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A Pilot Study on the Application of Acoustic Data Collected from a Korean Purse Seine Fishing Vessel for the Chub Mackerel

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Abstract

This paper describes the first use of acoustic data collected during normal fishing operations from a South Korean commercial fishing vessel. Acoustic data (120 kHz) were collected from a purse seine fishing vessel while targeting chub mackerel (*Scomber japonicus)* between 13 September and 7 October 2014 in the southern West Sea and near Jeju Island. Acoustic backscatter data from 21 fishing events were used to delineate fish school characteristics and to estimate the chub mackerel biomass which was compared with the catch. With regard to the fish school description, the volume back scattering strength (S_V) and thickness of the fish schools presented differently. The average and standard deviation of S_V was −47.3 ± 2.1 dB. The fish lengths varied greatly and some schools were inordinately long (average and standard deviation length of 137.0 ± 329.6 m). The fish school area largely altered. The average distributional depth and the distance between fish school and sea bottom were 31.8 m and 42.7 m, respectively, indicating that the fish schools attracted by light were mainly located close to the water surface. On average, the chub mackerel biomass was 1.7 times larger than the catch. The correlation between the chub mackerel biomass and the catch was low positive ($r = 0.3$, $p < 0.05$). This paper presented that available echo sounders installed fishing vessels can be used for helping in the chub mackerel resources management in South Korea.

Keywords Commercial fishing vessel · Echosounder · Chub mackerel · Biomass · Fish schools

Introduction

The waters surrounding the Korean Peninsula are rich with sea life, and the surrounding seas are important resources both economically and culturally for the peoples of this region. In the Korean South and West seas the warm Tsushima and Jeju currents meet the cold West Sea bottom current and coastal waters. The fronts where these water masses meet and mix are nutrient rich forming frequent and persistent eddies (Yang et al. 1998). These fertile frontal systems influence the production, distribution, and seasonal migration of pelagic fishes in the region (Oh and Suh 2006). The rich waters of the Korean South and West Seas are also important fishing grounds for the large purse seine fishery which targets these pelagic fishes (Yang et al. 1999).

The Pacific chub mackerel (*Scomber japonicus*; hereafter chub mackerel) is one of most important pelagic species in South Korea, China and Japan (FAO, 2016). The chub mackerel are widely distributed in temperate and subtropical waters of the Pacific Ocean. In the northern Pacific Ocean chub mackerel are distributed in coastal waters around South Korea and Japan, as well as in the East China Sea. In seas of South Korea, they exhibit seasonal migration moving toward the north in summer to feed on copepods, crustaceans, small fish, and squids and to the south in winter for spawning (Choi et al. 2004). On their northward migration the population splits when they arrive off the Seongsanpo Port of Jeju

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Island in February or March. A portion of the population travels towards the East Sea and another portion towards the West Sea. The ratio of the migration population between the East Sea and West Sea is various due to marine environment, mainly water temperature (Yang et al. 1999; Hwang et al. 2001).

In South Korea, the chub mackerel has been mainly caught by the large purse seine fishery. The large purse seine fishery had average USD 241,768,541 of earnings for last five years (2013 ~ 2017) out of average earning (USD 7,014,568,316) from all the domestic inshore fishery components for the same time period (Statistics Korea 2018). The large purse seine fishery primarily targets not only Pacific chub mackerel (*Scomber japonicus*; hereafter chub mackerel), but also horse mackerel (*Trachurus japonicus*), sardine (*Sardinops melanostictus*), squid (*Doryteuthis bleekeri*) and Japanese Spanish mackerel (*Scomberomorus niphonius*; Lee 2009). The average annual yield of this fishery for the past five years was 174,178 metric tons (t). Approximately 60.5% of this production was chub mackerel (105,337 t). The chub mackerel caught by this fishery was occupied 87.5% of entire yield of the species (Statistics Korea 2018). In addition, chub mackerel from the large purse seine fishery constituted 2.1% (USD 149,802,926) of all South Korean seafood sales for the past five years (Statistics Korea 2018). In comparison, between 2003 and 2012 chub mackerel had the highest production of all mackerel species globally (reported from 72 fishing countries; FAO 2012), comprising 33% (17,956,049 t) of the total 54,342,423 t captured. In this time period South Korea was the fourth highest producer of mackerel with 8% of global mackerel production only surpassed by Japan (26%), China (25%), and Chile (14%; FAO 2007; FAO 2012). Accordingly, this species caught by the large purse seine fishery in South Korea is very important.

The chub mackerel stock has declined for decades. In detail, the total yield of the chub mackerel from 1999 to 2017 has had fluctuations, and it certainly had a tendency to be decreased (Statistics Korea 2018). The maximum total yield of the chub mackerel was 203,743 (t) in 2001, while the minimum yield was 94,687 (t) in 2010. In 2017, the yield of the chub mackerel was 104,521 (t) which was relatively low (Statistics Korea 2018). The main reason could be overfishing the species (Cho et al. 2001). In 1999, stock quota systems (Total Allowable Catches, TACs) was employed for the species. Currently, 70 port observers perform the comparison between the TACs quota of fishing vessels and their catch landed in sales association (118 ports). However, the stock has continued to decline. It can be stated that the stock biomass of the chub mackerel has been shrunk under the present management system. It is required to improve the management system for the chub mackerel. Another issue is high cost of operating the large purse seine fishery. On the other hand, the large purse seine fishery is conducted by squadrons of vessels, each squadron working in tandem. A squadron most commonly consists of a main fishing vessel (net vessel), two light vessels, and three carriers for transporting supplies and catch. In a few countries such as South Korea, Japan, China, and Taiwan, light vessels have been used in purse seine fishery since 1950s. The fishing operation using lamps is primarily conducted from sunset to sunrise, and the operation without using a lamp is also done in daytime. A great number of crew members for example 73 work together. Overall the profitability drops compared to an amount invested. Accordingly, this fishing gear and method should be improved to be more efficient.

Commercial echosounder systems (e.g. Simrad ES60 and ES70) installed on commercial fishing vessels are being widely used for scientific purposes. In Australia at St Helens Hill and St Patricks Head acoustics surveys from commercial fishing vessels have been used to estimate orange roughy biomass (Ryan and Kang 2005). In Alaska, Barbeaux et al. (2013, 2014) used acoustic data collected opportunistically from commercial fishing vessels to estimate the temporal and spatial distribution of walleye pollock (*Theragrus chalcogrammus*) in the Bering Sea, as well as investigate the potential impacts of the fishery on local populations. O'Driscoll and Macaulay (2005) described several studies using acoustic data collected from commercial vessels. Such studies highlight the advantages, such as low costs, extended spatial and temporal coverage, synoptic data collections, and platform availability, of using commercial fishing vessels to collect acoustic data (Karp 2007; Barbeaux et al. 2013). Acoustic data from commercial fishing vessels can provide information on fish abundance, distribution, and school; providing information essential for improving the management system of the chub mackerel.

The South Korean government has recognized the needs of improvements for the chub mackerel management system and its fishing operation method. First of all, with the current resources, useful information on the improvements was sought. For example the chub mackerel biomass from acoustic data collected in a commercial fishing vessel could support the role of port observers. If the biomass from acoustic data is the same as the catch landed, commercial echosounders would replace port observers. The possibility of this idea was examined in this study. The morphometric and positional Information on fish schools inside the net would be useful in improving the fishing operation method. For instance, the main distributional depth of the fish schools could help in targeting the water depth during casting the net. Accordingly, the objective of this study is to examine the availability of acoustic data from a commercial echosounder installed a South Korean large purse seine fishing vessel for providing the improvement of the chub mackerel management system and its fishing operation method. This paper is a pilot study, describes on the geometric properties of chub mackerel schools, and compares the biomass of the chub mackerel and catch.

Materials and Methods

Purse Seine Fishing Operation and Acoustic Data Collection

A typical fishing operation method, that is the fishing operation in this study, was that two light vessels and a net vessel were scouting the schools of chub mackerel. Once they found the fish schools, the first light vessel used lamps on board and underwater lamps to attract the fish school. By using the underwater lamps, not only large sized fish schools but also scattered small fish schools could be aggregated. Then, the second light vessel approached to the first light vessel. Underwater lamps from the second light vessel were located to the same water depth as that of the first light vessel. The underwater lamps from the first light vessel were turned off. The fish schools aggregated were moved from the lamp of the first vessel to that of the second one. The first light vessel travelled toward the net vessel. The rope of the underwater lamp in the second vessel was slowly rolled up. Accordingly, the fish schools aggregated around the lamp were getting close to the vessel as the distance between the lamp and the second light vessel was shortened. The net vessel handed over a rope connected the end of the net to the first light vessel. The net vessel played a role as a speed boat. It started to cast the net from the location of the first light vessel and encircled on the centre of the second light vessel (Fig. 1). On the process of casting the net, the second light vessel turned underwater lamps on and kept attracting the fish schools. When the net was completely cast, the second light vessel travelled outside the net. Acoustic data were collected from the second light vessel.

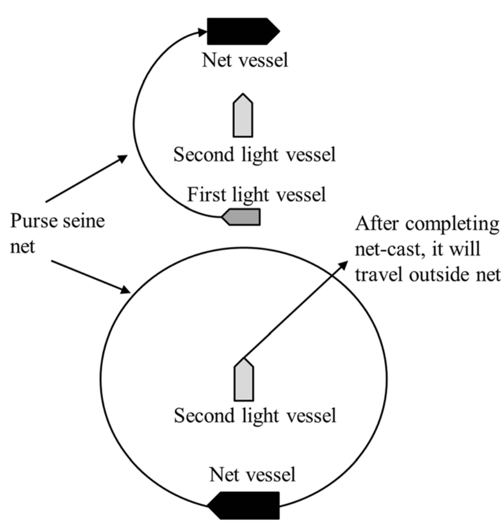

Fig. 1 Schematic diagram of the typical purse seine fishing operation. The net vessel plays a role as a speed boat and starts to cast the net which is connected to the first light vessel. During the fishing operation, the second light vessel lights on to attract fish schools. When net is completely casted, the second light vessel travels outside the net

The purse seine fishing vessel used in this study was the "71 Kumyoung" (87 t, Kumyoung fishing company) which played a role as the second light vessel. The vessel collected data while fishing and searching for the chub mackerel schools in the northeast of Jeju Island and in the southern West Sea off South Korea. The fishing period was from 13 September to 7 October 2014, and the target fish species was the chub mackerel (Fig. 2). The vessel was equipped with a Simrad ES70 echosounder with 120 kHz transducer. The transmitted pulse duration was 0.512 ms and the ping repetition rate was 360 ms. All setting parameters of the echosounder was identical throughout the fishing period. A GPS was fed to the sounder to provide location information. A portable hard disk was attached to the main computer which the ES70 acquisition software was running.

Purse Seine Catch Data

The purse seine fishing operations were conducted from sunset to sunrise. A navigation log book was provided by the Kumyoung fishing company; however it was found that locations and times of fishing operations were not reliable. When we compared them with echograms, times and positions of fishing operations from the log book did not correspond to those from the echograms. Note that catch results, for example, species composition, weights of representative fish species caught, and total catch amount, were not provided. Therefore, those information on the purse seine catch by the squadron of "71 Kumyoung" was extracted based on sales information to several sales associations during the fishing period. Precisely speaking, the carrier travelled for sales when the catch was fully filled in the storage. The carrier of "71 Kumyoung" squadron travelled 10 different Korean National Federation of Fisheries Cooperatives for 17 times from 13 September to 4 October, 2014. In this case, the distance to the fisheries cooperatives and the price of the chub mackerel were key elements to decide the best cooperatives for sale. There was more than one sale at the same day in the same location, so that it became 12 sale events in total (Fig. 6). Again, the sale was not done immediately after completing the fishing operation. National Institute of Fisheries Science (NIFS) port observers went to the fisheries cooperatives to obtain sales information from the squadron of "71 Kumyoung" including catch weight by major species, species composition, and total catch amount. The port observers also purchased samples of the catch delivered to the fisheries cooperatives by the squadron of "71 Kumyoung" on 19 October 2014. The samples were brought to the NIFS Jeju Island branch office where the length and weight of the chub mackerel in the samples were measured.

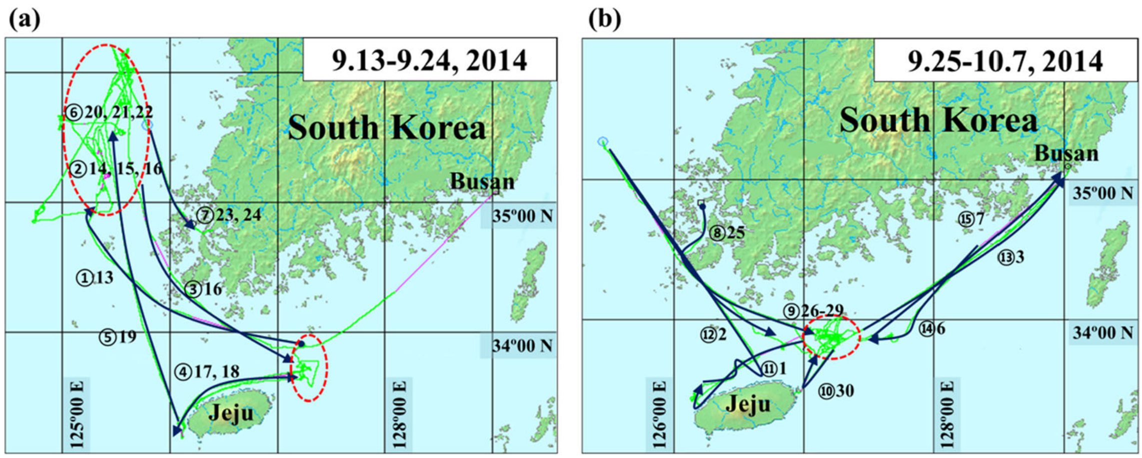

Fig. 2 The voyage track in green from: (**a**) September 12 to September 24 mainly in the southern West Sea; (**b**) from September 25 to October 7 of 2014 in northeast of Jeju Island. The dark blue long arrows indicate the navigational direction of the fishing vessel. The dotted red circles mark the locations where fishing operations are densely conducted

Basic Acoustic Data Analysis

The acoustic data were corrected for a systematic ping-indexed bias using a Java utility (Ryan and Kloser 2004) which is also available in the Echoview website. Echoview software (ver. 6.1, Echoview Software) was used to process the raw data from the ES70 sounder on the basis of the general flow of data analysis (Fig. 3). The fixed water surface line was set to remove data above 4.5 m. A sea bottom line was created using the "Maximum S_V (Volume back-scattering strength) with back-step" of line pick algorithm in Echoview. Data below the sea bottom depth were not considered in the analysis. The bottom line pick parameters start depth at 0 m, stop depth at 150 m, the minimum S_V for good pick was −45 dB re m^{-1}, the discrimination level was −50 dB re m^{-1}, and the back-step range was −0.5 m. The deepest depth for purse seine fishing was less than 150 m. The acoustic data analysis focused on the subset of data from when the vessel was actively fishing as observed in the echograms and voyage track. To observe the entire fish schools being located in the net, the resampled echograms are presented by using a resample operator (Fig. 4). It means that all data in the resampled echogram were like compressed entire data on the process of a fishing operation. This operator plays a role to reduce the number of data points, that is to say, to average S_V values in a given cell. For this part of the study the vertical resolution was fixed at 1 m while the horizontal resolution was varied between 0.3 and 1.4 m with an average horizontal resolution of 0.73 m.

Fish School Detection and Characterization

In order to characterize fish schools, the acoustic data were selected from each fishing operation time period. Before defining the fish schools, the acoustic back-scatters from the nets, as well as other acoustic noise were manually eliminated. The SHAPES school detection algorithm imbedded in Echoview was used to define and characterize fish schools (Coetzee 2000; Echoview 2015). The minimum S_V threshold of −70 dB re 1 m^{-1} was set. The setting for school detection was the maxima of vertical (3 m) and horizontal (5 m) linking distances, minima of candidate

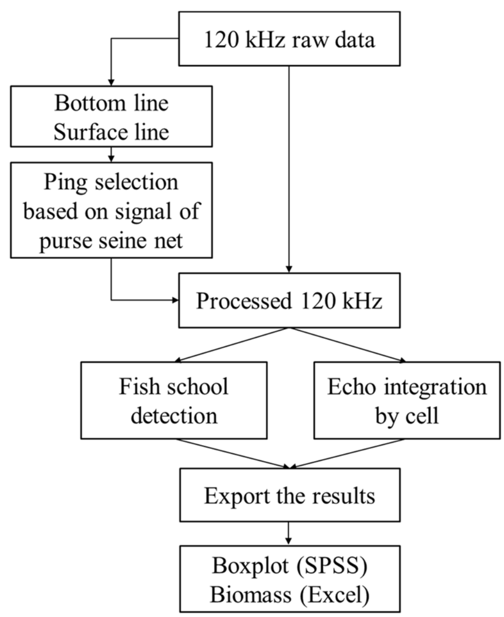

Fig. 3 General data flow of analysis. The raw data at 120 kHz from a commercial echosounder are processed. Firstly, the sea bottom line and surface water line are created. Only data between two lines are analyzed. Secondly, the pings on the basis of purse seine net signals are selected for furthermore analysis. On the selected echogram (volume back-scattering strength (S_V) echogram), fish schools are detected and exported, and mean S_V of fish schools in each fishing event is exported as comma separated value (CSV) format. Using the CSV file from fish school detection and SPSS software, the fish school characteristics are described in boxplots. Using the CSV file from mean S_V and excel program, the chub mackerel biomass is calculated

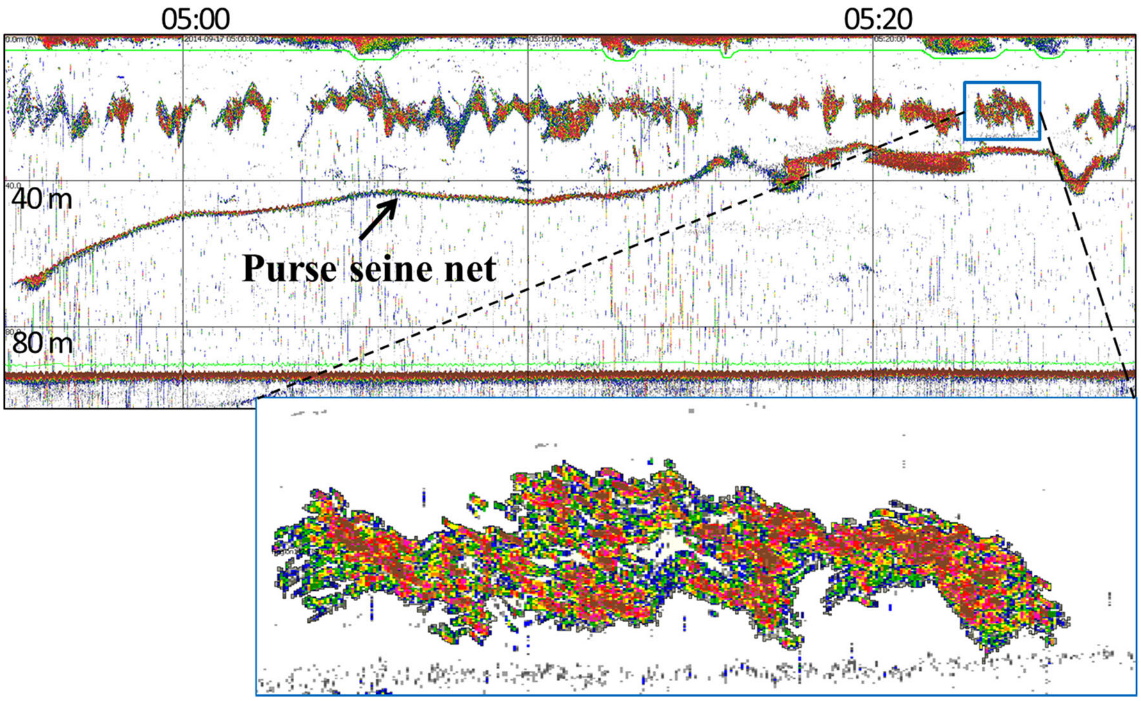

Fig. 4 An example echogram including the purse seine net and fish schools. The purse seine net signal lasts for approximately 30 min, indicating the duration of the fishing operation. The water depth of the net and fish schools status are seen. The fish school expanded in the blue rectangle has 47.3 m length and 6.3 m thickness, and is located at 20.6 m water depth. Time and water depth are seen

length (3 m), candidate height (2 m), total school length (4 m), and total fish height (4 m) (Echoview 2015). The properties of fish schools were generated including energetic (S_V), morphometric (length, thickness, and area of fish schools), and positional (distance between sea bottom and the lower part of the fish school, distributional depth of fish schools) descriptors and exported to the SPSS (ver. 10, IBM) to describe the properties using the boxplots. Here, the characteristics of fish schools were measured and extracted while the second vessel was drifted during the fishing operation. Thus, the characteristics of fish schools were not from natural circumstance. In especial, the length and area of fish schools would be exaggerated. Those values of the characteristics might be abnormal, however they would help in understanding the fish schools property on the process of fishing operation.

The Chub Mackerel Biomass Calculation

In order to estimate the chub mackerel biomass, only the data collected during fishing operation were selected and used. Fish signals inside the net on the echogram were used for estimating the chub mackerel biomass. The 21 fishing events were confirmed based on the net signals. On the echograms, net signal and noises were removed and only fish signals were detected to extract mean S_V (dB re 1 m^{-1}). It is note that the location of the "71 Kumyoung" was on the middle of the circled net which means that a mean S_v could be a representative value of all chub mackerels inside the net.

$$S_v = 10\log_{10}(s_v) \tag{1}$$

Where, s_v is volume backscattering coefficient (m^{-1}) and the linear value of S_v. In the equation, the capital and small letters are not exchangeable (MacLennan et al. 2002)

$$s_v = \Sigma\sigma_{bs}/V \tag{2}$$

Where, σ_{bs} is backscattering cross-section (m^2) and V is unit volume (1 m^3) occupied by multiple discrete targets. Namely, s_v is the sum is taken over all the discrete targets (fish) in the unit volume. Here, TS is target strength (dB re 1 m^2) and the logarithmic term of σ_{bs}. It can be simply explained as acoustic signal from an individual fish.

$$TS = 10\log_{10}(\sigma_{bs}) \tag{3}$$

When s_v and σ_{bs} are known, the number of fish in a cube (1 m^3) can be calculated. When the net volume is known, the number of fish in the net can be calculated by multiplying the number of fish in a cube by the net volume. Finally, the chub mackerel biomass is computed by multiplying the number of fish in the net volume by the body weight of a representative chub mackerel. In this study, the net volume of the purse seine was assumed to be cylinder. The circumference of the net was from 1350 to 1400 m which were provided from the fishing company. The average circumference (1375 m) was used to get radius. The height (50 m) was derived from the mean height of the net signals. The net volume calculated was 7,533,696 m^3. To obtain the number of fish per cube, the TS of a chub mackerel should be known. Here, to obtain the TS of a chub mackerel at 120 kHz, the relationship between the TS and the TL (total length of a chub mackerel, cm) was used (Lee and Shin 2005).

$$TS = 20\log_{10}(TL) - 66.9 \quad (4)$$

In order to know the total length and body weight of a chub mackerel, 178 samples of the chub mackerels were used and they were collected by port observers at the NIFS Jeju branch office on 19 October, 2014 which was closest date to the fishing date. The average total length and body weight from the samples were 33.4 cm and 427.5 g, respectively. Using the average total length in eq. (4), the TS became −36.4 dB. Accordingly, the average S_v (obtained from raw data in each fishing event) and TS (−36.4 dB) resulted in the number of fish in a cube. This number of fish was multiplied by the net volume (7,533,696 m^3) to obtain the number of fish in the net volume. The number of fish in the net was multiplied by the average body weight (427.5 g) to have the total weight of chub mackerel per fishing event. However, every fish inside the net was not chub mackerel. Thus, the catch rate of chub mackerel was considered. Finally, the total weight of chub mackerel per fishing event was multiplied by the catch rate of the chub mackerel per fishing event to obtain the weight of only chub mackerel, that is the chub mackerel biomass. The comparison between the chub mackerel biomass and catch was done based on sale date (12 days). Thus, the chub mackerel biomass per fishing event was restructured according to the sale date. In this study, the terminology of the chub mackerel biomass was not absolute biomass because calibration parameters were not available. The acoustic biomass estimates here were deemed useful because the difference between estimates using a calibrated system will be proportional to those calculated from an uncalibrated system as long as the same mean target strength and mean weight were used (Simmonds and MacLennan 2005).

Results

Voyage Track and Fishing Operation

The voyage track was divided into two segments for better visualization of the track: 12 ~ 24 September 2014 and 25 September ~ 7 October 2014 (Fig. 2; green line). The vessel began and ended its voyage in the port of Busan. The vessel travelled back and forth between the southern West Sea and waters surrounding Jeju Island fishing for chub mackerel during these time periods. In total the vessel spent 8 days fishing the waters northeast and east of Jeju Island and 6 days in the southern West Sea. It was observed that fishing operations were conducted after searching on average for 4 h 49 min. The average and standard deviation time duration of a fishing event was approximately 24 ± 10 min according to the net signals on the echograms. The total catch according to the sales relating to the squadron of "71 Kumyoung" was 481,896 kg; chub mackerel comprised average and standard deviation 78 ± 18% (361,224 kg) of the total catch by weight.

Description of Fish Schools

The morphometric, energetic, and positional characteristics of chub mackerel schools based on fishing event were described (Fig. 5). For all 21 fishing events strong backscatter was observed from fish schools. For this analysis we assumed all fish schools were chub mackerel, despite this species comprising only approximately 78% of the catch. There was variability in the overall S_V of the fish schools yet outliers were not much observed. The average and standard deviation S_V was −47.3 ± 2.1 dB ranging from −52.0 dB of the minimum average value to −41.5 dB of the maximum one. The first quartile, median, and third quartile of school length were 8.6 m, 27.3 m, and 81.9 m. The average and standard deviation length of fish schools from all fishing operations was 137.0 ± 329 m. The range between the first quartile and third one was relatively small, while many outliers were observed as high standard deviation was seen. The schools observed during fishing event on 14th September were the longest with first quartile, median, and third quartile for length at 49.8 m, 277.3 m, and 2700.7 m. The fish school area was correlated with fish length ($r = 0.8$, $p < 0.05$). Fish schools on 14th September had the largest area (average 1486.5 m^2) with a range from 36.5 to 16,629.7 m^2. The ranges of first quartile, median and third quartile distributional depth for all events were 12.8 and 41.0 m, 15.4 and 46.0 m, and 16.7 and 55.1 m. The first quartile, median, and third quartile for school thickness were 6.5 m, 10.4 m, and 16.3 m. The thickest school was fishing event on 26th September with an average thickness of 21.2 m. The average and standard deviation thickness of all fish schools was 12.7 ± 3.7 m. The range between the minimum and the third quartile was relatively small, yet some outliers were observed. The average distributional depth of all fish schools was 31.8 m with a range of 16.1 to 46.3 m, indicating that the lights brought fish to the water surface from the midwater. The deepest distribution depth was less than 80 m. The range of the minimum and maximum distributional depth was small and no much outlier was seen, indicating that fish

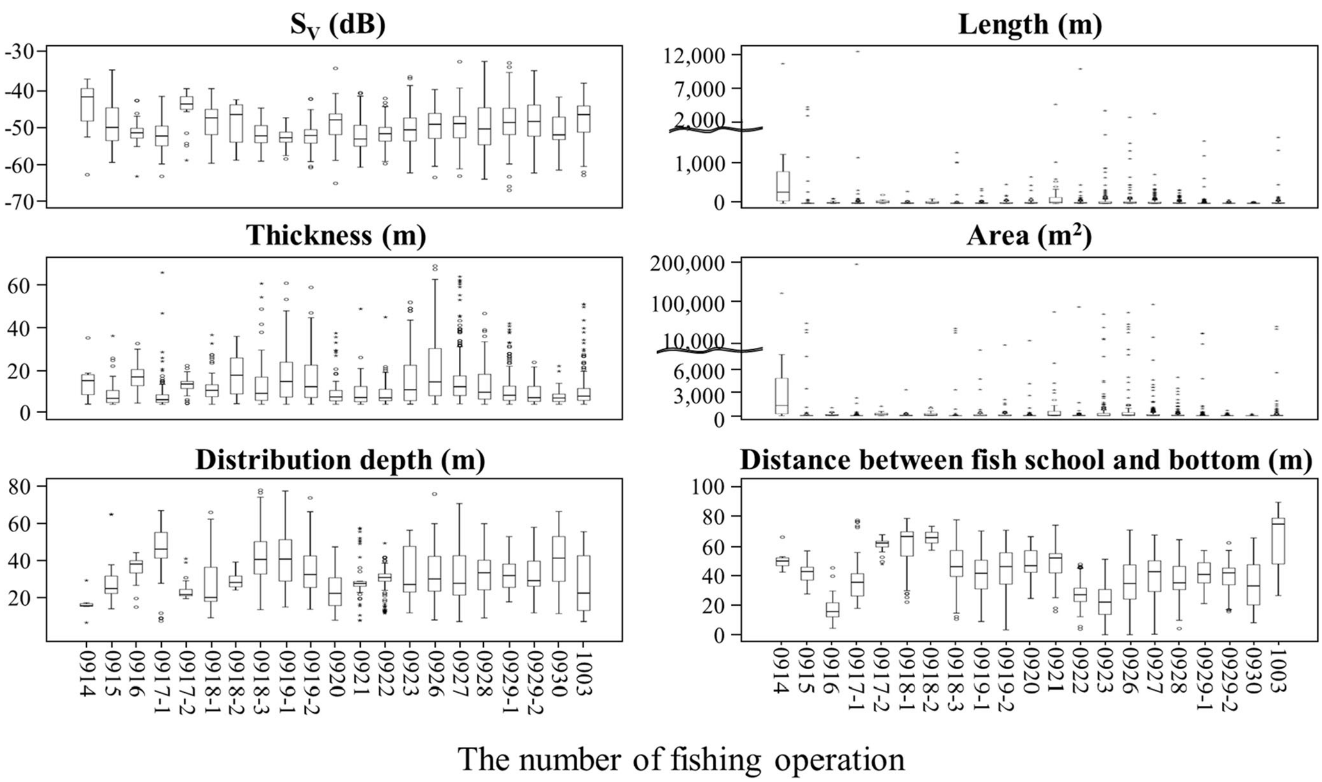

Fig. 5 Boxplot of the fish school properties included energetic (S_V), morphometric (length, thickness, and area of fish schools), and positional (distance between fish school and sea bottom, distributional depth) descriptors on the basis of fishing operations

schools were relatively swimming in a constant water depth during fishing operation. The fishing events with the largest schools on average had the lowest distributional depth (15.0 m first quartile, 15.4 m median, 16.7 m third quartile, and 16.1 m average depth). The fish school area was not correlated with fish distributional depth ($r = 0.02$, $p < 0.05$). Like distributional depth the distance between fish school and sea bottom was also variable, yet the range of data was not large. The first quartile, median, and third quartile ranges of the distance between fish school and sea bottom were 11.4 and 61.5 m, 15.3 and 74.9 m, 22.0 and 78.9 m. The average the distance between fish school and sea bottom of all fish schools was 42.7 m ranging between 17.0 and 65.2 m. Consequentially, all characteristics of chub mackerel schools varied with regard to fishing event. Precisely speaking, the morphometric characteristic of chub mackerel schools such as length, thickness, and area largely varied while other characteristics were somewhat altered, indicating that the underwater lamps made the vertical position of fish schools remain relatively constant in near water surface layer.

The Chub Mackerel Biomass and Catch

The chub mackerel biomass estimate on the basis of 12 sale dates was on average 1.7 times higher than delivered catch estimate, and its standard deviation was 1.3. The correlation between the chub mackerel biomass estimates and catch estimates was low positive ($r = 0.3$, $p < 005$).

Discussion

Noise Removal and Acoustic System Calibration

The removal of noise throughout the selected data was a tedious and time consuming endeavour. At times fish schools could not be adequately discriminated from the purse seine net for our analyses. At the present available technology and algorithms cannot autonomously identify and fully exclude noise (ICES 2007) and therefore substantial supervision of the data processing is required. To effectively use acoustic data collected from commercial fishing vessels opportunistically for scientific research, autonomous or semi-autonomous noise removal methods need to be developed, particularly for intermittent spikes. Such a semi-autonomous data processing software program is currently under development at the Alaska Fisheries Science Center, NOAA (Barbeauxpers.com). Some successful study cases were recently introduced (Ryan et al. 2015). An on-axis sphere calibration (Foote et al. 1987) of the acoustic system on board the "71 Kumyoung" was attempted on 10 October 2014. However, the vessel was not able to leave the port due to a lack of crew to run the vessel. The water depth between the transducer and the sea bottom was approximately 4 m. This depth allowed us to place the calibration sphere outside the near field for the 120 kHz transducer (0.9 m); however the shallow water and high level of noise at 120 kHz due to traffic in the area precluded a quality on-axis calibration.

The Comparison between the Chub Mackerel Biomass and Catch

Overall the chub mackerel biomass from acoustic data was higher than catch. Several reasons can be addressed. Firstly, the acoustic system calibration can make the biomass estimate from acoustic data reliable, this means that the difference can be lessened. Secondly, the mean S_V used in this study might have come from unnatural swimming status since the chub mackerels might have been trying to avoid the net. The TS-L relationship was estimated under the swimming condition with the average swimming angle of −5° and its standard deviation of 15°. Accordingly, to compute the chub mackerel biomass in extreme swimming circumstance the TS application of eq. (4) would cause some error. The TS should be obtained using a wide range of swimming angles which can be a research topic in near future. Thirdly, the cylinder shape was used to calculate the net volume. At the beginning of the fishing operation, the net shape was the cylinder. As the fishing operation proceeded, the net shape changed to semi ellipse. For convenient calculation of the biomass in this study, the cylinder shape was employed. To estimate the biomass more accurate a better net volume should be used. Lastly, noises might have been remained although manual noise removal was performed. Some noises overlapped with the signals from the fish might have been very difficult to be eliminated.

Fishing Companies Cooperation and Chub Mackerel Management

It was the first time for the fishing company to conduct cooperative research with NIFS scientists. Voluntary support from the fishing company and fisheries cooperative was not easy to be obtained. In fact, a very little financial incentive was given to the Kumyoung fishing company. It should be considered that appropriate reward should be given to a fishing company to collaborate with scientists. There are 27 squadrons in the South Korean large purse seine fishing fleet. Among these squadrons, echosounders have been installed on 63 vessels. However, only 42 vessels use the sounders for finding fishes, and only 7 vessels have echosounders suitable for data recording. Acoustic data from commercial fishing vessels have been shown to be valuable in other regions of the world. This study demonstrates that data can be recorded from the South Korean large purse seine fishery and provides an initial look at the possible benefits of collecting data from these vessels for which little reliable data is currently being obtained. If all seven vessels were to collect data, information useful for evaluating not only fishing locations and practices, but also the data could potentially help in characterizing the density and distribution of chub mackerel in the seas surrounding the Korean Peninsula and improving the fishing operation method more effectively with low cost. With regard to the usage of lamps in purse seine fishery, time, fuel, and effort for scouting the chub mackerel schools could be saved (Inada et al. 2010). This means that the purse seine fishery using lamps could be a sustainable fishing method since it can reduce air and water pollution as much as the amount of time and fuel saved.

In consideration with the mackerel management, Norway, Russia, Faeroe Islands, Iceland, and European Union under the International Council for the Exploration of the Sea has been using the TACs and quota system to manage the stock of Northeast Atlantic mackerel (*Scomber scombrus*). In those countries, fishery independent data such as egg survey, trawl survey, tagging survey, and acoustic survey have been used to tune the stock assessed by the age-structured model (Nottestad et al. 2016; ICES 2017). In Japan, the chub mackerel stock abundance was estimated using the same model as above one tuned with abundance indices from trawl survey, driftnet survey, acoustic survey, and egg survey (Watanabe and Nishida 2002; Ishida et al. 2009; Tanoue 2015). In South Korea, no scientific survey has been conducted to support to estimate the TAC for the chub mackerel. The chub mackerel biomass from acoustic data in this study can help in tuning the TAC value for the species although its accuracy should be raised. Ultimately, the result of this study can help in reducing the expenses of port observers. On the other hand, the purse seine fishing activity is not conducted for approximately three days before and after every full moon since fishers have observed that chub mackerel travel deeper in the water column and become less accessible to purse seines (Choi et al. 2004; Lee and Kim 2011). Because the vessels are still in the fishing areas, but are not fishing therefore, this would potentially be a good time period for fishing vessels to cooperate with scientific research. One possible project would be to ask fishing vessels that have the ability to record data to run formal transect lines to map chub mackerel distribution and possibly obtain biomass estimates. With seven vessels a rather large area could be surveyed in a short amount of time at little additional cost. The Korean government should hand over appropriate incentives to cooperative fishing companies to have favourable cooperation. Lastly, Northern Europe countries above-mentioned have been collaborating to agree their quotas. Such collaboration is critical to providing a better picture on the species distribution and its precise stock assessment. Currently, the chub mackerel stock in Asia is managed on the basis of the South Korean-Japanese fisheries agreement, the South Korean-Chinese fisheries agreement, and Chinese-Japanese fisheries agreement, respectively. It is imperative that efforts continue with regard to encouraging collaborative research among three countries such as South Korea, China and Japan since the distribution status of the species is transboundary.

Water Temperature and the Chub Mackerel

During this study daily total catch of all mackerel from the squadron of "71 Kumyoung" was 32,126 t and of chub mackerel was 24,082 t, including days of no catch (Figs. 5 and 6). The total weight of chub mackerel on 26 ~ 30 September in the northeast of Jeju Island was 198,792 t or 57% of the catch from the entire study period (13 September ~ 4 October). Water temperature is thought to have the most influence in determining fish distribution and therefore the extent and location of the fishing grounds. The location of fishable aggregations of mackerel is strongly related to the depth of the thermocline and the location of the horizontal gradient of water temperature since the mackerel schools try to be distributed in a favourable range of water temperature. The core fishing grounds were located between the southern West Sea and coastal waters in the northeast of Jeju Island due to rich nutrients at water fronts which can be located based on the location of the 15 °C isotherm (Cho et al. 1984). The location of this front changes seasonally and has been annually variable as well. The location of the core fishing grounds for the large purse seine fishery moves with this front. The average temperature of water surface was 19.7 °C at Heuksando, an island in the southern West Sea, from 14 to 16 September 2014 and from 20 to 22 September 2014, and 23.9 °C from 16 to 18 September 2014 and from 26 to 29 September 2014 at Geomundo, an island to the northeast of Jeju Island (MEIS 2015). In this year, the chub mackerel schools favoured rather higher water temperature around Geomundo in the northeast of Jeju Island than lower water temperature around Heuksando in the southern West Sea.

Conclusions

In South Korea, it was the first use of acoustic data (Simrad ES70, 120 kHz) collected during normal fishing operations from a commercial purse seine fishing vessel and associated catch data to be used to describe the fish school characteristics and evaluate fish biomass. The fishing using a fishing vessel ("71 Kumyoung") targeted the chub mackerel between 13 September and 7 October 2014 in the southern West Sea and near Jeju Island. Information on the purse seine catch by the squadron of "71 Kumyoung" was extracted based on sales information to several fisheries cooperatives during the fishing period. The fish school characteristics were delineated from 21 fishing events. As a result, with regard to the fish school description, the S_V and thickness of the fish schools presented differently. The fish lengths and areas extremely varied and some schools were inordinately long and large. The distributional depth and the distance between fish schools and sea bottom indicated that the attracted fish schools by light were mainly located close to the water surface. On average, the acoustic biomass was 1.7 times larger than the catch. The correlation between the acoustic biomass and the catch was low positive. It is note that the accuracy of the acoustic biomass can be improved by the calibration, and available echo

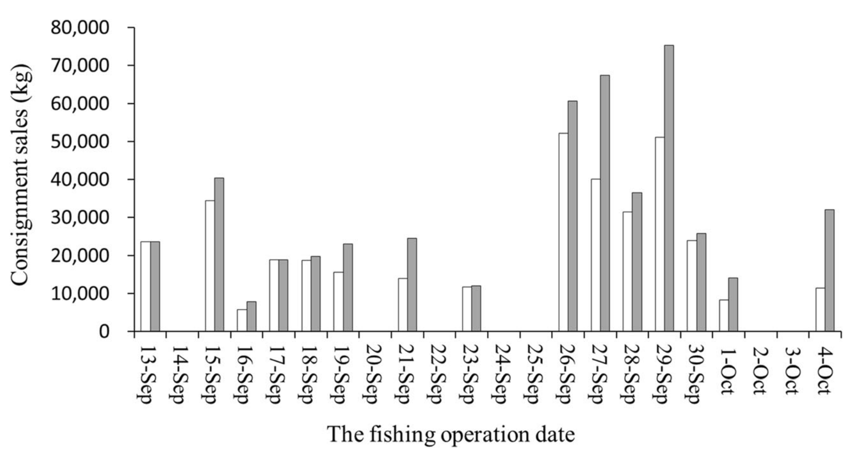

Fig. 6 Daily total weight (gray bar) and the chub mackerel weight (white bar) from sales with regard to the squadron of "71 Kumyoung" during the fishing period

sounders installed fishing vessels can be used for supporting in the chub mackerel resources management and in the purse seine fishing method in South Korea.

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