Jurvelius et al. 2008). To examine whether the proportion of biomass of fish species in Lake Superior varies significantly with season, moon phase, and depth, ANOVA was exploited (Yule et al. 2007). Analysis using ANOVA can provide substantial information, which can aid in understanding optimum survey conditions. In other words, the results can aid in designing the most appropriate survey plan for estimating the biomass of a target species largely invariant in relation to environments.

Various advanced statistical methods have been exploited in diverse research areas. In fisheries acoustics, particularly active acoustic research using an echosounder or multibeam sonar, numerous studies have applied these statistical methods. For example, to identify sardines, anchovies, horse mackerels, and a mixture of other pelagic fish species in the Central Mediterranean, the random forest method indicated an 85 % classification rate (D'Elia et al. 2014). Schools of anchovies, common sardines, and jack mackerels were classified using support vector machines (SVMs) and two types of artificial neural networks—multilayer perceptron (MLP) and probabilistic neural networks (PNNs) in south-central Chile. The average classification rates were 79.4 % for PNN and 89.5 % for MLP and SVM (Robotham et al. 2010). By using a quadratic discriminant classification method, Mckelvey and Wilson (2006) classified Pacific hakes, euphausiids, and their mixture along the Pacific coast off Oregon, Washington, and Vancouver Island with a success rate of 84 %. Moreover, for targeting a single fish species (walleye pollock), 12 classification typology for distribution patterns were categorized using cluster analysis (Burgos and Horne 2008). Furthermore, by using the Bags-of-Features (BoF), widely used for pattern recognition, juvenile and adult anchovy (*E. ringens*) clusters off Peru were accurately classified at classification rates of 89 % and 92 %, respectively (Fablet et al. 2012). Thus, several statistical methods for classification are available. In several circumstances, anchovy and other species coexist. Moreover, the distributional patterns of this species differ during day and night and are affected by environmental factors, such as water temperature, chlorophyll, and the existence of prey. For further in-depth knowledge regarding anchovy species, the aforementioned factors must be considered during analysis. Finally, an appropriate advanced statistical method must be developed for acoustical analysis of anchovy species in the future.

Acknowledgments The authors would like to thank Katy Zhu (lawyer) for assisting with English language usage in this article and the staff of R/V Tamgu 20 for aiding in the field survey. This work was supported by a grant from the National Institute of Fisheries Science (R2016027).

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