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Fisheries and Aquatic Sciences

Original Article
Fish Aquat Sci 17(3), 369-376, 2014

Overview of the Applications of Hydroacoustic Methods in South Korea and Fish Abundance Estimation Methods

Myounghee Kang*

Department of Maritime Police and Production System / The Institute of Marine Industry, Gyeongsang National University, Tongyeong 650-160, Korea

Abstract

I provide an overview of the application of hydroacoustic methods in South Korea to understand the current research status in relation to fisheries acoustics and to determine which areas require further study. One main purpose for using a scientific echosounder, a representative tool using the hydroacoustic method, is to evaluate the abundance of fisheries resources. Thus, two representative methods for abundance estimation are described. The history of fisheries acoustics worldwide is also summarized.

Key words: Hydroacoustics, Echosounder, Fish abundance, Korea

Introduction

'Scientific' echosounders are defined as enhanced 'ordinary' echosounders and can be used to quantitatively estimate fisheries resources and to research fish ecological characteristics. The sound transmitted from the echosounder travels long distances, several hundred to several thousand meters, under water. Accordingly, acoustic data from the echosounder can be converted into quantitative numbers and used to describe morphological images of fish schools at various water depths (Simmonds and MacLennan, 2005).

Conventionally, echosounders operate within a frequency range of several dozen to several hundred kilohertz. The most common frequencies are 38 and 120 kHz. The main purpose of using echosounders is to evaluate fisheries resources and to understand their ecological characteristics. Relative to fish stock assessment, an acoustic survey has the advantage of providing continuous acoustic data along pre-planned transect lines. Such surveys can be relatively easy to conduct and provide highly accurate data samples. A typical hydroacoustic survey is conducted concurrently with net sampling, because the composition and mean body length of fish species should be known to apply them in the process of abundance estimation. For net sampling, a desired species is targeted such that the species or a number of species constitutes a large part of the catch.

In South Korea, fisheries acoustic surveys began in the early 1990s. Studies using hydroacoustic methods have been published over the last 20 years. Now is a good time to review all publications related to hydroacoustic surveys conducted in South Korea to gauge what has been researched and which areas require further study. Internationally, many papers on the hydroacoustic method and its applications have been published. Two key textbooks have been used for the study of fisheries acoustics (Johannesson and Mitson, 1983; Simmonds and MacLennan, 2005). Among the uses of the hydroacoustic method to date, the most common is estimating the abundance of fish resources.

In this paper, nearly all published uses of the hydroacoustic method in South Korea are reviewed and categorized into four groups: abundance estimation, distributional characteristics of fish schools, target strength (TS) investigation, and species

Received 4 October 2013; **Revised** 12 February 2014
Accepted 12 June 2014

***Corresponding Author**
E-mail: mk@gnu.ac.kr

identification. The history of developing fisheries acoustics is summarized, and two representative methods for abundance estimation are described. Finally, the points to be considered in hydroacoustic applications in South Korea, including future directions, are mentioned.

History of fisheries acoustics

In the early 1900s, echo-ranging was developed, initially for locating icebergs, following the sinking of the Titanic. In 1929, the first successful experiment demonstrating the acoustic detection of sea bream swimming in an aquaculture pond was published (Kimura, 1929). In 1935, echograms of cod schools in Vestfjord, Norway were reported (Sund, 1935), marking the first use of echosounding for fisheries research. By 1937, acoustic surveys by Norwegians were conducted to plot the distribution of herring (Runnstrom, 1937; Sund, 1943). During World War II, there were rapid technological advances in echosounding. By the early 1950s, trial research for quantifying acoustic data was being conducted (Richardson, 1950; Cushing, 1952). Development of the echo integrator enabled the squared echo voltages to be determined over short time periods, and this became the basis for absolute abundance estimations (Dragesund and Olsen, 1965). The echo counting method was also developed (Midttun and Sætersdal, 1957). The classic crescent-shaped trace was created, in which a single fish could be detected. The trace could be counted to produce abundance estimates. From the start of the 1970s, there were further major advances in technology with the rapid introduction of relatively inexpensive digital electronics. This made the acoustic survey more accessible and practical. In recent years, split-beam echosounders, digital signal processing, and color displays have appeared. In addition, research on acoustic biology, such as TS versus fish length and the effects of tilt on TS have been conducted (Love, 1971; Nakken and Olsen, 1977). Absolute echo levels are now quantified using echo integration to yield a quantity that is proportional to fish density in accordance with the linearity principle. In the 1980s, experimental evidence of the linearity principle using live fish in cages as targets was demonstrated (Foote, 1983). A practical calibration manual describing the standard sphere calibration method was developed (Foote, 1987) and is still in use today. A wealth of fish TS measurements on caged aggregations and on the influences of fish physiology and behavior have now been reported (Foote, 1980; Edwards and Armstrong, 1983; Ona, 1990). In the 1990s, a great proportion of the work focused on ways to evaluate and improve the precision of acoustic data, specifically vessel noise specification and review (Mitson, 1995). Fish behavior, such as schooling patterns, has also been recognized as a key factor affecting fish stock assessment (Pitcher et al., 1996). For species identification, abundance assessments that rely on net sampling results can have major shortcomings. Thus, automatic and acoustic species identification, using multi-frequency (Brierley et al., 1998) and broadband (Simmonds et al., 1996) techniques, has great potential to increase the utility of multispecies surveys and the accuracy of abundance estimates, and to reduce the time required in net sampling.

Echo integration method

To assess the abundance of fish resources, two methods, echo integration and fish counting, are used commonly. Echo integration assumes that the total acoustic energy scattered by a group of targets is the sum of the energy scattered by each individual target. This assumption holds well in most cases. The total acoustic energy backscattered by a school or aggregation is integrated together, and this total is divided by the (previously determined) backscattering coefficient of a single animal, that is TS, giving an estimate of the total number of individuals. Many hydroacoustic surveys are conducted along preset transect lines. The per-transect abundance (tonnes) can be estimated as

$$Bt = \frac{\overline{S_{At}} \cdot \frac{\overline{W}}{1000} \cdot A_t}{4 \cdot \pi \cdot 10^{\frac{\overline{TS}}{10}}} \tag{1}$$

where $\overline{S_{At}}$ (m²/nmi²) is the mean returned acoustic signal for transect *t* given by the echosounder, A_t is the per transect survey area (nmi²), $\overline{TS}$ is the mean target strength (dB re 1 m²) of a target species in the survey area, and $\overline{W}$ is the mean weight (kg) of a target species, which is normally calculated using net samples. TS is a measure of the acoustic reflectivity of a fish, which varies depending on the presence of a swim bladder and on the size, behavior, morphology, and physiology of the fish (Simmonds and MacLennan, 2005). Generally, the TS can be obtained from *in situ* measurements of free swimming fish in the natural habitat, *ex situ* measurements of dead or live fish in a controlled environment, and numerical or theoretical backscattering models based on fish anatomy (Gauthier and Rose, 2001; O'Driscoll and Rose, 2001; Jech and Horne, 2002; Hazen and Horne, 2004). The per-transect abundance estimates are summed to give an estimate of the abundance for the total survey area, as follows:

$$\text{Biomass} = \sum_{i=1}^{n} Bt_i \tag{2}$$

where *n* is the number of transects. Generally, to describe the abundance in a survey area, the thematic map of S_A (nautical area scattering coefficient) values in a given interval (e.g., 0.05 n.m.) can be used.

Fish counting method

Fish counting requires individual targets to be spaced far enough apart such that they can be distinguished from one another, after which it is straightforward to estimate the number of fish by counting the number of targets. First, a single (or individual) target should be detected. To detect single targets, a single target detection algorithm should be used (Ona and Barange, 1999). The algorithm deals with data samples from each ping in a given time. The basic single target detection algorithm is based on the following: the preset pulse length discrimination level (PLDL) determines the inclusion of samples, the peak TS value (highest strength of target) is chosen from the included samples, the peak value must be larger than the given TS threshold, the target pulse length is determined by the difference in depth between the first and last included samples, and the pulse length must meet a criterion related to the transmitted pulse length. A perfect point target (TS) would occur when a received pulse is very similar or the same as the transmitted pulse. The fish counting method is composed of single target detection and fish tracking techniques (Blackman, 1986). Fish should be detected as single targets using single target detection algorism and connected as one fish track using fish tracking technique because the same fish can be insonified multiple times by several pings.

A comprehensive review of hydroacoustic applications in South Korea

Almost all publications in South Korea related to fisheries acoustics have been reviewed comprehensively. Domestic applications of the hydroacoustic method can be categorized as abundance estimation, TS investigation, distributional characteristics, and acoustic species identification. Additionally, points to be considered in terms of the hydroacoustic applications in South Korea are mentioned.

Abundance estimation

In the early 1990s, to estimate the abundance of demersal fishes distributed in the southeast, off Jeju Island, a commercial echosounder at 50 kHz and with an echo integrator was utilized (Lee and Lee, 1996). In the late 1990s, the South Korean government started to build marine ranches to increase fisheries resources, to support sustainable fisheries, and to manage fisheries and the coastal seas. Now, there are five marine ranches in the coastal seas: Tongyeong, Yosu, Uljin, Taean, and Jeju Island (MOMAF, 2004). Thus, there have been many studies on fish density and their distributional characteristics around marine ranches where artificial reefs have been established (Hwang et al., 2004; Kang et al., 2008; Lee et al., 2012). The densities of most fish distributions around the artificial reefs in the coastal seas off Tongyeong and Jeju Island marine ranches were assessed (Hwang et al., 2004; Kang et al., 2008). Generally, artificial reefs were installed in relatively shallow water, less than 200 m deep, at the marine ranches of Tongyeong and Jeju Island, such that a 120 kHz echosounder with an effective detection range of ~200 m can be used commonly. However, one study used an echosounder with 38 and 120 kHz to collect acoustic data in the marine ranch off Jeju Island, although only 38 kHz data were analyzed for calculating fish density (Lee et al., 2012). Many fish species are distributed within marine ranch environments. Thus, a general length-TS conversion equation for teleost fish has been used to estimate the density of most fishes in the environment. Here, length is measured directly from the mean body length of fishes in the catch. The two standard frequencies (38 and 120 kHz) for hydroacoustic surveys have been used to estimate anchovy abundance in the South Sea off South Korea. Anchovies play a pivotal role in sustaining the mean trophic level among the food chain of the coastal marine ecosystem in the seas off South Korea. Thus, it is an important species commercially and ecologically (Choo and Kim, 1998). Regarding the targeting of this important species, there have been several studies estimating its abundance and understanding its distributional characteristics (Kim et al., 2008; Oh et al., 2009; Choi et al., 2001). From these studies, anchovy abundance was found to vary by area and time (season and year). For abundance estimation, not only fish but also zooplankton were targeted (Kang et al., 2003).

For targeting zooplankton, Korean scientists have estimated its density using six frequencies. The study area was Sakami bay in Japan (Hwang, 2008). In the coastal waters off Uljin, the acoustic density of zooplankton was compared with the density of a close-open-close net. Density from the sounder was lower than that from the net, because the hydroacoustic density by depth was shown to be even, while the density from the net was highly variable (Hwang et al., 2005). It could be assumed that the net would not have been even throughout the water column. Recently, many giant jelly fish have migrated from China to South Korea and Japan, damaging the fisheries industry. Thus, the density by water depth and TS variation by swimming angle for targeting these giant jelly fish were examined using a 120 kHz echosounder (Lee et al., 2007).

Distributional characteristics

There are many studies on the behavioral and distributional characteristics of fish. In the early 1990s, the timing of diel vertical movements of pelagic fish in the East China Sea was examined using 25 and 100 kHz echosounder, in comparison with marine environmental information from conductivity, temperature, and depth (CTD) sensors. The change in S_V values was also shown by depth and time (Lee, 1994a; Lee, 1994b). Using a 38 kHz echosounder, the morphological and positional characteristics of anchovy schools, such as area, length, height, and perimeter, were described precisely (Kang et al., 1996; Kim et al., 1998). In the Yellow Sea, pelagic fish and demersal fish, defined as echo signals from the sea bottom to 5 m above the sea bottom, were divided to map their S_A on the ship's cruise providing the horizontal acoustic density. In addition, the vertical distribution of the schools were compared with water temperature (Hwang et al., 2002). Using a 38 kHz echosounder, the S_A of fish schools distributed around artificial reefs at Oeyeon-do, Boryung city were displayed on the cruise track, and their gathering status was displayed in three dimensions (Kim et al., 2011). Using an acoustic camera system (DIDSON), the number of fish migrating to upper streams from the sea in relation to the water level in a fish passage was measured, and the correlation between haul sampling and fish counted using the DIDSON in a fishing boat gateway was high (Yang et al., 2010). Studies by Korean scientists performing surveys in foreign seas sought to understand the density and distribution of krill in the Antarctic Sea using a 38 kHz echosounder (Kang et al., 2003), and to obtain the swimming speed and direction of Pacific saury in Funca bay, Japan, using an Acoustic Doppler Current Profiler (ADCP) (Lee et al., 2010).

TS investigation

There have been many TS investigations for various fish species. *Ex situ* TS measurements can permit assessing the effects of variables, such as species, body length, and orientation, on TS values. Through an *ex situ* TS experiment, the length-TS conversion equation has been commonly obtained using best-fit regression. The equation can be useful in that when the body length of a species is known, the TS can be deduced. In the mid-1990s, *ex situ* TS of mackerel and croaker were measured by tilt angle, and the length-TS conversion equations for 10 species caught using a bottom trawl net were determined (Lee et al., 1995). *Ex situ* TS for squid (Yoon and Ha, 1998) and anchovy (Yoon et al., 1996) using a 38 kHz device were analyzed, and length-TS conversion equations were determined. In the 2000s, TS experiments were conducted in more than 15 species distributed in the marine ranches using echosounders at 50, 70, 75, 120, and 200 kHz, which are now commercially available and commonly used (Lee and Shin, 2005). Furthermore, *ex situ* TS for striped beakperch, bluefin searobin, konoshiro gizzard shad, black porgy, fat greenling, and large yellow croaker were measured using 75 or 70 and 120 kHz (Kang and Lee, 2003; Mun et al., 2006; Lee, 2010; Lee, 2012). *Ex situ* TS of jelly fish, which has caused problems in Korean fisheries, was measured using 38 and 120 kHz to compare with the pulsation of a bell. The TS difference on the basis of the bell pulsation for two different sizes of jelly fish (35 and 25 cm) was ~7.8-10.3 dB (Yoon et al., 2010). *Ex situ* TS of squid at 38 and 120 kHz were determined using an underwater camera, and TS at 120 kHz was 1.3-2.5 dB higher than that at 38 kHz, and the mean swimming angle was -24° (Kang et al., 2004). Research also showed that the TS of anchovy from the side aspect was 2 dB higher than that from the dorsal aspect (Lee and Kang, 2010).

Species identification

The dB difference method has been widely used for species identification. The dB difference (ΔS_V) can be obtained by the equation (Kang et al., 2002),

$$\Delta S_V = S_{V\ f2} / S_{V\ f1} \quad (4)$$

where S_V is the mean volume backscattering strength, $S_{V\ f1}$ is the mean S_V (m^{-1}) in a cell at frequency 1 (e.g., 38 kHz), and $S_{V\ f2}$ is the mean S_V (m^{-1}) in a cell at frequency 2 (e.g., 120 kHz). This method is not universal due to the territorial uniqueness of the acoustic characterization of aquatic animals and the different combinations of acoustic systems and processing methods. However, this technique has been well established and is easy to use. Using the dB difference method, that is, the difference in the mean volume backscattering strength at two frequencies, commonly 38 and 120 kHz, krill (dB difference range of 2-16 dB) in the Antarctic sea, and fish (larger than 2 dB) and juvenile fish and plankton (7-18 dB) in the Yellow Sea were discriminated respectively; the interference from a Doppler signal at 100 kHz was also removed by masking dB differences larger than 20 dB (Kang et al., 2003).

Conclusions and future directions

During the early stages of hydroacoustic research in South Korea, acoustic data processing and analyses were not easy compared with those of the present. For example, sea bottom signals could not be removed with precision, and various noises from the ship, bad weather, and other acoustic equipment could not be deleted readily. In addition, extracting analyzed results, such as the characteristics of detected fish schools and S_V or S_A, was time consuming.

In the 21st century, there have been dramatic developments in IT and hydroacoustic techniques. As a result, hydroacoustic hardware now can produce high-resolution data, and present day software can accurately handle vast volumes of data at high speeds. Now, more precise information on aquatic organisms can be collected, and echo signals from organisms of interest can be determined, processed, and analyzed accurately.

It is important to understand that the establishment of hydroacoustic surveying and methods for data analysis and fitting them to environments with unique characteristics, such as the seas of South Korea, require considerable time and effort. As initial hydroacoustic surveys are performed, advantages and disadvantages of general hydroacoustic methods should be understood in the light of the characteristics of the seas of South Korea. The initial surveys should be developed into routine surveys. Highly developed countries have long been conducting routine monitoring surveys for single species in fisheries acoustics. Through routine hydroacoustic surveys over a long period of time, in-depth understanding of herring in Norway, sardines in the USA, and anchovies in Peru has been obtained (Østvedt, 1965; Gutierrez et al., 2007; Zwolinski et al., 2012).

In South Korea, the species targeted so far for hydroacoustic surveys include anchovies, jelly fish, zooplankton, and all fish, not specific species, in the study areas for a relatively short period of time. A single species from a region, if possible, regulated by the Korean government, needs to be selected to conduct hydroacoustic surveys regularly over a long period of time. In this way, the hydroacoustic survey will continue to develop to produce diverse knowledge on fish populations and geometric and behavioral characteristics of fish schools.

To obtain a comprehensive understanding, in the future, we need to investigate a target species, taking into consideration environmental information and/or its interaction with predators. Moreover, as routine monitoring surveys are conducted, the survey methodology should also be developed accordingly. Know-how on hydroacoustic surveying in the Korean environment will accumulate as a consequence.

TS from a fish of the same length and species is constant, but it can differ in the cases where a fish is insonified by different frequencies. For estimating fisheries resources, 38 and 120 kHz have been used as the *de facto* 'standard' frequencies, as mentioned in the introduction. Thus, TS values at these two frequencies should be used consistently to estimate fish abundance. TS for various fish species have been measured so far in controlled experimental environments; however, *ex situ* TS at 38 kHz has not always been obtained. TS at 38 kHz is required for abundance estimations in many cases, although it is hard to handle that frequency transducer because of its size and weight. Thus, a numerical and theoretical TS model should be investigated. In particular, TS models should be developed for each species of interest.

Many research studies using hydroacoustic techniques have been conducted in South Korea. However, currently, only a few hydroacoustic surveys performed for the purpose of estimating fish abundance have contributed directly to assessing fish stocks in relation to fisheries policies and management. Encouragingly, an exclusive fisheries resource management center will be built in the next two years. I hope that hydroacoustic surveys will be one of the main methods used for monitoring fish distribution patterns and behaviors, for assessing fish populations, and for understanding fisheries resources with respect to the marine environment. Data acquisition and analysis are both important aspects of hydroacoustic methods. Even before collecting acoustic data, it is important to take into consideration the method to be used to analyze them in the post-data processing stage. Also, an acoustic database needs to be established in the fisheries resources management center.

Several multi-beam or scanning sonar systems for fisheries research purposes are available in South Korea. Sonar systems are relatively new instruments, compared with echosounders, but have wide coverage for high-resolution data sets; thus, they have been used increasingly to understand the behavioral and geometric characteristics of marine organisms, in particular epi-pelagic fish schools (Gerlotto et al., 2006; Paramo et al., 2007) and precise topographic sea bottom measurements (Cutter et al., 2010). Therefore, trial research using existing sonar systems is expected to be performed in the near future. Automatic underwater vehicles, remotely operated vehicles, and dropping devices to install various sensors, such as acoustic cameras, video and stereo cameras, and transducers at different frequencies, have been used in advanced countries (Graham et al., 2004; Ryan et al., 2009; Sawada et al., 2009). It may be beneficial to use these technologies for fisheries research in South Korea too, for example, in artificial reef environments.

For species identification, primarily three characteristics are available: frequency characteristics, such as dB difference, fish school morphological and positional characteristics, and individual fish behavioral characteristics. In South Korea, there has been little research on species identification. Of the three characteristics, only the dB difference method has been used a few times. One reason why studies on species identification have been so limited is that only a few hydroacoustic surveys have been performed to target a single species. That is, many studies have been conducted with the aim of examining the entire fish population in particular survey areas. Thus, species identification was not an issue. Nevertheless, it is important to investigate species identification, because it is necessary to analyze data collected in routine surveys for monitoring fish species. In fact, many species in the seas of South Korea inhabit areas together or within close proximity of each other. It would be extremely difficult to acoustically identify every species in the seas off South Korea. However, some species that co-exist can be discriminated acoustically (Fassler et al., 2007; Korneliussen et al., 2009). More studies on species identification are required.

Finally, fisheries acousticians should collaborate with biologists and ecologists, because hydroacoustic methods should be applied on top of a good understanding of the ecology and biology of aquatic organisms. In the long term in South Korea, it is expected that the hydroacoustic method will be used actively by ecologists and biologists. For that to happen, a working group or seminar on fisheries acoustics would be a good start.

Acknowledgments

I would like to thank Katy Zhu for assisting with English expressions in this paper. I thank reviewers for their valuable comments to improve the earlier manuscript.

References

Blackman SS. 1986. Multiple-Target Tracking with Radar Application. Artech House, Dedham 464 pp.

Brierley AS, Ward P, Watkins JL and Goss C. 1998. Acoustic discrimination of Southern Ocean zooplankton. Deep-Sea Res II 45, 1155-1173.

Choi SK, Kim JY, Kim SS, Choi YM and Choi KH. 2001. Abundance estimation of anchovy (*Engraulis japonicus*) by acoustic and trawl surveys during spring season in the southern Korean waters. J Kor Soc Fish Res 4, 20-29.

Choo HS and Kim DS. 1998. The effect of variations in the Tsushima warm currents on the egg and larval transport of anchovy in the southern sea of Korea. J Kor Fish Soc 31, 226-244.

Cushing DH. 1952. Echo-surveys of fish. J Cons Int Explor Mer 18, 45-60.

Cutter GR Jr, Berger L and Demer DA. 2010. A comparison of bathymetry mapped with the Simrad ME70 multibeam echosounder operated in bathymetric and fisheries modes. ICES J Mar Sci 67, 1301-1309.

Dragesund O and Olsen S. 1965. On the possibility of estimating year-class strength by measuring echo-abundance of 0-group fish. Rep Nor Fish Mar Invest 13, 47-75.

Edwards JI and Armstrong F. 1983. Measurement of the target strength of live herring and mackerel. FAO Fish Rep 300, 69-77.

Fassler SMM, Santos R, Garcıa-Nunez N and Fernandes PG. 2007. Multi frequency backscattering properties of Atlantic herring (*Clupea harengus*) and Norway pout (*Trisopterus esmarkii*). Can J Fish Aquat Sci 64, 362-374.

Foote KG. 1980. Effect of fish behaviour on echo energy: the need for measurements of orientation distributions. J Cons Int Explor Mer 39, 193-201.

Foote KG. 1983. Linearity of fisheries acoustics, with additional theorems. J Acoust Soc Am 73, 1932-1940.

Foote KG. 1987. Fish target strengths for use in echo integrator surveys. J Acoust Soc Am 82, 981-987.

Gauthier S and Rose GA. 2001. Target strength of encaged Atlantic red fish (*Sebastes* spp). ICES J Mar Sci 58, 562-568.

Gerlotto F, Bertrand S, Bez N and Gutierrez M. 2006. Waves of agitation inside anchovy schools observed with multibeam sonar, a way to transmit information in response to predation. ICES J Mar Sci 63, 1405-1417.

Graham N, Jones EG and Reid DG. 2004. Review of technological advances for the study of fish behaviour in relation to demersal fishing trawls. ICES J Mar Sci 61, 1036-1043.

Gutierrez M, Swartzman G, Bertrand A and Bertrand S. 2007. Anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) spatial dynamics and aggregation patterns in the Humboldt Current ecosystem, Peru, from 1983-2003. Fish Oceanogr 16, 155-168.

Hazen EL and Horne JK. 2004. Comparing the modeled and measured target-strength variability of walleye pollock, *Theragra chalcogramma*. ICES J Mar Sci 61, 363-377.

Hwang BK. 2008. Zooplankton abundance and size estimation using a multi-frequency acoustic system. J Kor Fish Soc 41, 54-60.

Hwang DJ, Kim DE, Jeong SB, Son YU, Chae JH and Cho KR. 2005. Distribution of the deep scattering layer around Uljin coastal area. J Kor Fish Soc 38, 205-213.

Hwang DJ, Park JS and Lee YW. 2004. Estimation of fish school abundance by using an echo sounder in an artificial reef area. J Kor Fish Soc 37, 249-254.

Hwang DJ, Shin HH and Kang DH. 2002. Studies on fish distribution characteristics using a scientific echo sounder in the Yellow Sea. J Kor Soc Fish Tech 38, 140-148.

Jech JM and Horne JK. 2002. Three-dimensional visualization of fish morphometry and acoustic backscatter. J Acoust Soc Am 3, 35-40.

Johannesson KA and Mitson RB. 1983. Fisheries acoustics - A practical manual for aquatic abundance estimation. FAO Fish Tech Paper, No. 240.

Kang DH, Hwang DJ, Mukai M, Iida K and Lee KH. 2004. Acoustic target strength of live Japanese common squid (*Todarodes pacifica*) from applying abundance estimation. J Kor Fish Soc 37, 345-353.

Kang DH, Hwang DJ, Soh HY, Yoon YH, Suh HL, Kim YJ, Shin HC and Iida K. 2003. Density estimation of an euphausiid (*Euphausia pacifica*) in the sound scattering layer of the East China Sea. J Kor Fish Soc 36, 749-756.

Kang DH, Lim YJ, Lee CW, Yoo JT and Myung JG. 2008. Hydroacoustic survey of spatio-temporal distribution of demersal fish aggregations near the west coast of Jeju island, Korea. Ocean Polar Res 30, 181-191.

Kang DH, Sin HC, Kim SA, Lee YH and Hwang DJ. 2003. Species identification and noise cancellation using volume backscattering strength difference of multi-frequency. J Kor Fish Soc 36, 541-548.

Kang HY and Lee DJ. 2003. Fish length dependence of acoustic target strength for large yellow croaker. J Kor Soc Fish Technol 39, 239-248.

Kang M, Furusawa M and Miyashita K. 2002. Effective and accurate use of difference in mean volume backscattering strength to identify fish and plankton. ICES J Mar Sci 59, 794-804.

Kang M, Yoon GD, Choi YM and Kim ZG. 1996. Hydroacoustic investigations on the distribution characteristics of the anchovy at the south region of East Sea. J Kor Soc Fish Technol 32, 16-23.

Kim HY, Hwang BK, Lee YW, Shin HO, Kwon JN and Lee KH. 2011. Hydro-acoustic survey on fish distribution and aggregated fish at artificial reefs in marine ranching area. J Kor Soc Fish Technol 47, 139-145.

Kim JI, Yang WS, Oh TY, Seo YI, Kim ST, Hwang DJ, Kim EH and Jeong SB. 2008. Acoustic estimates of anchovy abundance along the Tongyoung-Namhae coast. J Kor Fish Soc 41, 61-67.

Kim ZG, Choi YM, Hwang KS and Yoon GD. 1998. Study on the acoustic behavior pattern of fish school and species identification. 1. Shoal behavior pattern of anchovy (*Engraulis japonicus*) in Korean waters and species identification test. J Kor Soc Fish Technol 34, 52-61.

Kimura K. 1929. On the detection of fish-groups by an acoustic method. J Imp Fish Ins, Tokyo.

Korneliussen RJ, Heggelund Y, Eliassen IK and Johansen GO. 2009. Acoustic species identification of schooling fish. ICES J Mar Sci 66, 1111-1118.

Lee DJ and Shin HI. 2005. Construction of a data bank for acoustic target strength with fish species, length and acoustic frequency for measuring fish size distribution. J Kor Fish Soc 38, 265-275.

Lee DJ and Lee WW. 1996. Hydroacoustic investigations of demersal fisheries resources in the southeastern area of the Cheju Island, Korea-acoustical estimation of fish density and distribution. J Kor Soc Fish Technol 32, 266-272.

Lee DJ, Shin HI and Shin HH. 1995. Fish stock assessment by hydroacoustic methods and its applications - I - Estimation of fish school target strength. J Kor Soc Fish Technol 31, 142-152.

Lee DJ. 1994a. Hydroacoustic observations on the diel distribution and activity patterns of fishes in the East China Sea - I - Activity patterns during the evening and morning transition periods. J Kor Soc Fish Technol 30, 239-250.

Lee DJ. 1994b. Hydroacoustic observations on the diel distribution and activity patterns of fishes in the East China Sea - II - Vertical speed of migration and variation in scattering strength. J Kor Soc Fish Technol 30, 251-262.

Lee DJ. 2010. Fish length dependence of target strength for striped beakperch, bluefin searobin and konoshiro gizzard shad caught in the artificial reef ground of Yongho Man, Busan. J Kor Soc Fish Technol 46, 239-247.

Lee DJ. 2012. Fish length dependence of target strength for black porgy and fat greenling at two frequencies of 70 and 120 kHz. J Kor Soc Fish Technol 48, 137-146.

Lee HB and Kang DH. 2010. In situ side-aspect target strength of Japanese anchovy (*Engraulis japonicus*) in northwestern Pacific Ocean. J Kor Fish Soc 46, 248-256.

Lee JB, Oh TY, Yeon IJ, Kim BY, Shin HO, Hwang BK, Lee KH and Lee YW. 2012. Estimation of demersal fish abundance using hydroacoustic and catch data in the marine ranching area (MRA) of Jeju. J Kor Soc Fish Technol 48, 128-136.

Lee KH, Kim IO, Yoon WD, Shin JK, and An HC. 2007. A study on vertical distribution observation of giant jellyfish (*Nemopilema nomurai*) using acoustical and optical methods. J Kor Soc Fish Technol 43, 355-361.

Lee KH, Lee, DJ, Kim HS and Park SW. 2010. Swimming speed measurement of Pacific saury (*Cololabis saira*) using acoustic doppler current profiler. J Kor Soc Fish Technol 46, 165-172.

Love RH. 1971. Dorsal-aspect target strength of an individual fish. J Acoust Soc Am 49, 816-823.

Midttun L and Saetersdal G. 1957. On the use of echosounder observations for estimating fish abundance. Special Publication, International Commission for the Northwest Atlantic Fisheries 11, 260-266.

Mitson RB. 1995. Underwater noise of research vessels. Review and recommendations. ICES Coop Res Rep 209, 61.

MOMAF. 2004. Feasibility studies on the marine ranching program of East, West and Jeju coastal areas in Korea. Report to the Ministry of Maritime Affairs & Fisheries.

Mun JH, Lee DJ, Shin HI and Lee YW. 2006. Fish length dependence of target strength for black rockfish, goldeye rockfish at 70 kHz and 120 kHz. J Kor Soc Fish Technol 42, 30-37.

Nakken O and Olsen K. 1977. Target strength measurements of fish. Rapp p-v Réun Cons Int Explor Mer 170, 52-69.

O'Driscoll RL and Rose GA. 2001. *In situ* acoustic target strength of juvenile capelin. ICES J Mar Sci 58, 342-345.

Oh TY, Kim JI, Seo YI, Lee SK, Hwang DJ, Kim EH, Yoon EA and Jeong SB. 2009. Comparison of geostatistic and acoustic estimates of anchovy abundance around the Tongyeong inshore area. J Kor Fish Soc 42, 290-296.

Ona E and Barange M. 1999. Single target recognition. ICES Coop Res Rep 235, 28-43.

Ona E. 1990. Physiological factors causing natural variations in acoustic target strength of fish. J Mar Biol Assoc UK 70, 107-127.

Østvedt OJ. 1965. The migration of Norwegian herring to Icelandic waters and the environmental conditions in May-June, 1961-1964. Fisken Havet 13, 30-47.

Paramo J, Bertrand S, Villalobos H and Gerlotto F. 2007. A three-dimensional approach to school typology using vertical scanning multibeam sonar. Fish Res 84, 171-179.

Pitcher TJ, Misund OA, Fernö A, Totland B and Melle V. 1996. Adaptive behaviour of herring schools in the Norwegian Sea as revealed by high resolution sonar. ICES J Mar Sci 53, 449-452.

Richardson ID. 1950. The use of an echo sounder to chart sprat concentrations. Ann Biolog Cons Internatio pour l'Explorat Mer 6, 136-139.

Runnstrom S. 1937. A review of the Norwegian herring investigations in recent years. J Cons Int Explor Mer 12, 123-143.

Ryan TE, Kloser RJ and Macaulay GJ. 2009. Measurement and visual verification of fish target strength using an acoustic-optical system attached to a trawl net. ICES J Mar Sci 66, 1238-1244.

Sawada K, Takahashi H, Abe K, Ichii T, Watanabe K and Takao Y. 2009. Target-strength, length, and tilt-angle measurements of Pacific saury (*Cololabis saira*) and Japanese anchovy (*Engraulis japonicus*) using an acoustic-optical system. ICES J Mar Sci 66, 1212-1218.

Simmonds EJ and MacLennan DN. 2005. Fisheries Acoustics, Theory and Practice, 2nd edn. Fish and Fisheries Series, Blackwell Publishing, Oxford, UK. 437 PP.

Simmonds EJ, Armstrong F and Copland PJ. 1996. Species identification using wideband backscatter with neural network and discriminant analysis. ICES J Mar Sci 53, 189-195.

Sund O. 1935. Echo sounding in fishery research. Nature 135, 953.

Sund O. 1943. The fat and small herring on the coast of Norway in 1940. Ann Biol Cons Int Explor Mer 1, 58-79.

Yang YS, Bae JH, Lee KH, Park JS and Sohn BK. 2010. Fish monitoring through a fish run on the Nakdong River using an acoustic camera system. J Kor Soc Fish Technol 43, 735-739.

Yoon EA, Hwang DJ, Hirose M, Kim EH, Mukal T and Park BS. 2010. Characteristics of acoustic scattering according to pulsation of the large jellyfish *Nemopilema nomurai*. Kor J Fish Aquat Sci 43, 551-556.

Yoon GD and Ha KL. 1998. Acoustic target strength of pelagic fish species to echo integration in Korea Waters. Ⅱ. Measurement of target strength of squid (*Todarodes pacificus*). J Kor Soc Fish Technol 34, 372-377.

Yoon GD, Kim ZG and Choi YM. 1996. Acoustic target strength of the

pelagic fish in the southern waters of Korea: *In situ* measurement of target strength of anchovy (*Engraulis japonica*). J Kor Fish Soc 29, 107-114.
Zwolinski JP, Demer DA, Byers KA, Cutter GR, Renfree JS, Sessions TS and Macewicz BJ. 2012. Distributions and abundances of Pacific sardine (*Sardinops sagax*) and other pelagic fishes in the California Current Ecosystem during spring 2006, 2008, and 2010 estimated from acoustic-trawl surveys. Fish Bull 110, 110-122.