Doctoral Thesis

Estimates of Japanese sandeel (*Ammodytes personatus*) distribution and biomass in the northern coast of Hokkaido, Japan, using a quantitative echosounder

計量魚群探知機を用いた北海道北部沿岸域におけるイカナゴ (*Ammodytes personatus*)の分布と生物量の推定

Safruddin

2013（平成 25 年）

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CHAPTER I. GENERAL INTRODUCTION

I.1 Background

The Ecosystem approach to fisheries framework has been developed on the founding principles and conceptual goals emerging from the decades-long process of elaboration of the foundations for sustainable development, aiming at both human and ecosystem well-being (Garcia *et al.*, 2003). Furthermore, to organize these as an integrated framework for fisheries, a process of selection and reformulation matured in the 1995 FAO Code of Conduct for Responsible Fisheries (CCRF).

In order to understand and ameliorate the complexities of fishery management, it is necessary to study the nature of uncertainty associated with the abundance of fish stocks, and the influence of the ocean environment (Rothschild *et al.*, 2005). Stock assessment is a key component of the ecosystem approach to fisheries. Consequently, the accuracy of fish stock status in the field is crucial for fisheries resource management. Fortunately, the coincidence of new or improved instruments and techniques in acoustics technology has led to many promising measurement (Koslow, 2009).

It has long been known that fish can be detected remotely through the reflection of sound waves, acoustical technology has had a major impact on fishing, sonar and echo sounders are used routinely in the search for profitable concentrations of fish

(MacLennan and Simmonds, 1992). In fisheries research too, acoustical technology has become increasingly important over the years. Monitoring marine ecosystems is a major issue in the current context of global environmental change. Over-exploitation of a single aquatic species can result in significant changes in the populations of other living resources and the function and structure of their ecosystem (Demer *et al*., 2009).

I.2. Sandeel ecology

Sandeels constitute an important element in many marine food webs. They are key prey species for many marine predators including birds, fishes and mammals because of their high energy content. Sandeels are closely linked with specific benthic habitats, alternatively lying buried in the substrate and swimming pelagically in well-formed schools (Robards *et al*., 1999a). The absence of a swim bladder allows this narrow, elongate fish to spend much time buried dormant in intertidal and shallow subtidal substrates, venturing out only to feed or spawn.

When buried in the seabed, sandeels require a very specific substratum (Holland *et al*., 2005), favouring coarse sand with fine to medium gravel and low silt content. Bottom depth plays an important role of sandeel distribution (Wright *et al*., 2000). Sandeels are abundant in shallow near shore areas ranging in depth to 100 m but are most common at depths less than 50 m (Robards *et al*., 1999b). Feeding schools are found in coastal waters within the proximity of burrowing habitat. Highest abundance of sandeel is found in burrowing habitat that is sheltered from onshore wave action (Robards *et al*., 2002).

The spring and summer months are the main feeding periods and sandeels display a diurnal behavioural pattern where they emerge during the day to form large schools feeding on a variety of zooplankton prey, and bury themselves in the seabed at night. Copepods are the primary food source, allowing for rapid energy accumulation during secondary production blooms (Robards *et al*., 1999b).

Life spans of sandeels range from 3 to 12 years within a genus (Robards *et al*., 1999b). Sandeel growth is dependent on both abiotic and biotic factors such as temperature, food availability, competition, and predation. As a result, stocks inhabiting different oceanographic regimes may exhibit differing growth and survival rates (Robards *et al*., 2002). Sandeels are both euryhaline and eurythermal, as well as tolerant of reduced oxygen concentrations. They bury in the sand, when water temperature or prey abundance is low. Kooij *et al*. (2008) noted that bottom temperature and surface salinity also played an important role in explaining their distribution and abundance.

I.3 Japanese sandeel and fisheries acoustics

Sandeels ("Ikanago" in Japanese) are small semi pelagic fish that belong to the family Ammodytidae. They have a worldwide distribution. Species of *Ammodytes* occur in three geographic areas: *A. marinus* and *A. tobianus* are found in the east Atlantic and European waters, *A. americanus* and *A. dubius* in the north-west Atlantic, and *A. hexapterus* and *A. personatus* in the North Pacific (Jensen and Christensen, 2008). Japanese sandeel (*Ammodytes personatus* Girard) distribution could be divided into northern and southern groups from the morphology or meristic count (Hashimoto, 1984). Japanese sandeel (sandeel herein) plays an important role in marine ecosystems, not only as a food source for several marine organisms but also as a target for Japanese fisheries (Nakata, 1988; Fujiwara *et al*., 1990; Tomiyama *et al*., 2005; Yamada, 2009).

Sandeels are widely distributed around Japanese coastal waters excluding Okinawa area. They live in sandy bottom areas near the coastal waters and often under the sand below the sea bottom at night in habitation (Mosteiro *et al*., 2004). In the northern coast of Hokkaido (NCH), they migrate through soya strait to this area in summer periods according to the rise of water temperature and coincide with plankton abundant, and then back to the south for spawning in last summer.

Sandeels are an important part of marine ecosystems due to their relevant biomasses at intermediate levels in the food web, notably contributing to canalize the energy connecting the lower and upper tropic levels. Moreover, sandeels have also become an important fish species for commercial fisheries in Japan. Such findings are based on Hashimoto (1984) who has been reporting the distribution of *Ammodytes* around Japan waters (Figure 1.1) overlain with bathymetric profiles derived from ETOPO2 data base.

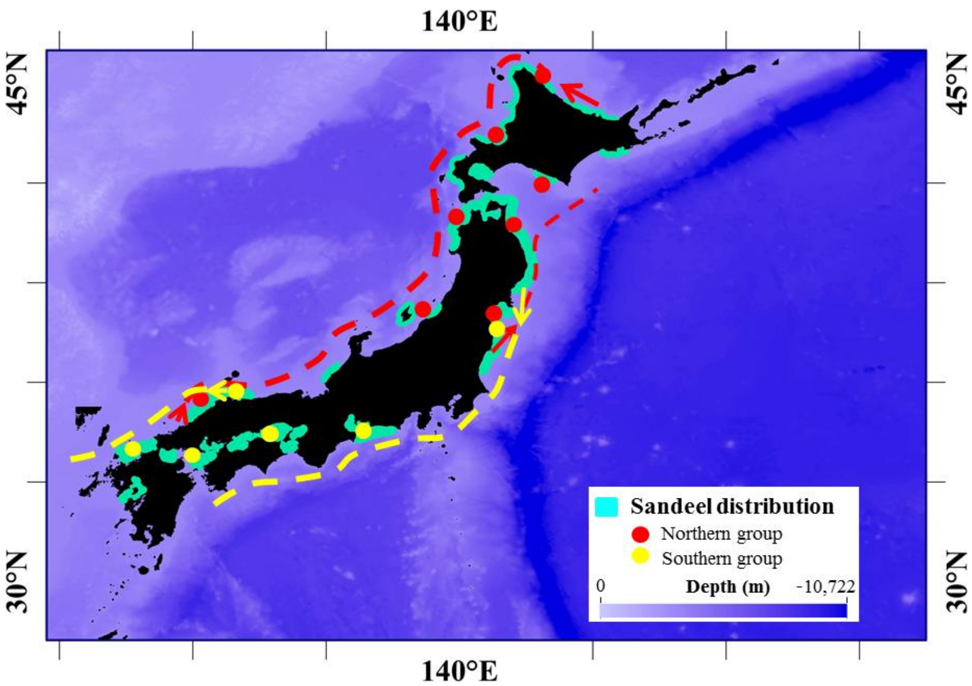

Figure 1.1 Distribution of *Ammodytes* spp. around Japan waters (Redrawn from Hashimoto, 1984).

Based on the commercial fisheries catches, annual fishery statistics can be evaluated. Thus, the trend of sandeel production in Japan and in comparison with

Hokkaido that started in early 1950's (according to statistics from the Ministry of agriculture, forestry and fisheries of Japan) is as presented in Figure 1.2. Landings of sandeel catches, mostly obtained from Hokkaido waters, were increasing towards and had a peak in 1970's. In the following years, catches decreased until in the year 2009. In the northern coast of Hokkaido especially around Soya Strait (Sarufutsu waters), trend of sandeel catches were corresponded with decreased catches in Hokkaido and Japan (Figures 1.2 & 1.3). Therefore, Sarufutsu waters are important fishing ground of sandeel fishery in Hokkaido or in Japan.

Stock assessments of Japanese sandeel have been made using catch per unit efforts (CPUE) methods but the estimation differ from the real abundance when CPUE and abundance do not have proportional relationship owing to various factors (Yasuma *et al*., 2009). *Vise versa*, acoustic methods are recognized as reliable for monitoring. Acoustic observation using quantitative echosounders can provide quantitative data in the short term and have been used for stock assessment of many species (Simmonds and MacLennan, 2005).

The fishing season for the adult sandeel fisheries off the NCH occurs during the summer (June–September) of every year. However, the status of sandeel stock just before the fishing season and the relationship between oceanographic changes in the fishing grounds are not well understood.

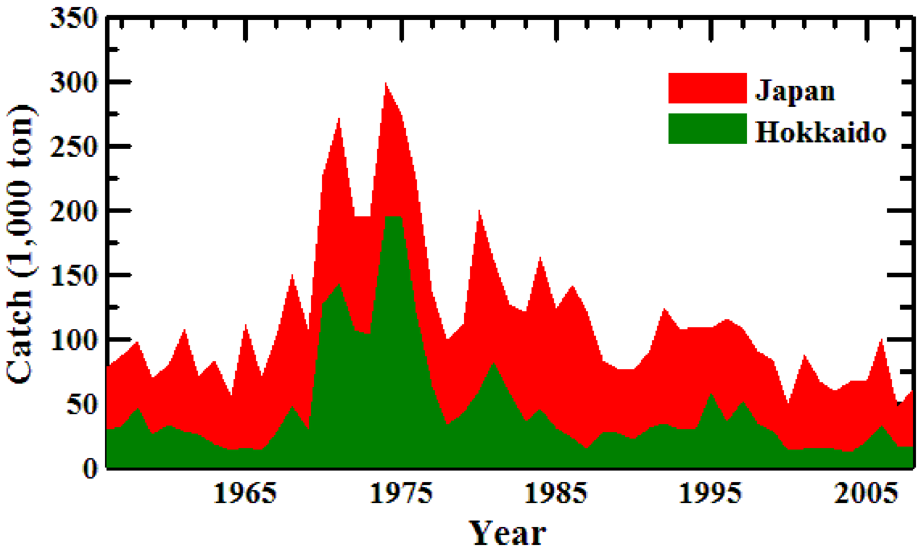

Figure 1.2 Annual catch of Japanese sandeel in Japan during the periods from 1956–2009. Sandeel caught from Hokkaido are also shown.

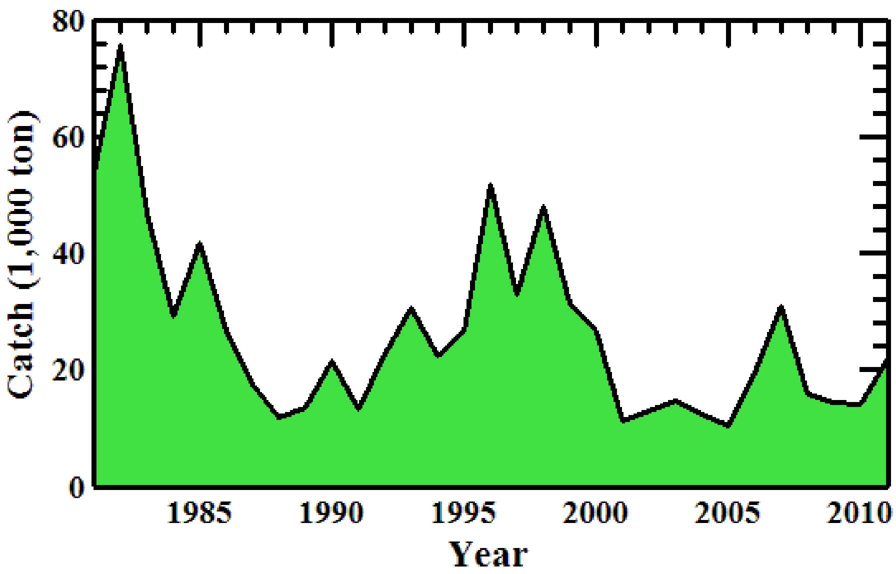

Figure 1.3 Annual catch of Japanese sandeel around Soya strait, Sarufutsu waters, northern coast of Hokkaido during the periods from 1980 – 2010.

To ensure efficient fisheries management policies in the future, fishery-independent methods to support sandeel abundance estimates and distribution are sought. In this study, acoustic method as a scientific quantitative method was employed to fulfill the shortcomings in the previous attempts to estimate the sandeel distribution and biomass and in relation with their environmental changes in the NCH.

Nowadays, researchers are using acoustic methods for estimation of fish abundance and distribution. This is due the acoustic methods make it possible to conduct continuous sampling to improve the accuracy of abundance estimates, non invasive, non-destructive, high-resolution and also cover large survey areas quickly (Miyashita and Tetsumura, 2001; Reeder, 2011).

From an acoustics point of view, sandeel is a challenging target, mainly because it has a weak acoustic target and peculiar behavioral straits. They form compact schools in the water column during the day, and subsequently descend into the bottom substrate at dusk (Kubilius and Ona, 2012). Therefore, acoustic survey is suitable when conducted in daytime to estimate quantitatively their abundance and distribution.

I.4 Aims of the study

This study is expecting fruitful result. Consequently, it is necessary to take account of the status of sandeel stock in the NCH in order to clarify the precise resource condition. This study has provided representative highlights from fish acoustics research in order to derive proper assessment. That is the reason for lack of information about the sandeel backscattering characteristics. However, to explain the echosounder data and to develop the sandeel identification algorithms, there is need to improve the understanding of the acoustic backscattering by fish. These motives are a priority to study the target strength (TS) of sandeel. This contribution leads to aims of study which is to assess the stocks and distribution patterns of fish by using acoustics data. Furthermore, get a better understanding the effect of oceanographic conditions, and to derive preferred condition of sandeel.

The overall goal of the study is to assist in ensuring that the best possible information and advice is generated from estimates of sandeel distribution and biomass to be used wisely in fisheries management, understanding the fish stock dynamics and providing the basic information a sustainable fishery especially in the area of interest.

I.5 Outlines of the thesis

To estimate the sandeel distribution and biomass in the NCH, acoustic method was used. In order to derive their habitat selection, the study applied several methods as schemed in the flow chart of Figure 1.4. As for the study work, the following procedure was followed:

1. Observation of the swimming angle of sandeel using an experimental water tank.
2. Measurement of the target strength of sandeel using theoretical model (distorted-wave born approximation, DWBA model) and laboratory experiments.
3. Conduction of the field surveys to collect acoustic and oceanographic data.
4. Obtaining the sandeel size composition as representative population that is collected from otter trawling (local commercial fisheries).
5. Derivation of the habitat selection of sandeel by applied statistical models.

The thesis is organized as follows: Chapter II explores the swimming angle of Japanese sandeel and illustrates modeling and laboratory measurements of acoustic backscattering (target strength) by the individual sandeel. Chapter III outlines *in-situ* measurements using acoustic data recordings for estimates of distribution and sandeel biomass. Chapter IV shows the effect of oceanographic conditions on sandeel distribution. The last section is Chapter V that provides general discussion, further considerations for the future works, recommendations for sustainable resource management and also summary of study.

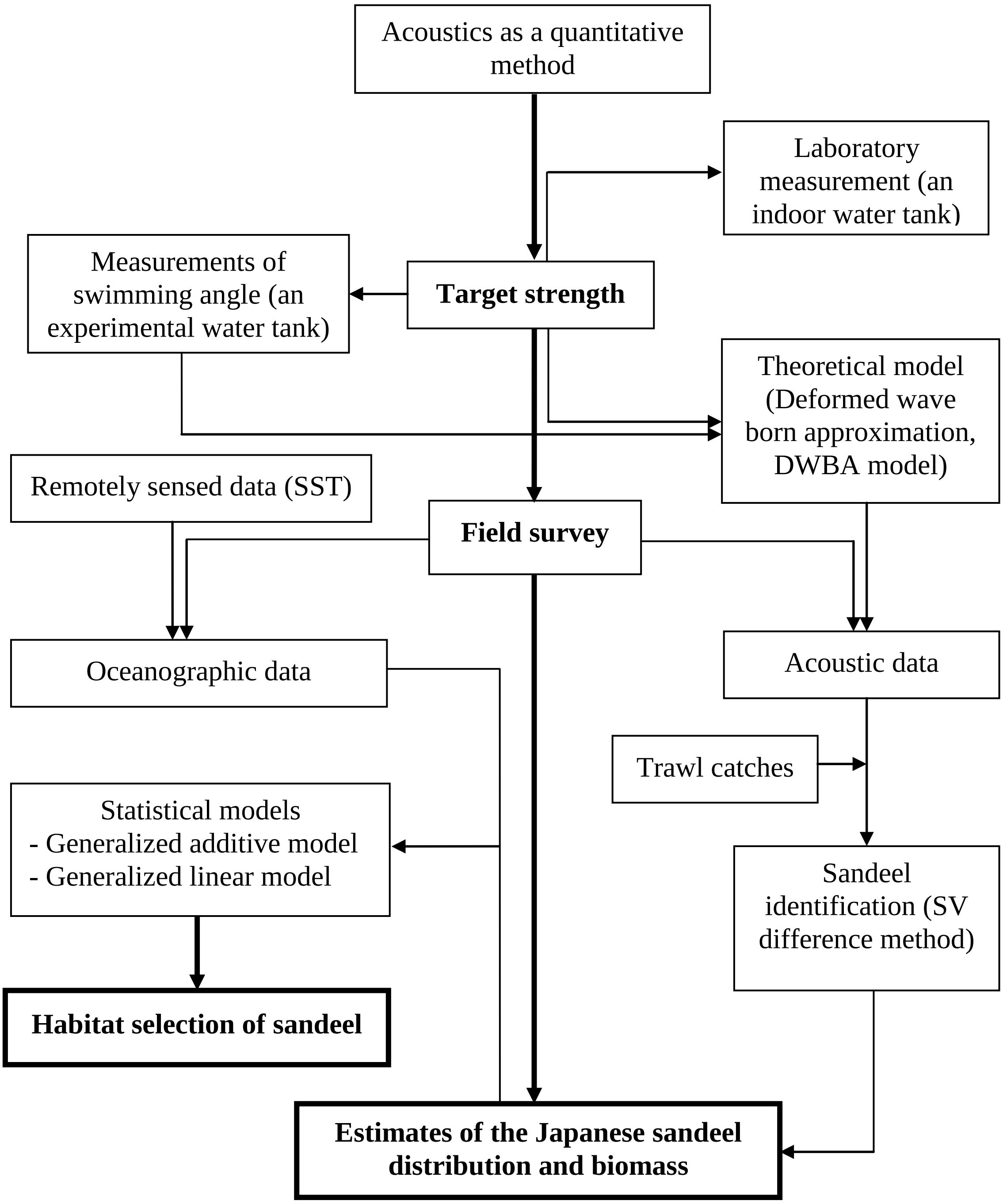

Figure 1.4 Schematic diagram of study methodology.

CHAPTER II. TARGET STRENGTH

II.1 Introduction

In many cases, biomass estimates using acoustic survey data incorporate average target strength (TS) equations that typically include only fish length (Foote and Traynor, 1988) as an independent variable. However, the variability in measured individual TS depends upon biological and physical factors such as swimming angle (McQuinn and Winger, 2003), length (Gauthier and Rose, 2001), morphology (Clay and Horne, 1994), ontogeny (Horne, 2003), physiology (Ona, 1990), depth (Mukai and Iida, 1996), and carrier frequency (Foote, 1985). Among these factors, swimming angle for swimbladderless fish such as sandeel, is the most important factor that influences variability in TS (Hazen and Horne, 2003).

Swimming angle is defined as the angle between the longitudinal body axis of the fish and the horizontal axis (Nakken and Olsen, 1977). Fish swimming angles depend on the activity of the fish. Fish need to conserve energy as other creatures do thus there is no reason to suppose that they are constantly executing sudden maneuvers. Therefore, the measurements of swimming angle are very important in the fisheries field and especially fisheries acoustics. Such information can be used to calculate the average TS of individual fish. Kang *et al*. (2005) suggested that to minimize error in converting volume backscattering strength into biomass, the influence of swimming angle on TS must be verified. Due to a small change in orientation of the fish relative to the echo sounder's transducer surface, it may drastically change the TS at each frequency used. For a downward looking transducer, operating at geometric scattering frequencies, swimming angle is generally considered the primary influence on fish TS for swimblanderless fish. As dorsal average TS is very sensitive to changes in swimming angle (Foote, 1980).

The echo energy from the target depends primarily on the differences in density between the reflecting organ and the water surrounding the fish. It does not matter whether the density of the reflecting organ is higher or lower than that of water (Simmonds and Maclennan, 2005). The acoustic backscattering characteristic of the fish target is central to the estimates processes and the common measure of that characteristic is the backscattering cross section (Thomas *et al*., 2002).

In acoustic abundance estimates, the average TS or average backscattering cross section is needed when converting integrated echo energy to biomass (MacLennan and Simmonds, 1992). To convert acoustic energy into estimates of fish biomass, TS of a representative fish mush be known. Hence, identification of TS value has been one of the most important efforts in the fisheries acoustics community. In fish the swimbladder organ contributes 90 to 95% more to the acoustic scatter of TS (Foote, 1980). However, little work has been done on the acoustic properties of swimbladderless fish and in particular their TS. Since sandeel do not have swimbladder, there is no dominating reflector inside the target, thus the TS value could be influenced by their swimming angle, fish sizes and frequency of the transducer.

For practical purposes, it is important to measure the TS by experimental and theoretical methods (Simmonds and MacLennan, 2005). The results of TS measurements have been reported in many papers especially for sandeel species (e.g. Armstrong, 1986; Simmonds and MacLennan, 2005; Thomas *et al*., 2002; Yasuma *et al*., 2009; Kubilius and Ona, 2012). However, the resulted TS values showed larger differences and are still unclear.

To obtain more precise TS of Japanese sandeel, consequently, the present study employed the theoretical TS estimates by using the distorted-wave born approximation (DWBA) model (Chu *et al*., 1993; Stanton *et al*., 1998; Stanton and Chu, 2000; and McGehee *et al*., 1998). The DWBA model was originally develop for studies of zooplankton. However, it has also been applied to swimbladderless fish such as Atlantic mackerel (Groska *et al*., 2005) and Japanese anchovy (Ito *et al*., 2011). Beside the theoretical TS, the measured TS of sandeel using experimental water tank was conducted with the suspension of target and used split beam echosounder as popular representatives of the controlled experiments (Sawada *et al*., 1999).

In order to deduce quantitative information about fish target by using an echosounder, vertically oriented transducer is recommended, hence the information of dorsal aspect of fish TS is required because; (1) in some cases a target detected with forward-looking sonar can be classified with an echosounder, and (2) the only acoustic fish detection equipment on many commercial fishing vessels is an echosounder (Love, 1970).

Acoustic technology is recognized as a reliable monitoring method for estimates of fish stock status in the field. Thus, the ability of TS understanding caused by a fish becomes a priority. It was the main motivation of this study. More than that, knowledge of the acoustic TS of a fish is needed to enable the performance of the present and future sonar equipments to be determined for a fish target.

The objectives of the present study were to measure the TS of Japanese sandeel by predictions calculation using the DWBA models with different swimming angles, giving their TS as functions of swimming orientation. The swimming angle distribution of larger sandeel was clarified by observing the swimming behavior of sandeel in an experimental water tank. Validation of theoretical TS results was compared with the measured TS results under fully controlled conditions in an indoor water tank for, *ex-situ* experiments. These works are basic information and useful in fisheries acoustics community that can be significantly improve the precision and accuracy of the sandeel abundance estimates and distribution through acoustic surveys in the field.

II.2 Materials and methods

2.1 Measurements of swimming angle

Swimming angle data was collected from free-swimming sandeel from 20 to 21 July 2011, at the Wakkanai Fisheries Research Institute, Hokkaido Research Organization, Japan. The experiment was conducted in a rectangular tank (2.05 m × 2.0 m × 1.2 m) (Figure 2.1), with no sand at the bottom to prevent the fish from burrowing. The tank was filled with seawater without any water flow. The experiment was carried out under uniform condition such as light intensity and water temperature. Temperature and light intensity were measured by using digital temperature and hand flux meter, respectively. Temperature in experimental tank during observation was in ranges of 16.2 –16.4 ºC and light intensity was measured at 275 lx at the water surface.

Adult sandeel were maintained in a water tank that blocked natural light during acclimatization periods before being used in the experiment. Experiments were conducted during the daytime when the sandeel swimming behavior is active. In contrast, they stayed in the tank bottom during the nighttime.

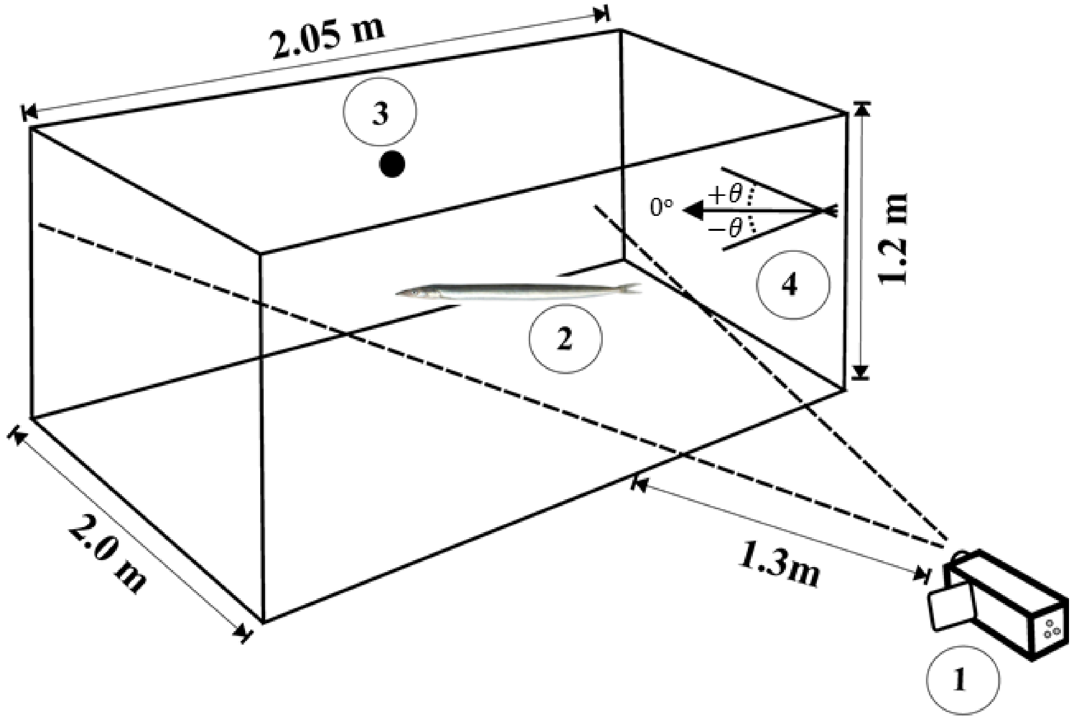

Figure 2.1 Schematic diagram of the experimental tank; (1) camera, (2) specimen, (3) reference point, and (4) the swimming angles, respectively. The camera was installed at the front of the experiment tank.

The swimming angle of sandeel was recorded using a digital HD video camera recorder (HDR-SR12; Sony, Tokyo, Japan). A video camera was set up in front of the experimental tank (Figure 2.1). Fish samples were allowed to acclimatize for at least 10 minutes before video camera recording were done.

Twenty live fish ranging from approximately 21.0 to 28.7 cm in standard length (*SL*) were used to measure the swimming angle. Fish density was assumed as a representative of the natural conditions for a sandeel school in the field during daytime.

Swimming behaviors of fish were recorded in two days. For first day, observation time started at 13:55 am until 18:00 pm and second day from 08:50 am until 15:00 pm, respectively. Measurements were conducted while fish swam slightly above the bottom because of the limiting tank windows.

The obtained video recordings were converted to images at 30 second intervals during the experimental periods. Furthermore, the images were analyzed by using image editing software (SCM Measure; Moritex, Tokyo). In the image analysis, the centerline of a fish being measured could not bend. Positive angles were for fish with *heads-up* and negative angles were for *heads-down* fish (Ito *et al.*, 2011). The swimming angle distribution from the images was required to calculate the averaged TS according to Foote (1980). But prior, the information of swimming angle distribution was normalized using probability density function (PDF).

2.2 Measurements of target strength

To estimate the TS of sandeel, a key quantity in many investigations and also a prime factor for stock assessment by acoustic techniques, precision measurement of the

TS of fish species is needed in order to estimate fish abundance. Thus two techniques of measurements were applied namely; (1) numeric or theoretical backscattering model based on the fish anatomy using deformed cylinder model, and (2) laboratory measurements using an indoor tank experiments in which the specimen was dead fish (Figures 2.2 & 2.3).

2.2.1 Theoretical target strength

The theoretical model was applied to estimate TS variation as a function of fish swimming angle. The theoretical TS of sandeel were estimated using distorted-wave born approximation (DWBA) models. Scattering models based on a simplified DWBA method were estimated with two frequencies responses (38 and 120 kHz) related to fish orientation from -90^{o} to $+90^{o}$ at 1^{o} intervals (swimming angle: *head-down*, *head-up* position) at a dorsal aspect. The images of fish samples were digitized based on the outline of the body shape to obtain the position vector along the body axis and the cross-sectional radius of the cylinder from each image of specimens on which the body-mass and sound speed was measured (Chu *et al*., 1993; Stanton *et al*., 1998; Groska *et al*., 2005) (Figure 2.2).

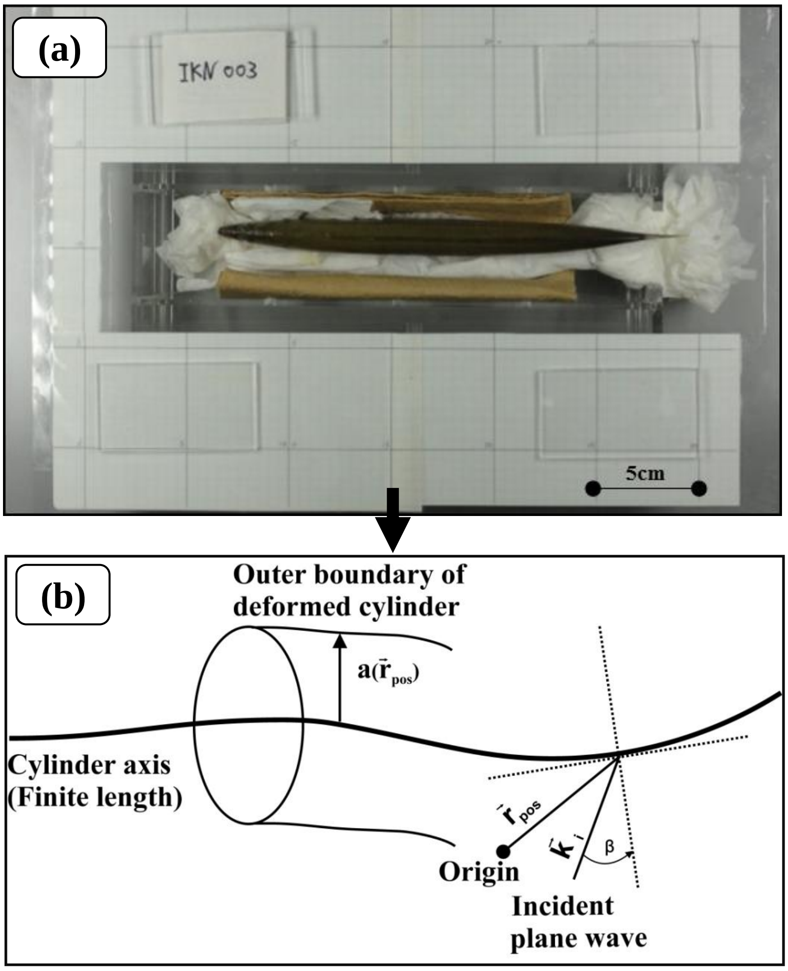

Figure 2.2 The principle of the theoretical model; (a) image of fish on dorsal aspect, and (b) deformed finite cylinder and scattering geometry.

2.2.2 Experimental target strength

Laboratory measurements were carried out to obtain the measured TS of sandeel from 23 to 25 January 2012, respectively, at National Research Institute of Fisheries Engineering, Fisheries Research Agency, Ibaraki, Japan. The experiments were conducted in an indoor tank (10 m × 15 m × 10 m) (Figure 2.3). The tank was filled with freshwater although sandeel is marine fish. In this case, it was not possible to use seawater for the present experiments. Only one fish was observed at a time and it was positioned near to the surface for ease of access. An echosounder unit (Table 2.1), split beam transducer set on the bottom of the tank operating at 38 kHz was employed to measure the TS of the individual sandeel.

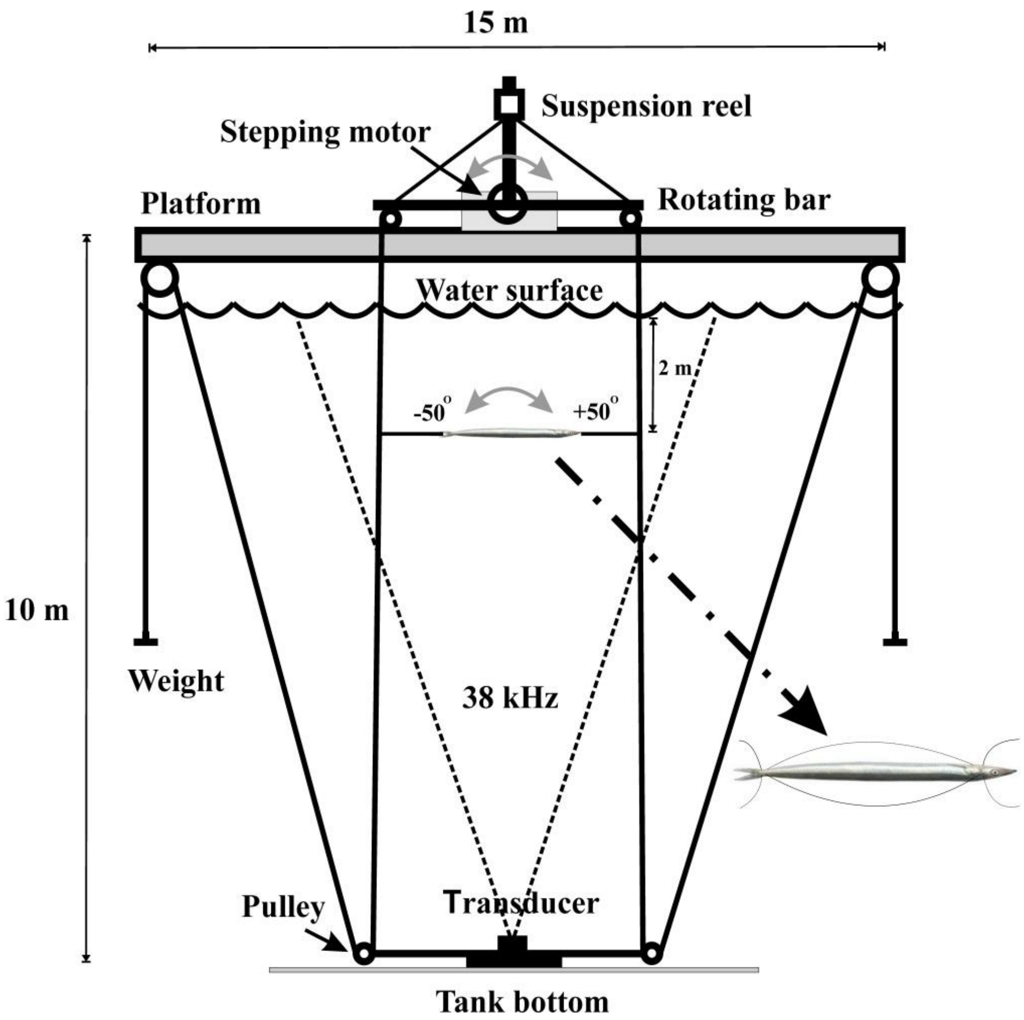

Figure 2.3 The experimental set up. The target position was suspended and changing the swimming angle controlled by the rotating system.

Table 2.1 Technical specifications of echosounder that were used in the indoor tank for experimental target strength measurements.

Parameter	Specification
Echosounder type	KFC 3000, Kaijo
Transmission Frequency (kHz)	38
Transmission power (W)	5000
Sound speed (m s^{-1})	1449.30
Tilt angle (deg)	–50 to +50
Ss (minutes)	40
Pulse length (ms)	0.6
Ping intervals (s)	1
Delay (ms)	10
TVG function (log *R*)	40
3dB beam angle	7.10

Calibration was conducted before and after the TS measurements using a tungsten carbide sphere (38.1 mm diameter) that was suspended at about the similar position with the specimen at around 2 m in the water tank (Foote *et al*., 1987) or around 7 m from the surface of transducer. According to Henderson and Horne (2007) depth range ensured that fish was out of the transducer near fields for the frequency at 38 kHz of 1.09 m. The references TS value of the sphere was adjusted according to water temperature of 10.30 ^{o}C and sound speed of 1449.30 ms^{-1} through in water tank at the time of the experiments.

The fish suspension and rotation system followed that of Sawada *et al*. (1997; 2002) and Yasuma *et al*. (2006), with several modifications (Figure 2.3). The experiment was performed on dead fish, which was mounted in a fixed position to ensure that the body does not move, expect when the wire length were adjusted. The fish were kept in an upside down position in the central part of the sound beam by a frame of thin nylon gut. As the fish were lowered beneath the water surface, in which care was taken to remove all air bubbles because of observed air bubbles when the specimens are exposed to air.

The specimens were placed at ranges from the transmitting and receiving transducers that were chosen to be great enough so that it was always in the far field of transducers and within on-axis points of the beam, but short enough so that there would no interference caused by reflection from the frame or boundaries. Very small hooks were attached to the head and tail, and thin horizontal lines positioned the specimen between two vertical lines in the suspension methods. The ends of two lines were attached to the rotating bar and the other sides were attached to small weights.

A computer by one degree increments was used to control stepping motor rotates bar. To measure directivity patterns of TS in the dorsal aspect, the swimming angle of the specimen was control from -50^{o} to $+50^{o}$ (*head-down* to *head-up*) by 1 degree increments and measurements were done automatically from the start to the end. Each measurement continued for 40 minutes. In all the experiments, single-detection data (TS) was saved at ping intervals of 1.0 second. Furthermore correlated with a specific swimming angle of individual sandeel, the TS data were collected. The acoustic data were analyzed and TS calculated from each echoes.

2.3. Data analysis

2.3.1. Swimming angle

The swimming angle distribution from the images was used to calculate the average TS (TS_{avg}) according to Foote (1980). This was done after the normalization of the distribution of swimming angle using a probability density function (PDF), which can be formulated as

$$PDF\,(a \le x \le b) = \int_a^b f(x)\,dx \qquad (2.1)$$

where the *PDF* of *x* is a function *f* (*x*). It is expressed in terms of an integral between two points, $a = -36.09^{\circ}$ and $b = +55.24^{\circ}$ as the minimum and maximum values, respectively, of the swimming angle.

2.3.2. Theoretical target strength

To compute the theoretical TS, the sound speed (*h*) and density contrast (*g*) were assumed to be constant throughout the fish body. Values for these were taken from

Yasuma *et al*. (2009) for adult sandeel: h = 1.018, g = 1.032 as these values were used. The DWBA model is composed of the following volume integral that can be written as

$$f_{bs} = \int_{\vec{r}_{pos}} \frac{k_{sw}^2 a_c}{4k_{animal}} \left(\frac{1+h^2}{gh^2} - 2 \right) \times e^{2ik_{animal}\vec{r}_{pos}} \frac{J_1(2k_{animal} a_c \cos\beta_{tilt})}{\cos\beta_{tilt}} + \left| d\vec{r}_{pos} \right| \quad 2.2)$$

where f_{bs} is the complex backscattering amplitude, the relation backscattering cross-section σ_{bs} is given by the TS is calculated by $\sigma_{bs} = \left| f_{bs} \right|^2$, $\vec{r}_{pos}$ is the position vector along the body axis, k is the wave number shown by $k = 2\pi/\lambda$ where λ is acoustic wavelength, subscript *sw* refers to the surrounding seawater and subscript animal refers to sandeel, J_1 is a Bessel function of the first kind of order 1, a_c is the cross-sectional radius of the cylinder and β_{tilt} is the local angle between the cylinder axis and the incident wave (McGehee *et al*., 1998; Matsukura *et al*., 2009; Ito *et al*., 2011). In this study, the 72 specimens were digitized to obtain of $\vec{r}_{pos}$ and a_c from each image of specimens on which the body-mass and sound speed were measured (Chu *et al*., 1993; Stanton *et al*., 1998; Groska *et al*., 2005) (Figure 2.2). This equation was implemented numerically using Matlab (version 7.9.0.529; MathWorks, Natick, MA, USA) codes to estimate the TS of deformed cylinder (McGehee *et al*., 1998) with some modifications (Appendix 1).

Using this result, the mean and standard deviation for the swimming angle distribution was substituted into theoretical scattering model. The averaged TS were calculated in linear domain from the average of the backscattering cross-sections, and not from the average of the individual TS (Simmonds and MacLennan, 2005). Furthermore, the TS of individual fish were used to obtain two TS measurements: the maximum dorsal aspect TS (TS_{max}) and the average dorsal aspect TS (TS_{avg}). Maximum TS was easily obtained from the measured TS functions. Average TS was derived from the Equations (2.3) and (2.4) (Foote, 1980; Ito *et al*., 2011).

$$\sigma_{avg} = \int_{-\pi/2}^{\pi/2} \sigma(\theta) f(\theta) d\theta \tag{2.3}$$

$$TS_{avg} = 10 \log \sigma_{avg} \tag{2.4}$$

where θ is defined as swimming angle, $f(\theta)$ was assumed to be a truncated normal distribution function. The truncations were made at $\bar{\theta} - 3S_\theta$ and $\bar{\theta} + 3S_\theta$, where $\bar{\theta}$ and S_θ that denoted the mean and standard deviation of the swimming angle, respectively.

2.3.3 Experimental target strength

The dorsal aspect TS of sandeel was measured using large water tank in the laboratory. During the experiments, the recorded data consisting of corresponding values of voltage and swimming angle were transferred. The calculations of TS were done by computer in which the Equation 2.5 was applied

$$TS = 20 \log_{10}\left(\frac{V}{Vr}\right) + TSr \tag{2.5}$$

where V is the observed voltage, V_r is the voltage from the reference sphere and TS_r is target strength of the reference sphere in decibel (dB).

The resultant theoretical TS was made from the relationship between TS and fish length following Love (1971); Simmonds and Maclennan (2005) expressed as

$$TS = m\,10\log_{10} SL + b \tag{2.6}$$

where m and b are species-specific slopes and intercepts, and SL is the standard length of the fish, which was determined from the fish samples. For each regression, the slope, intercept, R^2, and p-value were calculated (Simmonds and Maclennan, 2005; Henderson and Horne, 2007).

II.3 Results

3.1 Swimming angle

To calculate the swimming angle of sandeel, 1,197 images collected from approximately 11 hours of video records were used. Because of the poor image quality caused by the target, it was not perpendicular to the camera's focal axis and the centerline of a fish that was bending. Therefore, further analysis was possible for only 95 ideal images allowable for analysis (Figures 2.4 & 2.5). Figure 2.4 shows the swimming angles or vertical orientation of sandeel in the range of -36.09^{o} to $+55.24^{o}$ and swimming angle distribution in percentages frequency (Figure 2.5).

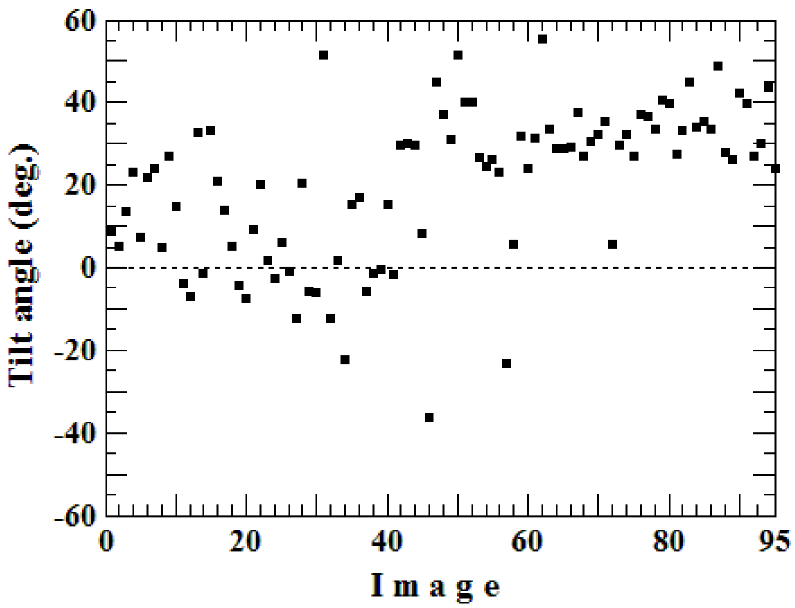

Figure 2.4 Swimming angle distributions of Japanese sandeel that were obtained from *ex-situ* measurement in the experimental water tank. The data were obtained from live sandeel.

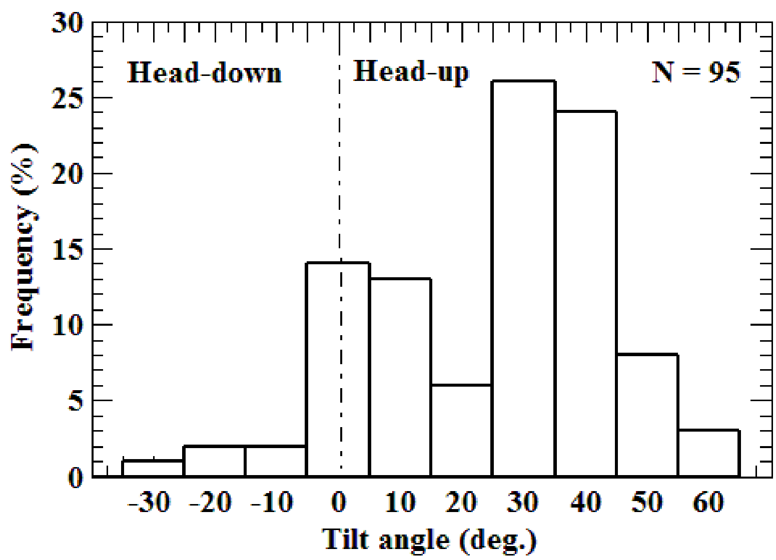

Figure 2.5 Swimming angle frequency distributions of the Japanese sandeel obtained from *ex-situ* measurements in an experimental tank. The data were obtained from live fish. Number of images is also shown.

Overall the swimming angle tended to be positive, i.e. sandeel was in a *head-up* position for approximately 81.1% of the observations. The mean and standard deviation of swimming angle were 20.38 ± 18.5^{o}, respectively. The numbers of swimming orientation measurements made at negative swimming angles were relatively low. This was because in the normal condition, without swimming, the swimming angle had a positive value.

3.2 Target strength of Japanese sandeel

3.2.1 Theoretical target strength

A total of 72 fishes were used to calculate the acoustic backscatter model from the dorsal aspect of fish. Figure 2.6 depicts the typical examples of TS as a function of swimming angle properties at 38 and 120 kHz, the frequencies commonly used in acoustic fish abundance and distribution estimation, which were calculated by DWBA models. The varied TS in relation with changes of swimming angle showed peaks at around 0^{o} at both frequencies. The TS values at both frequencies of smaller fish length were consistent near the main lobe. However, the value of TS at 38 kHz was higher than those at 120 kHz for larger fish length. The values of TS_{max} and the TS_{avg} as functions of fish standard length on logarithmic scale at the both frequencies are plotted in Figure 2.7.

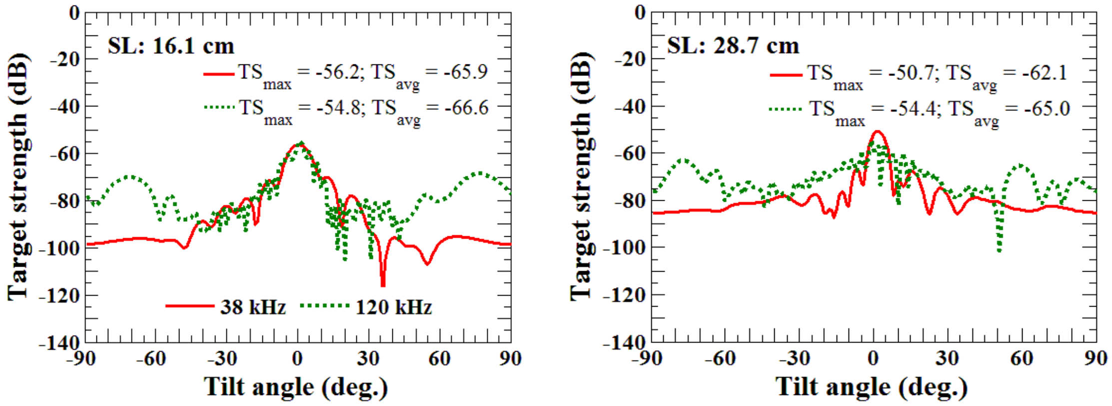

Figure 2.6 Theoretical TS as function of swimming angle, estimated by DWBA model at 38 kHz (*bold lines*) and 120 kHz (*cross marks*), respectively.

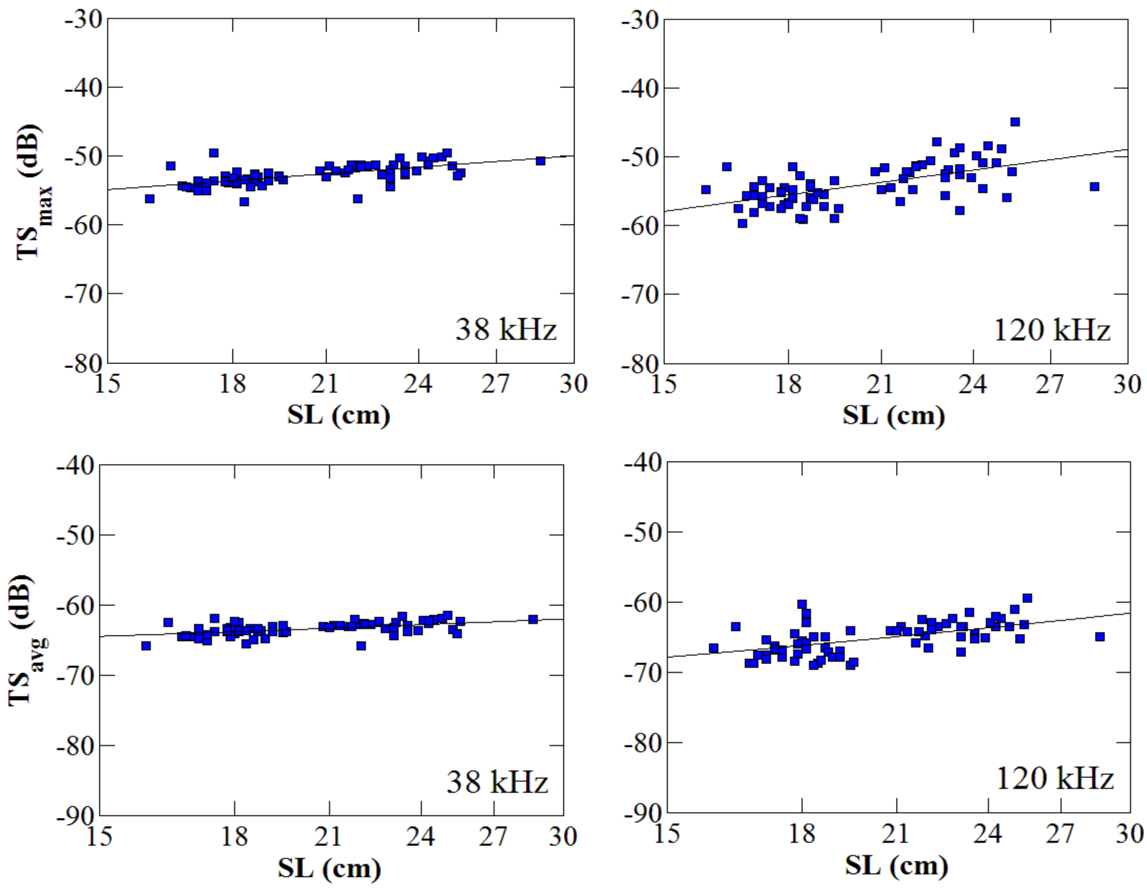

Figure 2.7 The relationship between TS (TS_{max}, TS_{avg}) and linear values of standard length (cm) at 38 and 120 kHz, n = 72.

In most cases, the TS_{avg} in adult sandeel, was higher at 38 kHz than 120 kHz. The best fit regression lines were $TS_{38kHz} = 8.2\log_{10}SL - 74.1$ and $TS_{120kHz} = 20.9\log_{10}SL - 92.6$, respectively. The obtained results showed a little discrepancy for both frequencies ($\Delta TS = 120_{kHz} - 38_{kHz}$) i.e. were –1.3 dB for the maximum TS, and –1.8 dB for the averaged TS in 72 samples. Equations of regression lines for both frequencies are given in Table 2.2.

Table 2.2 Equations for linear regression in Figure 2.7 and target strength at each frequency.

Target strength	**Frequency (kHz)**			
	38		**120**	
	Range	TS-length equation (R^2; *p*-value)	Range	TS-length equation (R^2; *p*-value)
TS_{max} (dB)	–56.7 to –49.5	$TS_{max} = 16.3 \log_{10} SL - 74.1$ (0.40; < 0.001)	–59.7 to –44.9	$TS_{max} = 29.9 \log_{10} SL - 93.3$ (0.36; < 0.001)
TS_{avg} (dB)	–65.9 to –61.5	$TS_{avg} = 8.2 \log_{10} SL - 74.2$ (0.25; < 0.001)	–69.1 to –59.5	$TS_{avg} = 20.9 \log_{10} SL - 92.6$ (0.30; < 0.001)

3.2.2 Experimental target strength

It is difficult to get the TS of fish species for the wide range of swimming angle in the TS measurement (*in-situ*). On the contrary, fish species, length, height, and weight are already known in the case of the controlled methods (*ex-situ*). The laboratory experiment was conducted (Figure 2.3) to confirm the appropriateness of the resultant TS by DWBA models.

The water tank experiment had 4 sandeel specimens that were measured. The results demonstrated the TS variation between theory and laboratory measurements at 38 kHz (Figure 2.8). The resultant TS patterns of laboratory measurements were tend to be corresponding with theoretical TS, especially in the regions of the main lobe. However, the theoretical values were a lower on the side lobes, which were the number of the directivity-pattern lobes and the width of an individual lobe as it increases. Maximum TS values at 38 kHz were measured for both experiments of the theoretical and ranged from –50.2 to –49.5 dB and mean of –50.0 dB. Meanwhile for the experimental tank, it was noted in the range values of –48.0 to –46.0 dB and mean value of –46.8 dB. Whereas for the averaged TS, the obtained TS values were in the ranges of –62.2 to –61.5 dB and mean of –61.8 dB for the theoretical TS, and the measured TS values was in the ranges of –66.4 to –61.5 dB with mean of –65.0 dB. Additionally, it seemed that the swimming angles of fish have greatest contribution on TS variability.

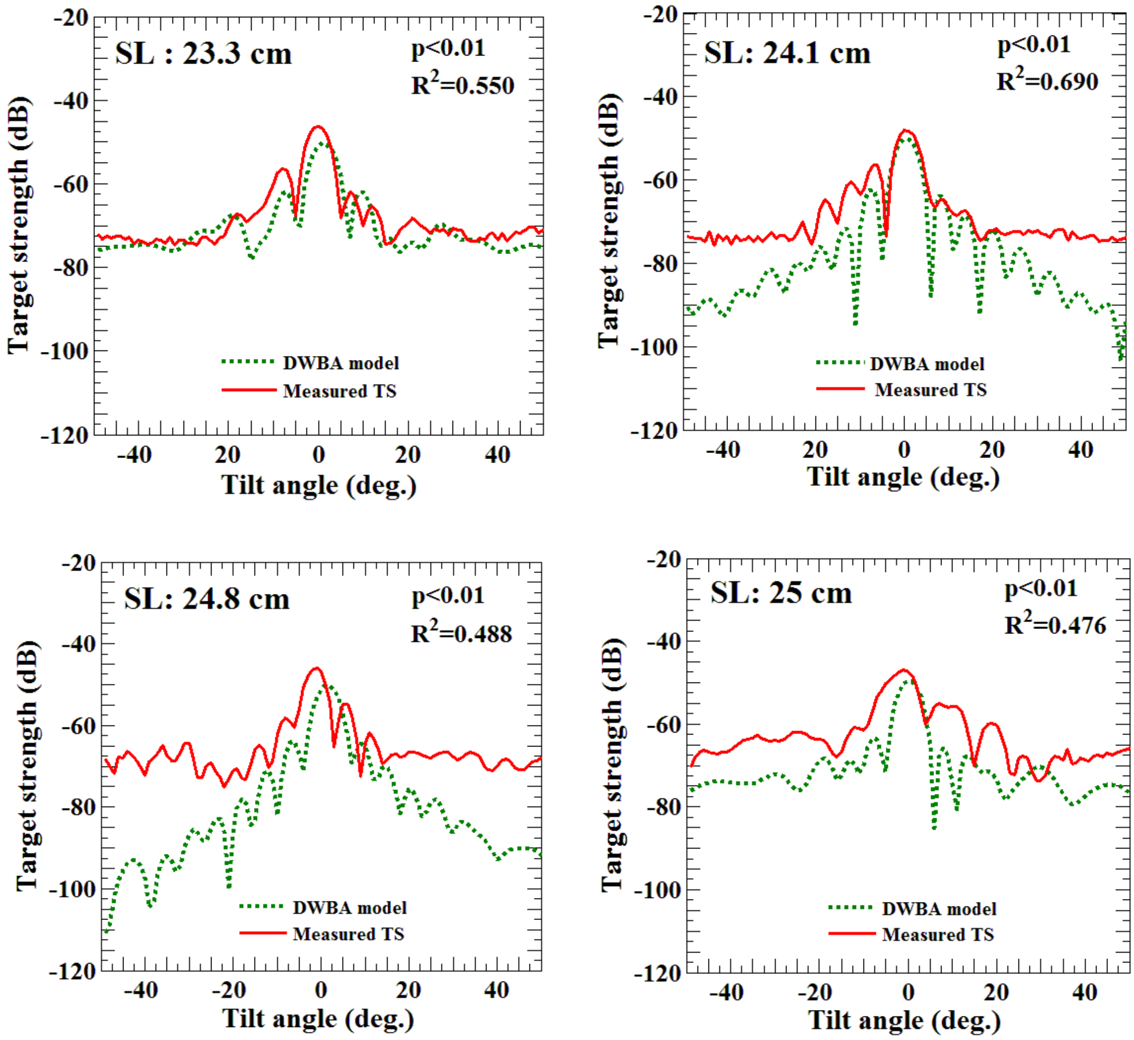

Figure 2.8 Typical variations in the TS as function of swimming angle that were estimated by the distorted-wave born approximation (DWBA) model (*solid lines*) and experimental (*dotted lines*) at 38 kHz, respectively. Fish size is noted for each.

II.4 Discussion

4.1 Swimming angle

Swimming angle for swimbladderless fish is the main factor influencing the accuracy of TS. Hence, TS estimates should ideally include the swimming angle distribution if possible (Ona, 2001). During the observations, the swimming angle varied depending on the activities of the sandeel. Figure 2.5 shows the bimodal distribution of the swimming angle. It may have occurred due to small sample size in the measurements (n=95). If more images were analyzed, the result might have become a normal distribution as presented by Kubilius and Ona (2012) who measured the swimming angle of lesser sandeel (*A. marinus*) in small on-board fish tank and found a monomodal distribution of the swimming angle (n=534). The current study was used a monomodal distribution that was normalized by PDF to calculate the average target strength pattern as shown in the results herein. Measurements of swimming angle are required for the accurate estimates of the TS of sandeel. It had larger effect on TS variation than fish length and frequencies responses, and the variation with angle changes was quite large (Hasen and Horne, 2003).

Sandeel are generally negatively buoyant. Consequently, they must swim with some positive body tilt to maintain altitude (Kubilius and Ona, 2012). In line with Ona (2001), who noted that negatively buoyant fish often swim with a slight *head-up* posture, the present study found that the mean swimming angle distribution of Japanese sandeel was 20.38^{o} (S.D.= 18.5^{o}), which was slightly different from the results presented by Kubilius and Ona (2012) for the lesser sandeel ($23.7^{o} \pm 18.2^{o}$) who investigated the TS and swimming angle distribution in a water tank experiment by using an echosounder (acoustic data) at 200 kHz and video camera (swimming angle data). This difference probably resulted from variations between the species, experimental design, and environmental conditions during the measurements.

Even though fish orientation does not explain all of the variation observed in TS, however, swimming angle of swimbladderless fish is the most important factor influencing TS, and large variations in TS can be induced by changing the swimming angle (Simmonds and Maclennan, 2005). Because acoustic scattering depends strongly upon swimming angle, knowledge of its distribution will help to interpret acoustic survey data (Stanton *et al.*, 2003). In the field, a small change in fish swimming angle relative to the transducer' surface can have dramatic effects on the backscattering cross section (Nakken and Olsen, 1977; Ona, 1984).

The Figure 2.6 showed that swimming angle had a large effect on TS variation than fish length, and frequencies responses. These results will be strengthening the previous study that the TS values for a swimbladderless fish is dependent on swimming angle (Hasen and Horne, 2003), and the variation with angle changes is quite large.

This work for suggests further *in-situ* measurements to provide more precise information regarding the swimming angle of Japanese sandeel. Probably, the most important sources of error when calculating the swimming angle calculation were generated by the artificial environment of the experimental tank, including its rectangular form and limited size, and also the need to simulate natural conditions in the tank such as water temperature, light intensity, and water flows.

4.2 Target strength

It is not possible to obtain valid TS distributions from within dense fish schools using acoustic data in the field. This could be because there is always more than one fish inside the sampling volume which the classic problems of fisheries acoustics. Measurements of target and characters of the echoes received from fish, *in-situ* measurements, will give a reliable guide to the size of fish and possibly later, an indication of at least gross differences between various types of fish (Haslett, 1969). In general, the amounts of sound reflected by the fish are low in head and tail aspects, high near broadside aspect and intermediate in dorsal aspect. The resulted TS were for better understanding the true TS of Japanese sandeel to improve the acoustic data interpretation that derived from the acoustic survey. These are preliminary results and could be valuable in improving the accuracy of sandeel biomass estimates.

Target strength estimates of fish in a wide variety of experiments and measurements have been conducted because of its importance and required to analyze acoustic data and furthermore convert to fish biomass. On the contrary, there is lack of information about TS of larger sandeel. Theoretical model applied for estimating TS has several merits, *inter alia*, they can be estimated both for the frequency characteristics of backscatter and the backscatter pattern related to fish orientation (Yasuma *et al*., 2009). The present study is the fundamental examination to estimate the theoretical TS of adult sandeel (Figure 2.6; Table 2.2).

The TS function on theoretical backscattering model at 38 kHz (Figure 2.6) is more fluctuating on the side lobe. However, the TS values for both frequencies at 38 and 120 kHz are tended to be consistent on the near main lobe especially for small fish length. The discripancy in the results were not only due to frequencies responses used in the theoretical model, but also caused by fish length that seemed to have a contribution in the variability of TS. Therefore, fish length should be considered in TS measurements. More reliable TS information measured *in-situ* measurement is desired, yet it is the most difficult way of measuring TS of a fish in this period.

The slope at 120 kHz was close to 20 (Figure 2.7; Table 2.2), suggesting that acoustic backscattering strength was proportional to the square of body length using a least-squares linear regression fitted between TS and log fish length. *Vice versa*, this value was smaller at 38 kHz, suggesting that backscattering strength tends to be stable with the change of body length. Based on these results, one possible reason is the body length of fish samples that were used in narrow ranges. However, the fish lengths are representative of the sandeel stock in the northern coast of Hokkaido.

The results of TS-length relationship obtained for individual sandeel will be useful in the analysis of the averaged backscattering cross-section of sandeel schools. Due to the absence of a swimbladder which is the main acoustic feature of sandeel, modeling of TS can increase our knowledge of scattering from other swimbladderless fish.

It is difficult to get TS of fish species for the wide range of swimming angle in the *in-situ* measurements of TS. If the TS *in-situ* is measured, there are some short comings such as it is difficult to identify fish species and evaluate length of fish precisely (Sawada *et al*., 1997). Furthermore, signal to noise ratio (SNR) became small when fish swim at outer part of the main lobe of the beam. In addition, it is difficult to get TS of fish species for the wide range of swimming angle.

On the contrary, fish species, length, highest, and weight are already known in the case of the controlled methods. Kang *et al*. (2004) stated that the merits of the *ex-situ* method such as in the indoor tank is that species identification and fish sizes information of the sampled fish are quite clear. However, the disadvantage of this method is that the fish behavior is unnatural and occasionally it provides insufficient data. Henderson and Horne (2007) noted that backscatter models have been used in conjunction with *ex-situ* and *in-situ* measurements and in many cases have shown fair to excellent agreement between model prediction and empirical measurements.

There was good agreement between the experimental and theoretical TSs although the measured TSs were higher than those calculated from the theoretical measurements (Figure 2.8). Field measurements of TS tend to be higher compared to the maximum values estimated in laboratory (Sawada *et al*., 1997). Correlation coefficients of the resulted TSs at 38 kHz for both experiments are calculated to evaluate the goodness of fit between the theoretical and experimental TS values (Figure 2.8).

The laboratory measurement of the TS of individual sandeel was conducted with some limitations, which might lead to different results from accurate values in the natural condition. This could be because: (1) frozen specimens were used in the experiments, therefore, may cause significant changes in material conditions, such as tissue composition and water content (Yasuma *et al*., 2009); (2) target strength measured at constant temperature (± 10 ^{o}C); (3) sandeel TS measured in fresh water, which it is different with the real habitat in sea water. For this experiment assumed at this time that significant differences between *ex-situ* and *in-situ* conditions assumed did not occur.

Scantily information was available regarding the TS value of Japanese sandeel. The acoustic back-scattering properties of sandeel have been measured by some authors. Among them, Yasuma *et al.* (2009) reported their work for juvenile (3.4 –6.7 cm, n = 68) and adult fish (7.5–11.5 cm, n = 20) using liquid deformed cylinder (liquid DCM) models. They reported that TS of near dorsal aspect and tilt-averaged TS differed by up to 7 dB and the slope logarithm standard length (*SL*) of adult sandeel was close to 20. They summarized that TS-length regressions of *A. personatus* was TS = 20 $\log_{10}L$ – 89.2 at 38 kHz and TS = 20.7 $\log_{10}L$ – 92.1 at 120 kHz, respectively. On the other hand, TS-length equation of others sandeel species (*Ammodytes* sp) have been noted previously. Target strength of *A. hexapterus* was estimated by the equation: TS of = 20 $\log_{10}L$ – 93.7 at 38 kHz (Armstrong, 1986) and TS = $20\log_{10}L$–80.0 at 120 (Thomas *et al*., 2002). Recently, Kubilius and Ona (2012) proposed the TS-fish length relationship, *A. marinus,* as TS = $20\log_{10}L$–93.1 at 200 kHz. The findings as noted in Table 2.2 showed the large differences to the former. The reason for differences in TS values is unclear. Probably because the present work applied a different method to estimate TS values of adult sandeel and also considered the information of swimming angle distribution in TS calculation.

This work was the fundamental study to document the swimming angle of Japanese sandeel (*A. personatus*) in the experimental tank and in the application of the theoretical scattering model such as a DWBA model. Swimming angle for swimbladderless fish such as sandeel was the main factor influencing the accuracy of TS. Hence, the present study considered the swimming angle distribution in TS estimates. The results were successfully documented in which some factors affecting TS such as swimming angle, fish length, and frequency responses. The TS information of adult sandeel derived in this study could be meaningful to estimate the abundance and distribution of sandeel in the field using a quantitative echosounder, which it used on research vessels in Japan.

CHAPTER III. ESTIMATES OF DISTRIBUTION AND SANDEEL BIOMASS

III.1 Introduction

Sandeel species are known to be important forage fish, occupy middle tropic levels, as keystone species in the North Pacific Ocean ecosystem because they maintain the tropic ecosystem level which they make a link or compose an integral part of the ecosystem as both predator and prey, and also they are target species for commercial fisheries. However, little is known about the real abundance and distribution of Japanese sandeel, *A. personatus* in this area, especially in the northern coast of Hokkaido during summer periods.

The abundance and distribution estimates of sandeel form vital information to the fisheries management and also for the understanding of ecosystem dynamics. Hence, a more reliable stock assessment method is needed than the currently used conventional catch per unit effort (CPUE) methods.

Acoustical methods that are used to estimate fish abundance and distribution have widespread use in fisheries sciences today (MacLennan and Simmonds, 1992). Field surveys are expensive and time-consuming. Thus, it is important that the acoustic surveys are designed to maximize the information that can be obtained about the quantitative distribution of sandeel in the field.

Japanese sandeel is normally a schooling fish, exhibit semi-pelagic shoaling behavior and undertakes regular vertical migrations especially during daytime. Therefore, on the acoustic survey of biomass estimates, schools are usually identified and measured rather than individual fish themselves. Sandeel are difficult to detect as single targets in the field, because they do not have a gas-containing swimbladder that provides high acoustic reflection (Simmonds and MacLennan, 2005). Consequently, for smaller individuals, they are generally better detected at higher frequencies (Johnsen *et al*., 2009).

Biomass density calculations are attributed to the acoustic survey goal or are needed for total biomass or abundance calculations. In acoustic abundance estimates, the averaged TS value of fish is required when converting integrated energy to fish biomass (MacLennan and Simmonds, 1992). Hence, in advanced acoustic methods, it is essential to collect samples by sandeel capture devices such as trawling to determine the information of sandeel sizes in an area of interest and thereby giving fishery independent information on the characteristics of sandeel stock. While adopting the TS value for acoustic survey efforts, the fish biomass can be calculated. TS-length relationship for sandeel as noted previously in Chapter II was used to analyze acoustic data and furthermore, estimates of sandeel distribution and biomass.

Recently, results of monitoring acoustic survey have already been combined with geographic information system (GIS) tools to visualize information in the maps format. It is of the advantage that GIS users can overlay spatially corresponding ecological information and produce maps for further discussion in management decisions.

The aim of present study is to estimate the sandeel distribution and biomass off the northern coast of Hokkaido, for the period just before the main fishing season, in early summer using a quantitative echosounder. This information is useful for many purposes such as the estimation of sandeel stocks for sustainable resource and management of sandeel fishery.

III.2 Materials and Methods

2.1 Study area

The study area was located off Sarufutsu, northern coast of Hokkaido, Japan, (Figure 3.1). A random design with transect lines of acoustic surveys and measurements of oceanographic conditions were conducted annually during the summer in June 2010 and 2011 and July 2012, respectively. In July 2009, only acoustic data was available. This the time just before the main fishing season is undertaken for adult sandeel in this area. Data collections were conducted by Wakkanai Fisheries Research Institute, Hokkaido Research Organization, on board RV Hokuyo Maru (270 ton) during the daytime because in nighttime sandeel is buried in sea bottom thus inaccessible.

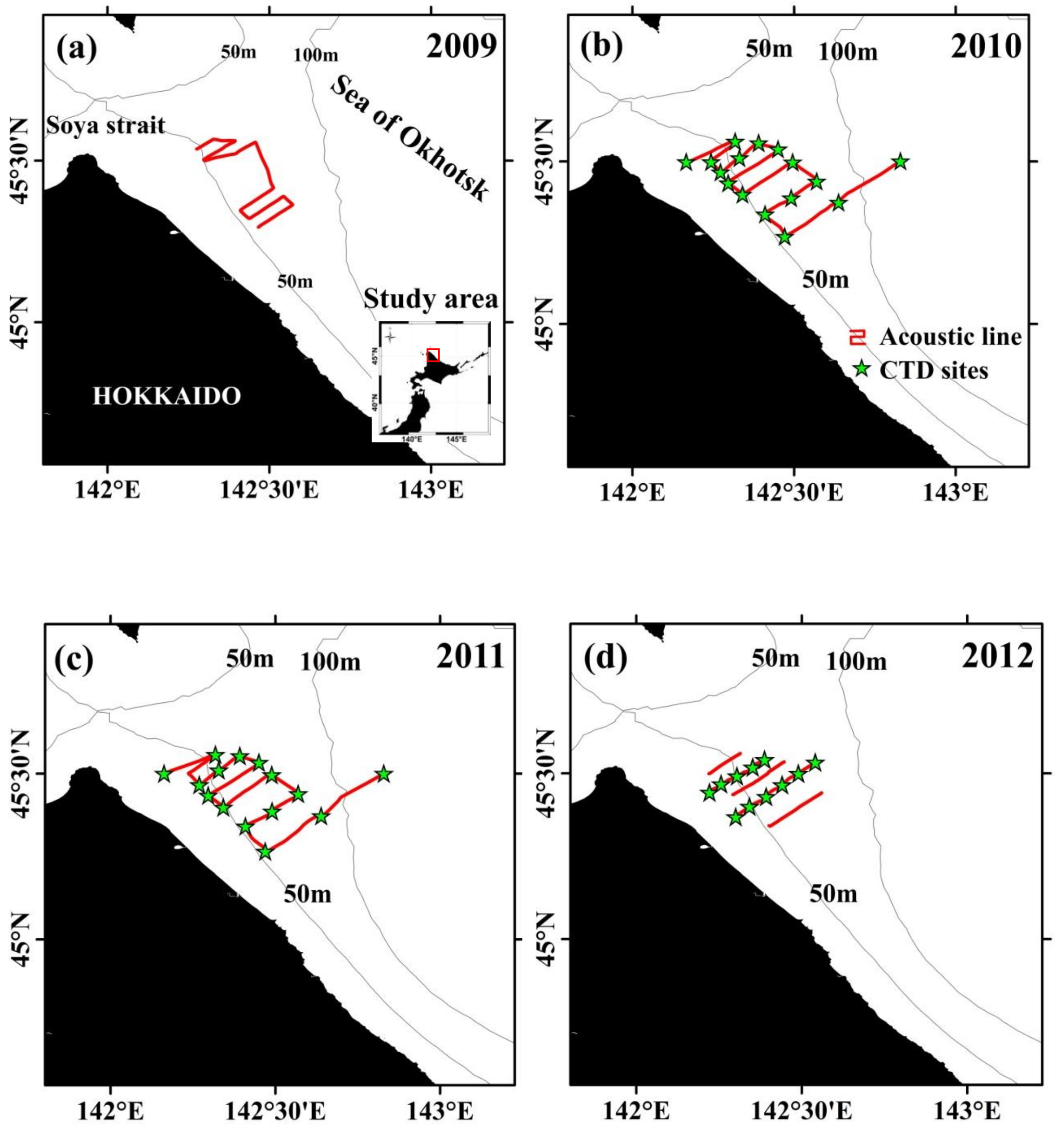

Figure 3.1 The study area. Survey designs of acoustic surveys were conducted; (a) 2009, (b) 2010, (c) 2011 and (d) 2012. CTD sites are also shown.

2.2 Data collection

2.2.1 Acoustic data

The acoustic data were collected using a quantitative echosounder (EK60, SIMRAD, Norway) operating at 38 and 120 kHz using split-beam transducer mounted on the vessel's hull. The vessel speed was approximately 3 to 3.5 knots in the time ranges of 30 to 60 minutes during acoustic surveys. The transmit power was set at 2000 watts (38 kHz) and 500 watts (120 kHz) and pulse length was set at 1.024 ms for both frequencies (Table 3.1).

Table 3.1 Technical specifications of echosounder that were used in monitoring of acoustic surveys.

Parameter	Specification	
Echo sounder type	EK 60, SIMRAD	
Transmission frequency (kHz)	38	120
Transmission power (W)	2000	500
Absorption coeff. (dB/m)	0.0334390	0.0334390
Sound speed (m s^{-1})	1476.71	1476.71
Pulse length (ms)	1.024	1.024
TVG function (log *R*)	20	20
Transducer gain (dB)	25.08	26.61
Sa correction (dB)	–0.81	–0.31
3dB beam angle	7.10	7.10

Source: acoustic data in 2010.

Calibration of echosounder was carried out using the copper sphere technique as described in the EK60 online manual based on Foote *et al.* (1987) prior to acoustic survey. Otter trawling (local commercial fisheries) as a sampling gear was used to identify species composition directly from acoustic back scatterings recorded during acoustic survey.

The acoustic data were obtained by continuous recordings while cruising; however, the oceanographic factors such as temperature and salinity in the depth ranges were only available from the CTD stations. It would be discussed in next chapter. Acoustic data were analyzed using the software of Echoview version 4.90 (Myriax Software Pty, Ltd).

2.2.2 Otter trawling catches data

Fish sizes information is ideally determined by fishing, but it is not easy to sample the same fish that have been observed by the acoustic instruments. Hence, fish samples of adult sandeel were obtained from otter trawling catches, which operated in the study area and which corresponded with the time of acoustic surveys. Information on the size of sandeel in standard length is required in acoustics data analysis.

2.3 Data analysis

2.3.1 Sandeel identification

The acoustic data was collected from the annual acoustic surveys. The surveys were carried out during daytime when the sandeel schools were migrating up from the sea bottom and feeding on zooplankton in the water column. Then, the obtained acoustic data were post processed using Echoview software.

Visual scrutiny of echogram was important part of fish biomass estimates analysis (Figures 3.2 & 3.3). The constituent of sandeel schools echo traces were done based on visual interpretation or scrutiny of echogram by using two-frequencies echoes (38 and 120 kHz). The study also referred to prior studies about the morphological echo traces of sandeel (e.g. Mosteiro *et al*., 2004; Simmonds and MacLennan, 2005; Mackinson and Kooij, 2006). After that, the echo traces of sandeel schools were hand-picked. In the algorithm of echoview software, the range bitmap data were arranged in different range values based on the size of trawling catches by combined the ping rate in interval ranged of 3. Further, the volume back scattering strength (SV) difference between 38 and 120 kHz was applied to differentiate the back scatters of sandeel and another targets.

The typical examples of sandeel echo traces and volume backscattering strength (SV) examples were as given in Figures 3.2 & 3.3, respectively. The exclusion zones were set for both the surface at 3 m depth and the bottom of 0.5 m as dead zone. The threshold of SV values in the range of –75 to –60 dB was applied to filter ambient noise and to separate the unwanted target such as other non-fish targets and plankton.

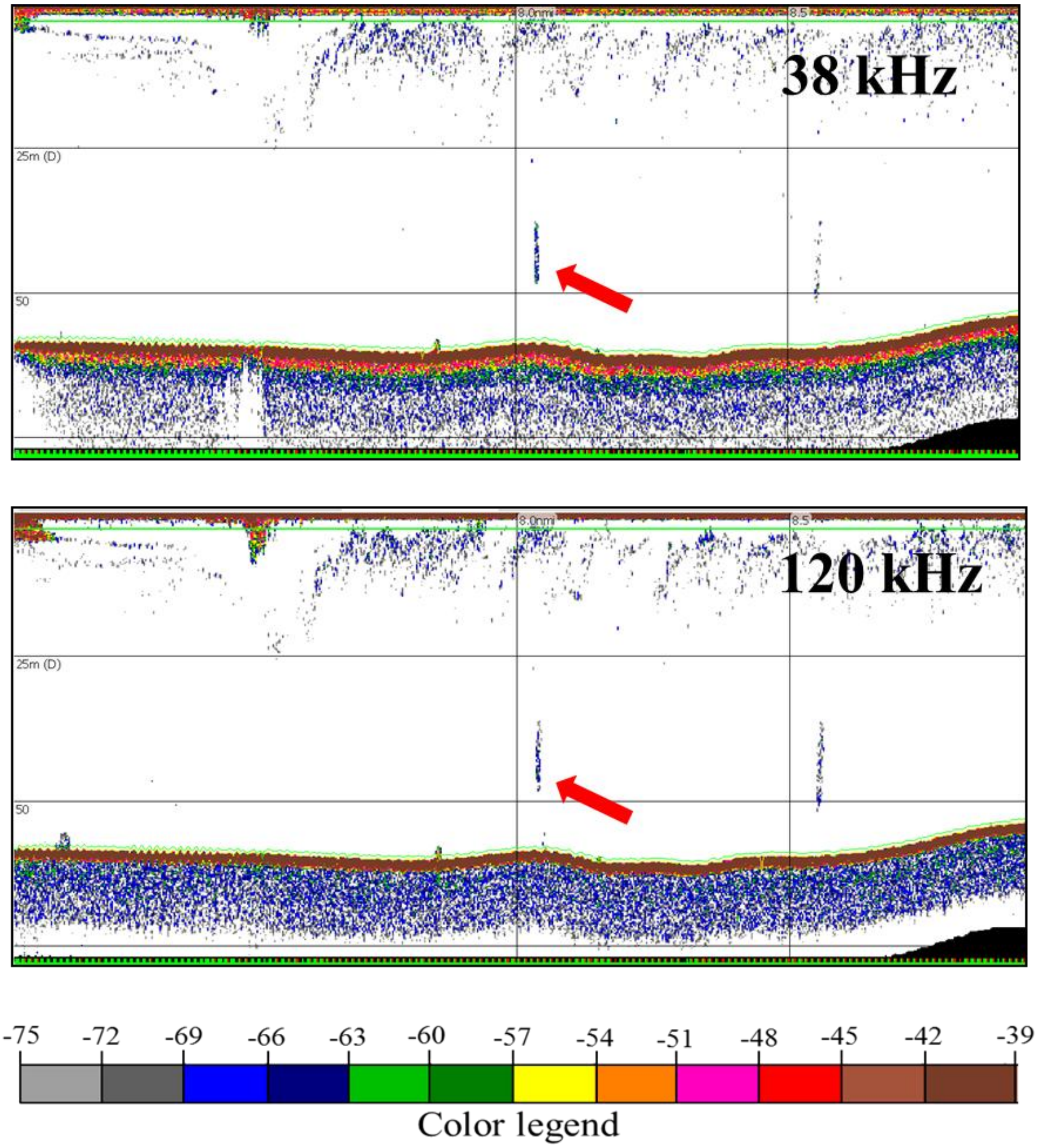

Figure 3.2 An example of echo traces of the Japanese sandeel schools (shown by red arrows) on the echogram; 38 kHz (*upper*) and 120 kHz (*lower*). Acoustic survey provided data such as latitude, longitude, bottom depth, and also fish density.

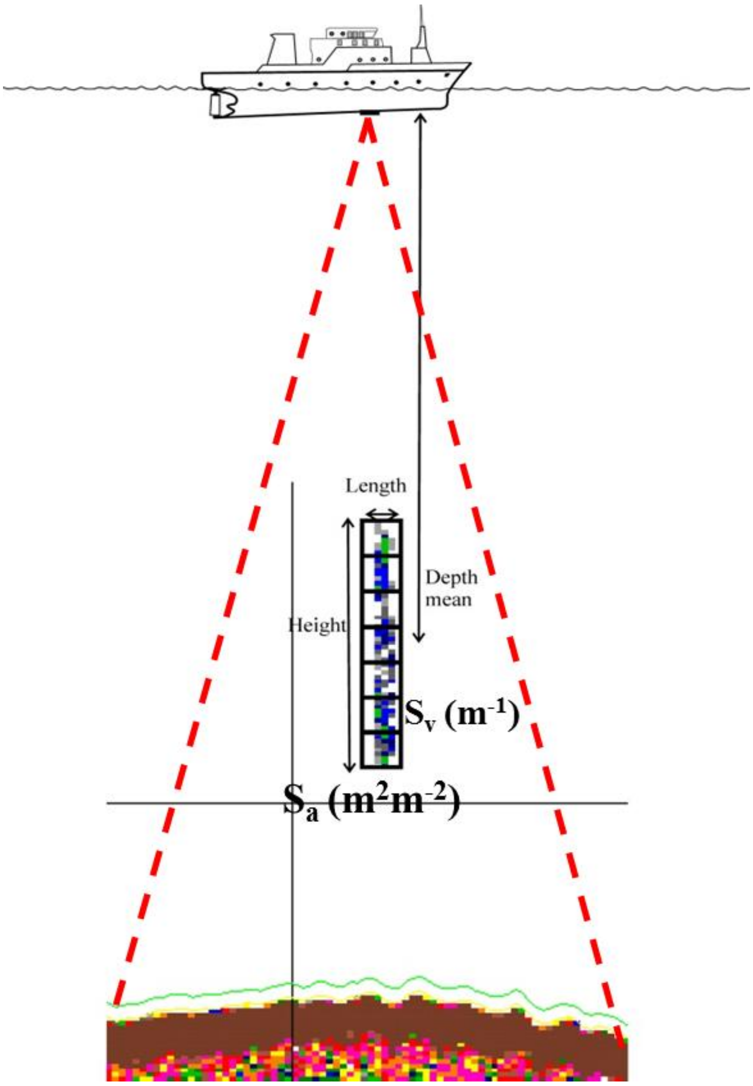

Figure 3.3 Morphological and illustration of area backscattering coefficient (S_a) that was measured for one typical school during data processing.

2.3.2 Otter trawling catches

Fishers are undoubtedly good observers. Spending significantly more time in the water than fisheries scientists, fishers tend to note and often record the factors that lead to successful catches. On the other hand, scientific surveys designed to determine fish distribution and biomass tend to be less spatially concentrated than the grounds targeted by fishers; the idea being to find out not only where fish are, but also where they are not (Mackinson and Kooij, 2006).

The inability to acquire biological data such as length and age, fisheries acoustic surveys are typically integrated with other sampling methods to confirm target identification, to obtain biological data and to estimate biomass. The collection of sandeel samples remain essential part of the acoustic survey procedures. The accuracy and preciseness of acoustic estimates of sandeel distribution and biomass are dependent on the quality of the biological information, which provides the basis for determining the target size and acoustic TS estimates. This information on the biological characteristics of acoustic targets is obtained from otter trawling (local commercial fisheries).

2.3.3 Estimates of sandeel biomass

Species-specific abundance and biomass estimates are the end result of fisheries acoustic survey. Converting echo level to biomass is a multi-step procedure. The echo intensities of the detected sandeel schools are integrated and converted into fish biomass density (number of individual in m^{-2}). Fish abundance was calculated from the Equation (3.1) (Shida, 2010).

$$\text{Abundance} = \left(\frac{\sum_{k=i} \sum_{j=i} \text{Density}}{L_k} \right) \times A \tag{3.1}$$

where *L*: length of transect line, *A*: area covered by transsect line, *k*: Horizontal grid number and *i*: vertical grid number

To convert the echo integrator output as shown in echograms (Figures 3.2 & 3.3), the sandeel schools were recorded during the acoustic surveys that were calculated using measurements of the volume backscattering strength (SV) values. The volume back scattering strength (Miyashita *et al.*, 2004) is shown as follows

$$SV = 10\log(sv) = 10\log(n\sigma_{bs}) \tag{3.2}$$

where *sv* is the linear value of *SV* and *n* is the biomass. *SV*, which depends on the frequency because the TS are frequency dependent, can be written as

$$sv(f) = n\sigma_{bs}(f) \tag{3.3}$$

making a ratio of *SV* between two frequencies cancels the common term *n* and leaves a frequency dependent TS ratio. The ratio is the difference in the decibel notation as shown in the Equation (3.4) was applied

$$\Delta SV = SV_{120\text{kHz}} - SV_{38\text{kHz}} = TS_{120\text{kHz}} - TS_{38\text{kHz}} \tag{3.4}$$

where ΔSV represents volume backscattering strength difference. Based on the Equation (4.3), the TS difference (ΔTS) method used for sandeel identification and furthermore, estimate the sandeel biomass. Target strength (TS) of sandeel to estimate ΔSV were calculated from the DWBA model with fish sample from the otter trawling.

2.3.4 Distribution patterns

The spatial distribution of sandeel abundance which was assumed to be expressed by fish biomass density was visualized by using Geographical Information System (ESRI, Arc.GIS 10.0). By using geo-statistical technique, which allows analysts to quantify the patterns of sandeel distribution, is now available in common GIS graphic interface.

III.3 Results

3.1 Sandeel catches

The interpretation of fish samples was collected by otter trawling to determine the size composition of the sandeel population in the study area. The information of fish standard lengths is required in calculating TS and to make the relationship between fish length and acoustic backscattering which needed in the estimates of sandeel biomass.

Sandeel sizes from trawling-catches were measured for individual standard length (SL, cm) in four years data (Figures 3.4a–d). The mean body length and standard deviation in 2009 and 2010 were of 18 ± 2.5 cm and 20.9 ± 2.4 cm, respectively, (Figures 3.4a–b). While in 2011 and 2012 quite large sizes of 22.4±1.7 cm 23.5±1.3, respectively, (Figures 3.4c–d) were obtained. The ages were determined and verified from the sampled fish having a considerable variation in size at age, that was investigated using otolith size and gonadal sex index (GSI) analyses, which were provided by Wakkanai Fisheries Research Institute, Hokkaido Research Organization. The age of fish for each year corresponded well with fish length that were mostly at age–1 (2009), age–2 (2010), age–3 (2011) and age–4 (2012), respectively, (Figures 3.4a–d & 3.5a–d).

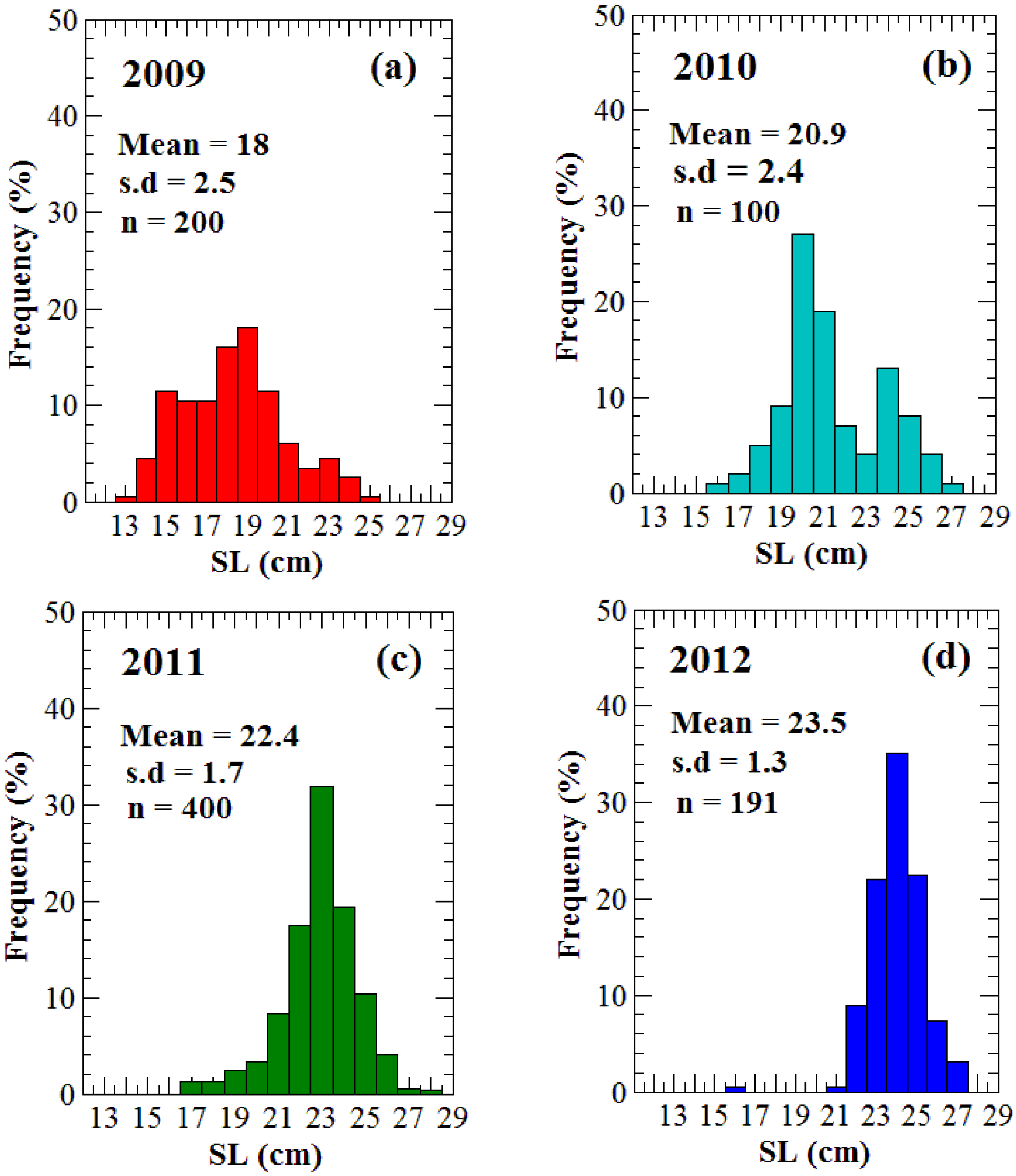

Figure 3.4 The standard lengths (SL) of sandeel obtained from otter trawling; (a) 2009, (b) 2010, (c) 2011, and (d) 2012. Mean and standard deviation of fish lengths, and number of fish samples for each year are provided.

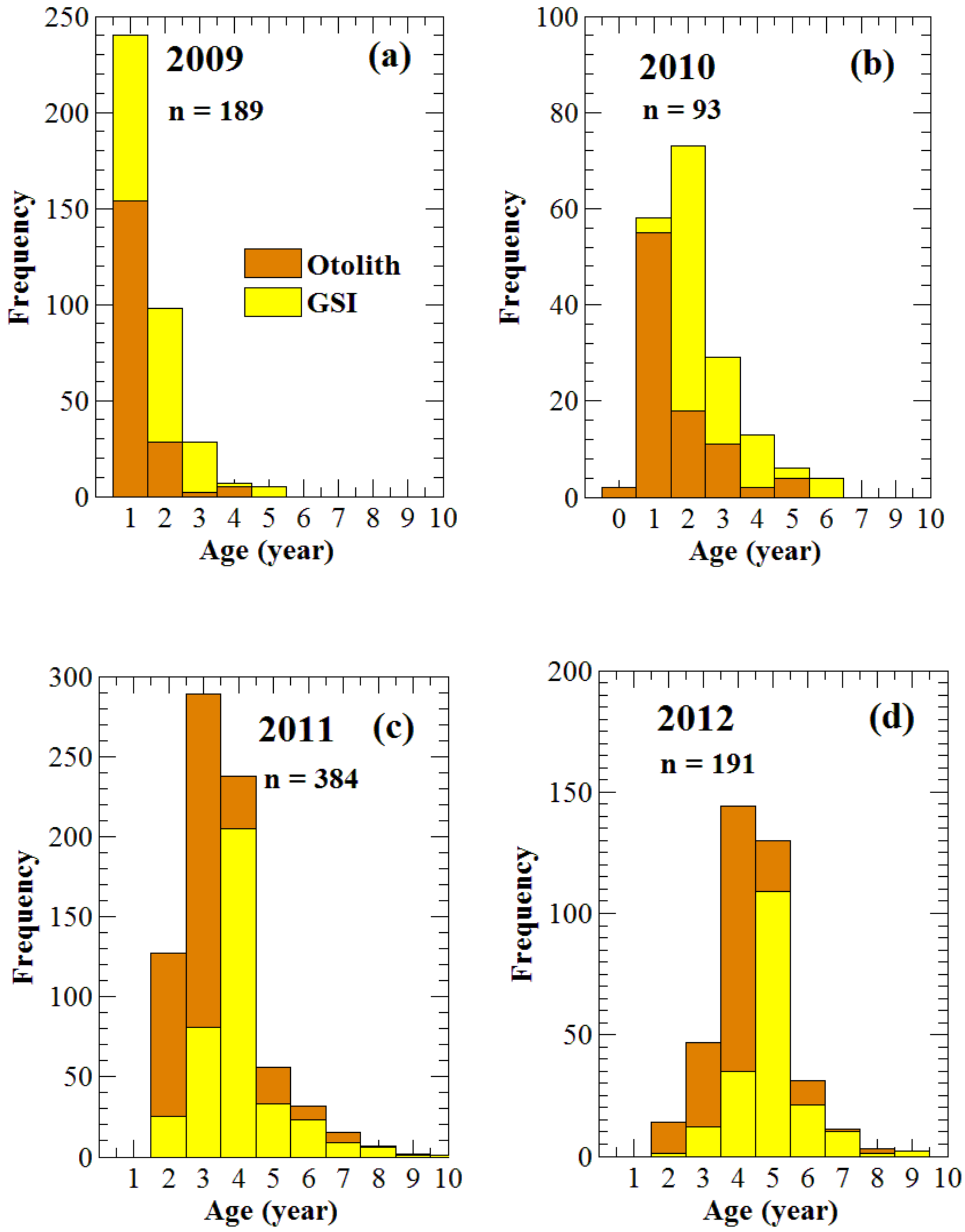

Figure 3.5 The ages of sandeel obtained from otter trawling; (a) 2009, (b) 2010, (c) 2011, and (d) 2012 (source: Wakkanai Fisheries Research Institute, Hokkaido Research Organization).

3.2 Identification of sandeel schools

Acoustics species identification is very important for fisheries' operations and scientific surveys. This study attempted to get proper estimates of sandeel distribution and biomass from acoustic backscattering data. Two frequency measurements on sandeel that were made at 38 and 120 kHz demonstrated that backscatter intensities at different frequencies have a specific pattern considering the trawl catches (Figures 3.4 and 3.6).

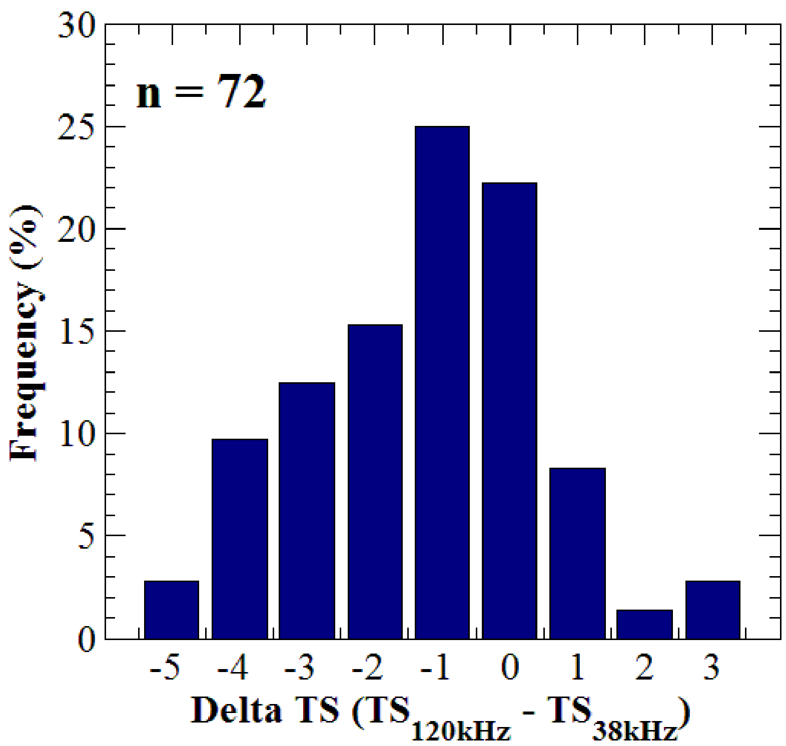

Figure 3.6 The values of target strength difference were obtained based on DWBA model estimation at 38 and 120 kHz of 72 specimens.

The echo traces of sandeel schools were identified based on echogram information. For more accurate sandeel identification, the current study also considered prior knowledge of echogram characteristics such as depth distribution of sandeel, shapes of the school and layer structure. However, the main method of sandeel identification used was SV difference between 38 and 120 kHz. Fish length information was obtained from direct sampling (otter trawling).

Figure 3.6 shows that the TS values of sandeel were influenced by frequency responses that were ranged of –5 to +3 dB between at lower frequency (38 kHz) and at higher frequency (120 kHz). The results of TS difference were obtained with by considering the information of target strength of sandeel.

3.3 Estimates of sandeel distribution and biomass

Echo integrator surveys were conducted annually during early summer from 2009 to 2012. Sandeel distribution and biomass were recorded by acoustic method using a quantitative echosounder (Figures 3.7 and 3.8; Table 3.2). Most of sandeel schools were detected near the coastal waters in four years data acoustical recording and were mostly found in the western part of the study area. The area backscattering coefficient (ABC) of sandeel schools (Figure 3.7) showed that mostly sandeel schools were distributed in the water coastal area zones and were mostly concentrated in the western part of the study

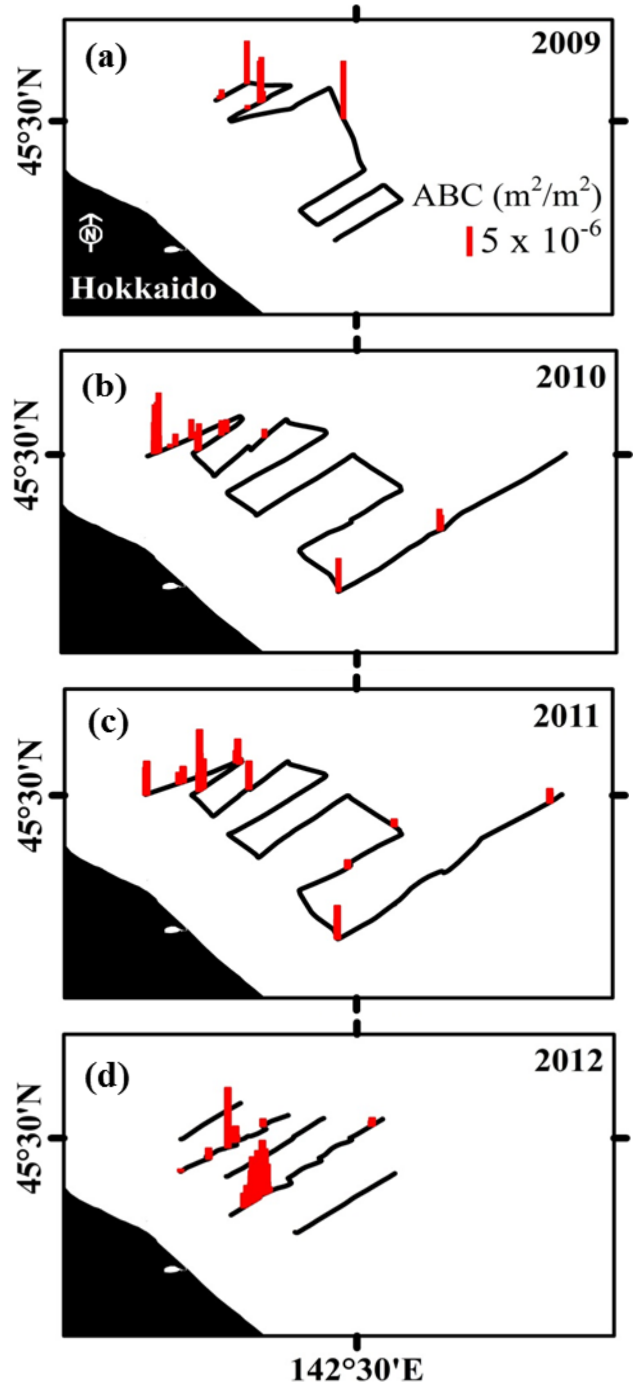

Figure 3.7 Area backscattering coefficient of sandeel schools distributions recorded during acoustics monitoring; (a) 2009, (b) 2010, (c) 2011, and (d) 2012.

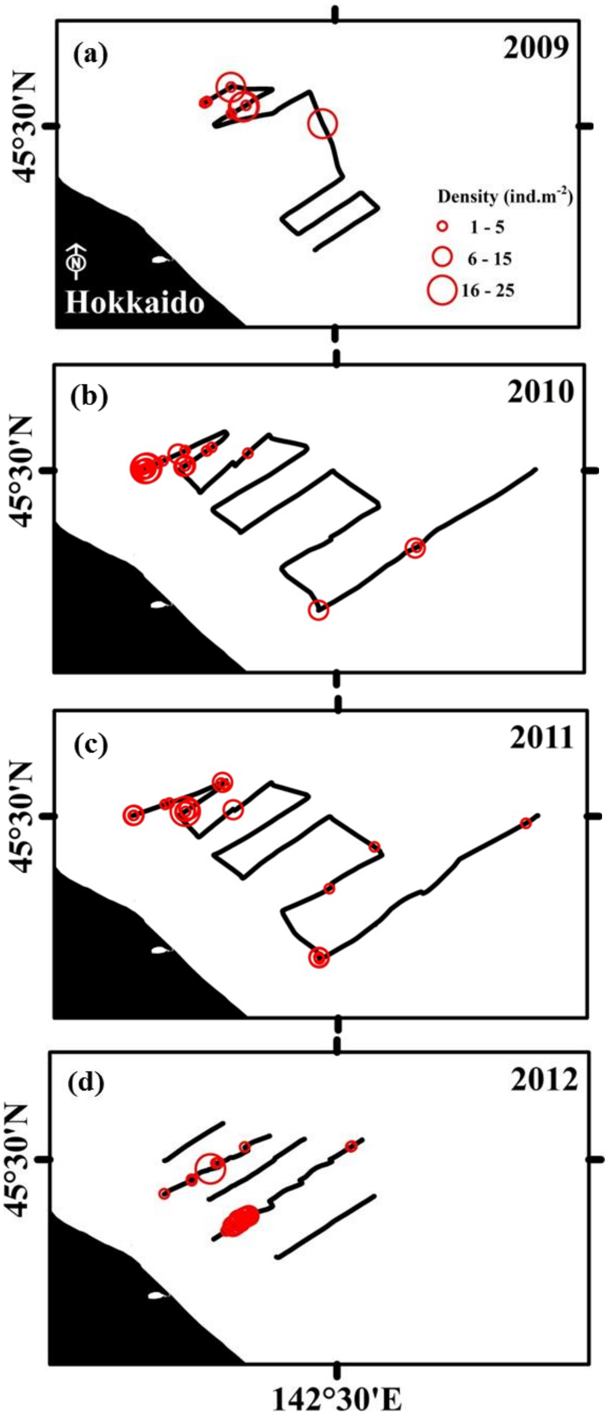

Figure 3.8 Sandeel schools distributions recorded during acoustics monitoring; (a) 2009, (b) 2010, (c) 2011, and (d) 2012. Fish biomass densities for each year were also shown.

area. It was noted that the biomass densities of the schools ranged from 1–25 ind. m^{-2} (Figure 3.8). The Table 3.2 showed that sandeel biomasses varied each year. The higher fish abundance was found in 2012 (119.5 tons) and lower abundance occurred in 2011 (5.2 tons).

Table 3.2 Sandeel biomass and abundance estimates from 2009 – 2012.

Year	Total length of transects (km)	Area (km^2)	Biomass (ind.)	Average body weight (g)	Abundance (ton)
2009	92.2	369.1	370,363	35.4	13.1
2010	159.7	753.8	1,557,030	50.4	78.5
2011	159.7	751.0	80,292	64.7	5.2
2012	88.9	432.8	1,688,261	70.8	119.5

III.4 Discussion

Acoustic methods provide information to describe the fish abundance and distribution in the field. Acoustic fish species identification has been one of the most important efforts in the fisheries acoustics community. In fisheries research, identification of acoustic targets traditionally combines knowledge of distribution and behavior patterns of constituent species with collection and analysis of acoustic and catch data (Horne, 2003).

With the absence of swimbladder, which is the major reflector and contributor of over 90% of the backscattering from fish, sandeel is generally better detected at higher frequencies (Kubilius and Ona, 2012). Developing acoustic methods for identification of fish remains a long-term objective of fisheries acoustics. The accuracy of fish abundance estimates increased when the acoustic backscattering characteristics of the fish are known, including their expected variability and uncertainty (Gorska *et al*., 2005). To get a better understanding of acoustic backscattering of sandeel and also frequency responses, the study measured the TS to obtain the true TS for Japanese sandeel. Further, the echo traces of sandeel school was identified using TS difference method at 38 and 120 kHz before estimates of sandeel biomass density in each school using scale factor (TS value) under taken.

In acoustic fish identification, the knowledge of the shape of school and their location in the water column provides a means of species identification. However, it is much more subjective and is not precise since some species can show the same distribution patterns.

In the previous studies, several methods and techniques have been used in addressing the problem of acoustic identification especially for sandeel species. Earlier acoustic surveys attempted to identify the echo traces of sandeel using two frequencies at 38 and 120 kHz (Mackinson *et al.*, 2005). Johnsen *et al.* (2009) reported that two most abundant sandeel age groups can be quite accurately distinguished using multi-frequency.

The current study identified sandeel schools using TS difference between 38 and 120 kHz that was successful to separate sandeel schools and unwanted target. Due to the presence of adult or larger sandeel in the study area, as indicated in the otter trawling catches, thus better estimates of sandeel biomass using frequency at 38 kHz than 120 kHz (Table 3.2). This could be because of the effects of fish swimming angle in acoustic backscattering strength which is more stable.

Horne (2003) stated that the amount of sound energy returned from a target is dependent on the choice and configuration of the hardware that such frequency response will used depending on water characteristics, location, composition, and behavior of the detected targets. The current study identified sandeel schools using two frequencies echoes. Since the interference patterns caused by two or more dominant scatters in the organism vary with frequency, single frequency measurements are not sufficient to accurately characterize the scattering physics (Reeder, 2011).

Acoustic surveys are routinely used to assess fish distribution and abundance. Understanding the spatial distribution of sandeel schools was expected to enable future improvement in the reliability of acoustic abundance estimates (Figures 3.6a–d). By analyzing the echo traces, this study provided detailed morphological descriptions of fish aggregations. Further, the biomass density of sandeel schools can be derived. Since sandeel are frequently scattered close to the sea bottom at night, makes fish echo trace partitioning less reliable. Hence, daytime acoustic data are used for sandeel biomass estimates to reduce the error in fish estimates. Another factor that should be considered in sandeel biomass estimates is aestivation as an ecological characteristic of sandeel if when the sea surface temperatures are over then 17 ^{o}C. In this period, they stay under the sand in sea bottom (Makino, 2011).

The acoustic survey and associated otter trawling catches data were obtained from a suitable aggregation of sandeel in the NCH, southern the Sea of Okhotsk. There was limitation to catch representative samples of the sandeel which have been observed acoustically. Simmonds and MacLennan (2005) suggested that trawling is conducted to determine the species and size composition of the local population which may not be the same over the whole of the surveyed area. In the present study, it was difficult to concurrently deal with both the acoustic survey and operating trawl at the same time. Thus, the sandeel caught were collected by local commercial fisheries that operated in the study area. Ideally, during the acoustic surveys, observed changes in the characteristics of the acoustic recordings are compared to the changes in trawl catch composition. This information is used as the basis for combining catch information with acoustic results.

Based on the results of the acoustic surveys, sandeel distribution and biomass varied for every year. Probably because the biomass migration were varied based on the changes in the oceanographic condition in every year as discusses in next chapter. Besides that, the acoustic surveys were carried out with different sampling designs (Figures 3.1a–d).

The current study applied acoustic measurements (Maclennan and Simmonds, 1992; Miyashita and Tetsumura, 2001) to improve sandeel distribution and biomass estimates for describing the real abundance of fish in the study area. The study result showed that acoustic method is reliable to estimate the Japanese sandeel (*A. personatus*) distribution and biomass in the field.

CHAPTER IV. EFFECT OCEANOGRAPHIC FACTORS ON SANDEEL DISTRIBUTION

IV.1 Introduction

The NCH is known to be one of the habitats of the Japanese sandeel in Japan waters during summer months (in early June to end of September). Probably when plankton production increases in this area and water temperatures get warmer thus adult sandeel migrate from the Sea of Japan into NHC through the Soya strait. The sandeel start to enter the Sarufutsu waters in early June when their principal food, zooplankton, disappears from the surface layers on the feeding grounds after the spring bloom. They stay in the NCH until the end of September when they start their spawning migration.

The oceanographic conditions in this area are highly influenced by Soya Warm Current (SWC) and East Sakhalin Current (ESC). These currents are mixed along the NCH in summer months. The SWC, Tsushima current extension, is warm water of the Japan Sea that enters the Okhotsk Sea through the Soya strait and flows southeastward along the NCH. It is considered that the currents are caused by a difference in water level between Japan Sea and Okhotsk Sea (Talley and Nagata, 1995). On the other hand, ESC from the Sakhalin Island brings colder and fresh water to southeastward around the NCH (Aota and Matsuyama, 1987; Matsuyama *et al*., 2006; and Uchimoto *et al*., 2007).

Due to the waters mixture caused by SWC and ESC, variations in oceanographic conditions can be changed in natural fluctuations of sandeel stock where they feed. In addition, changes of their physical environment may have profound effects on their abundance, migration patterns, distribution, and also growth (Murase *et al*., 2009). Therefore, it is very important to understand how the oceanographic factor affects sandeel distribution and abundance and in the NCH. This study provides the opportunity to investigate the Japanese sandeel under different oceanographic conditions related to the acoustic estimates of sandeel distribution and biomass, of which the results are discussed in Chapter III.

One of the common features of survey data such acoustic estimates is the high degree of measurement error. Sampling designs attempt to reduce such error by appropriate stratification although environmental covariates introduce additional variability (Swartzman *et al*., 1999). Determination of the relationship between variables such sandeel biomasses were observed including their environments that should be guided by statistical principle. The present investigation is examined the effect of oceanographic factors on sandeel distribution and biomass, followed by application of statistical models.

The objectives of this study are: (1) to determine effects of oceanographic factors on sandeel distribution and biomass; and (2) to characterize the suitable conditions of sandeel, referred to as the preferences of oceanographic condition. The overall goal of the study is to assist in ensuring that the best possible information and advice is generated from the relationship between oceanographic factors based on sandeel distribution and which can be used wisely in management of the sandeel fishery, hence providing the basis information for sustainable fisheries especially in the study area.

IV.2 Material and Methods

2.1 Acoustic data

The scientific surveys were conducted off northern coast of Hokkaido in June 2010 and 2011, and in July 2012, respectively, to collect acoustic data. The data provided geo-referenced positions (latitude and longitude), school depth, bottom depth, and number of sandeel per square meter as presented in Chapter III. The study data were obtained by monitoring acoustic surveys (Figures 3.1b–d).

2.2 CTD data

The dynamics of oceanographic condition in the NCH can be influenced by the existence of sandeel in this area. Oceanographic factors such as temperature, salinity and water depth were investigated annually in 2010 to 2012. CTD cast was conducted (Figures 3.1b–d).

2.3 Satellite remote sensing data

The spatial dependence has a key role in ecology for the understanding of the relationships between organisms and their environments. To determine the overall oceanographic conditions in the study area and its surrounding area, sea surface temperature (SST) data derived from a satellite, the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua was used. The SST data was downloaded from http://oceancolor.gsfcnasa.gov/.

To describe the annual changes of oceanographic condition, SST in the study area and its surrounding area, the present study also used the satellite remote sensing data of monthly SST in June of 2010 to 2011 and in July of 2009 and 2012 which were derived from Aqua/MODIS, National Oceanic and Atmospheric Administration (NOAA) permitted with Standard Mapped Image (SMI) level 3 binary data using HDF file and monthly mean temporal resolution and 0.04 degree (4 km) of longitude and latitude spatial resolution. The derived SST was arranged to correspond with the time of acoustic surveys.

2.4 Data analysis

2.4.1 Remotely sensed sea surface temperature data

The SeaWiFS Data Analysis System (SeaDAS 5.3) was used to extract monthly SST that corresponded to latitude and longitude positions of study area. The SST data was visualized using simple kriging of ESRI, Arc.GIS 10.0 tools to describe the SST variation during the acoustic surveys, which explicitly models spatial autocorrelation (Gorgakarakos and Kitsiou, 2008).

2.4.2 Matching acoustic data to CTD data

The spatial interpolation such as geo-statistical analysis with simple kriging method (ESRI, Arc.GIS 10.0) was applied to estimate the levels of all oceanographic factors at the locations of acoustic surveys including sandeel school positions in the water column. Furthermore, the temperature and salinity structures in the depth changes on each school were visualized by using an Ocean Data View (ODV, Schlitzer, 2010).

2.4.3 Construction of statistical models

Statistical models (Hastie and Tibshirani, 1990; Faraway, 2006; Kooij *et al*., 2008; Murase *et al*., 2009) are applied to the acoustic and oceanographic datasets to establish the effects of oceanographic factors on the sandeel schools abundance and distribution in the water column. The models such as generalized additive models (GAMs) and linear model/generalized linier models (GLMs) were constructed in R program version 2.15.0 (R Development Core Team, 2012) using the GAMs/GLMs function of the mgcv package (Wood, 2006) to predict the spatial patterns of Japanese sandeel in which sandeel school biomass density (inds./m^2) was the respond variable and the candidate predictor factors were the oceanographic factors (temperature, salinity and depth). The datasets were then used to develop the statistical predictive models.

GAM as an exploratory tool that was used to identify the shapes of the relationships between oceanographic factors and sandeel biomass as it was most likely that the expected relationships are non-linear. Furthermore, the shape of the relationships between the sandeel biomass and each predictor (temperature, salinity and depth) were identified. For a GLM, the appropriate functions were used to identify these shapes in the linear model respectively as shown in Equations (4.1) and (4.2) were applied

$$g(\mu_i) = \alpha_0 + s_1 (\text{temperature}) + s_2 (\text{salinity}) + s_3 (\text{depth}) + \varepsilon \quad (4.1)$$

$$g(\mu_i) = \beta_0 + \beta_1 (\text{temperature}) + \beta_2 (\text{salinity}) + \beta_3 (\text{depth}) + \varepsilon \quad (4.2)$$

where g is link function, μi is the expected value of the dependent variable for both presence/absence (1 and 0 values) and presence of sandeel (school biomass density), α and β_0 are the model constant, s_n is a smoothing function of the predictor variables and ε

is a random error term, β_n is the vector of model coefficients. The sandeel biomass follow continuous distribution hence the Gaussian family which is associated with the identity link functions was chosen. The binomial family with logit link function was used for presence/absence of sandeel schools. Models were constructed from the simplest form using one independent factor e.g. temperature only, with subsequent addition of predictor factors. Model selection was based on significance of predictor terms, reduction in Akaike Information Criterion (AIC), and deviance explained value (Faraway, 2006; Wood, 2006). Constructed GAMs/GLMs were made from the best model selected from a set of 7 models. GAMs/GLMs were employed to compare the resulted models prediction based on the statistical criterion and furthermore, they were used in explanations of all variable observation including relationship between variables.

IV.3 Results

3.1 Oceanographic conditions

3.1.1 Sea surface temperature

The satellite images of SST (Figures 4.1a–d) as supplementary information to increase precision were used to observe the intrusion of warm waters (SWC currents from the Sea of Japan to the Sea of Okhotsk).

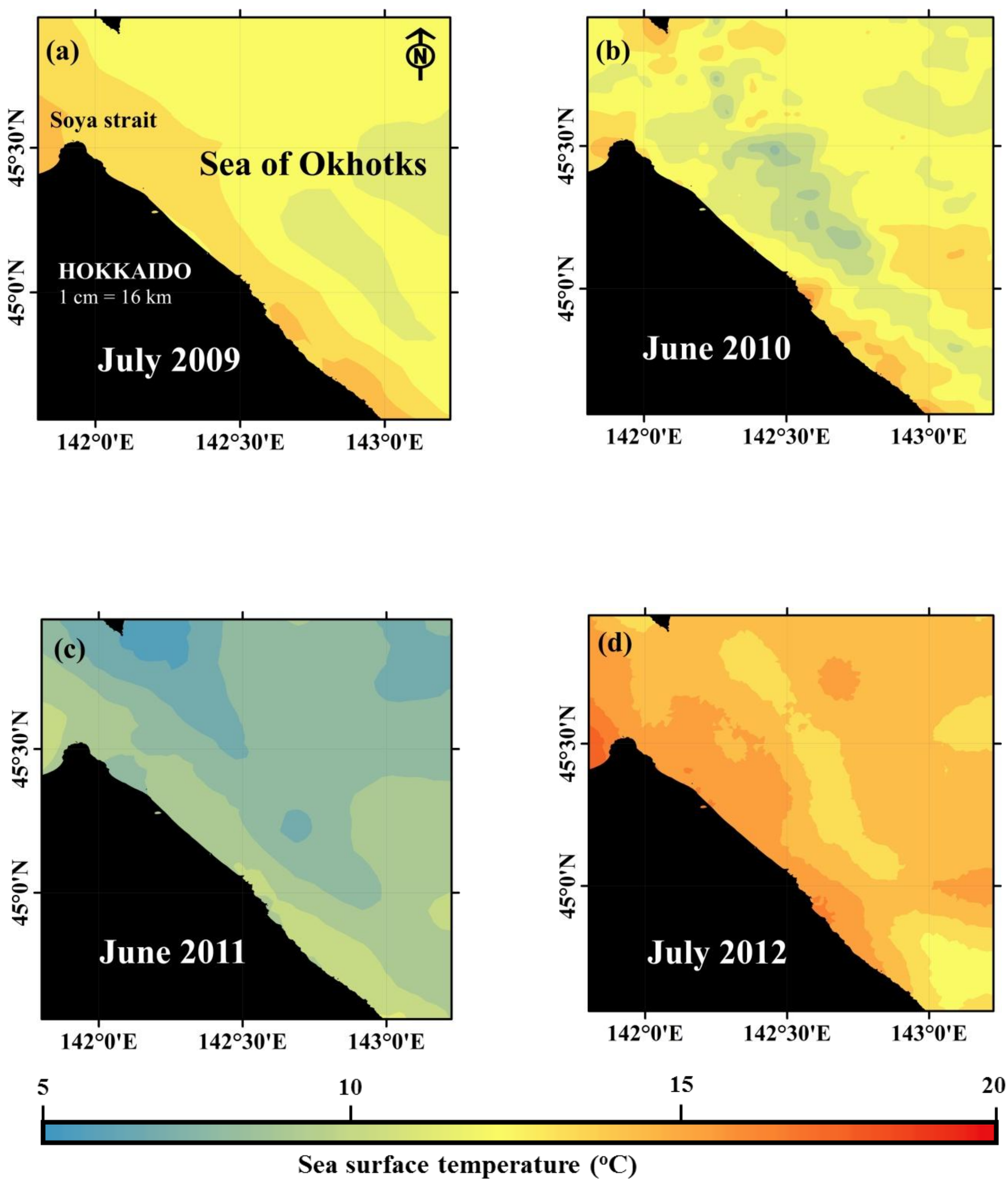

Figure 4.1 The horizontal profiles of sea surface temperature (SST); (a) 2009, (b) 2010, (c) 2011, and (d) 2012. The SST provided by AQUA–MODIS, NOAA.

Figures 4.1a–d show the SST in the NCH influenced by year and the water masses of SWC and ESC occurred, and were not completely mixed, easily to identify, in which warmer temperature indicated SWC and cold water was ESC water. Thus the water temperature changes may influence the sandeel distribution pattern in the water column. To verify this phenomenon, the current study also provided the horizontal and vertical profiles of oceanographic condition in the study area. Sea surface temperatures indicated significantly differences among sites of study area. The SST in 2011 was colder than those measured in other years. On the other hand, SST in July 2009 and 2012 were higher than in June 2010 and 2011, respectively.

3.1.2 Vertical profiles of oceanographic conditions

The Figures 4.2–4.4 showed that sandeel schools preferred to inhabit an area where the temperature was warmer and mostly occupied area in the range of 10.0–11.0 ^{o}C . In relation to salinity these observations highlight differences in school biomass in the overall salinity values. Schools were not found in the lower salinity area around at 32.8 psu or less. On the other hand, the schools congregate in salty conditions which were abundance in ranges values of salinity around at 33.8 and 34 psu especially in 2012. Mostly sandeel schools were recorded in coastal area at a depth of 50 m or less for each year for three years datasets because the Japanese sandeel, *Ammodytes personatus* is abundant in the near coastal area.

The profiles of temperature and salinity structures for both horizontal and vertical orientations with depth ranges in the different years (Figures 4.5 & 4.6) and showed that the warm temperature in the surface than in the near bottom and followed with salinity which increased gradually with depth. SWC water from the western (left side of profiles on each figure) part was shown in warmest and saline water. *Vice versa*, colder and fresh water was brought by ESC water (right side of profiles on each figure). Figures 4.5 & 4.6 showed that sandeel schools occupied the area in water column near the sea bottom where they selected warmer temperature, saline water conditions, and shallow water.

The varied sandeel biomasses were recorded during the acoustic surveys, which were higher in 2012 and other years. To get a better understanding these of phenomenon, the present study showed that the sandeel distribution and biomass with the oceanographic condition were overlain and characterized for each year of 2010 to 2012 (Figures 4.2 – 4.6).

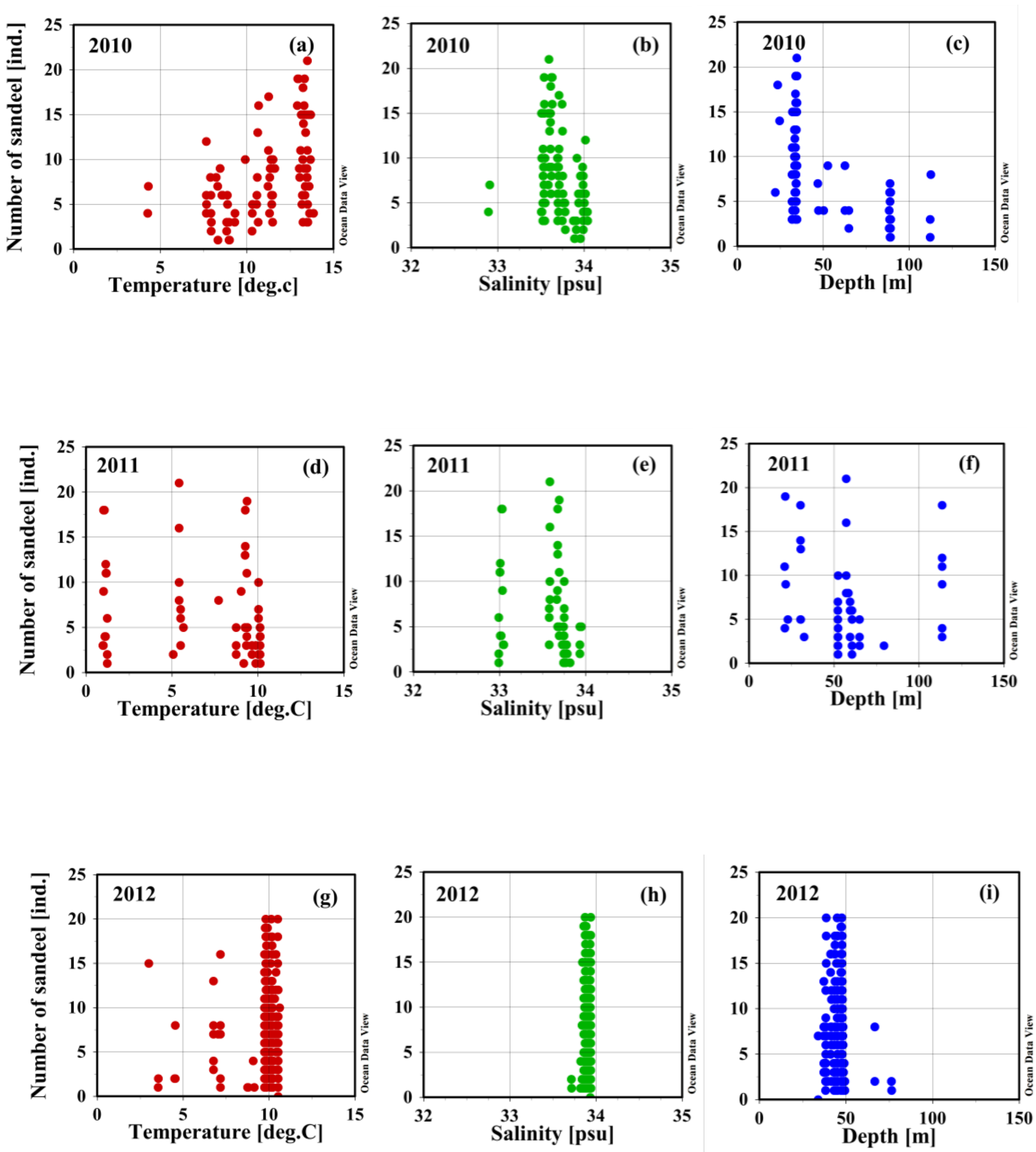

Figure 4.2 Scatter plots of oceanographic factors (temperature, salinity and depth) related with sandeel school aggregation in the water column; (a–c) 2010, (d–f) 2011, and (g–i) 2012. Sandeel school density is also shown.

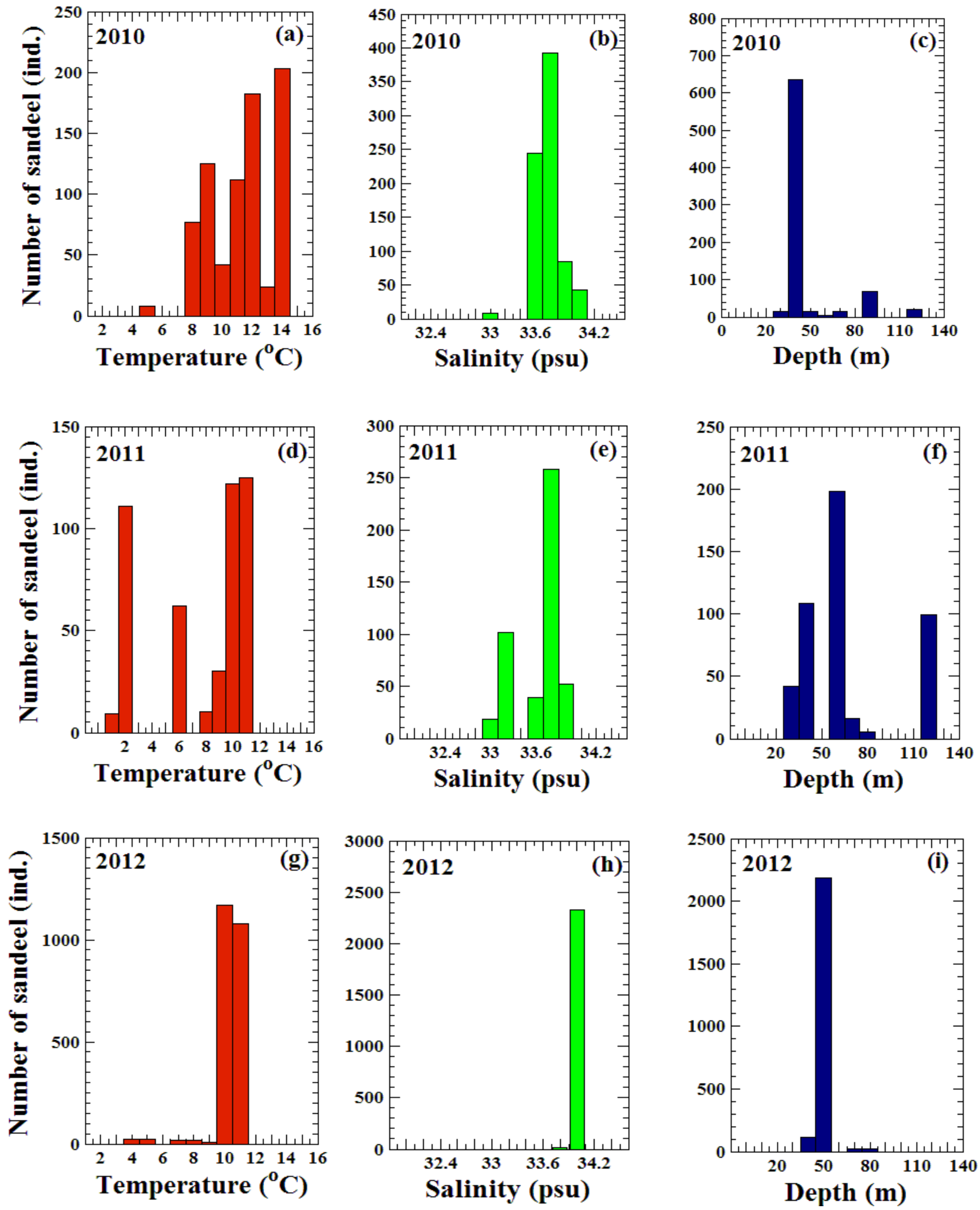

Figure 4.3 Preferences of oceanographic conditions for Japanese sandeel; a–c (2010); d–f (2011); g–h (2012).

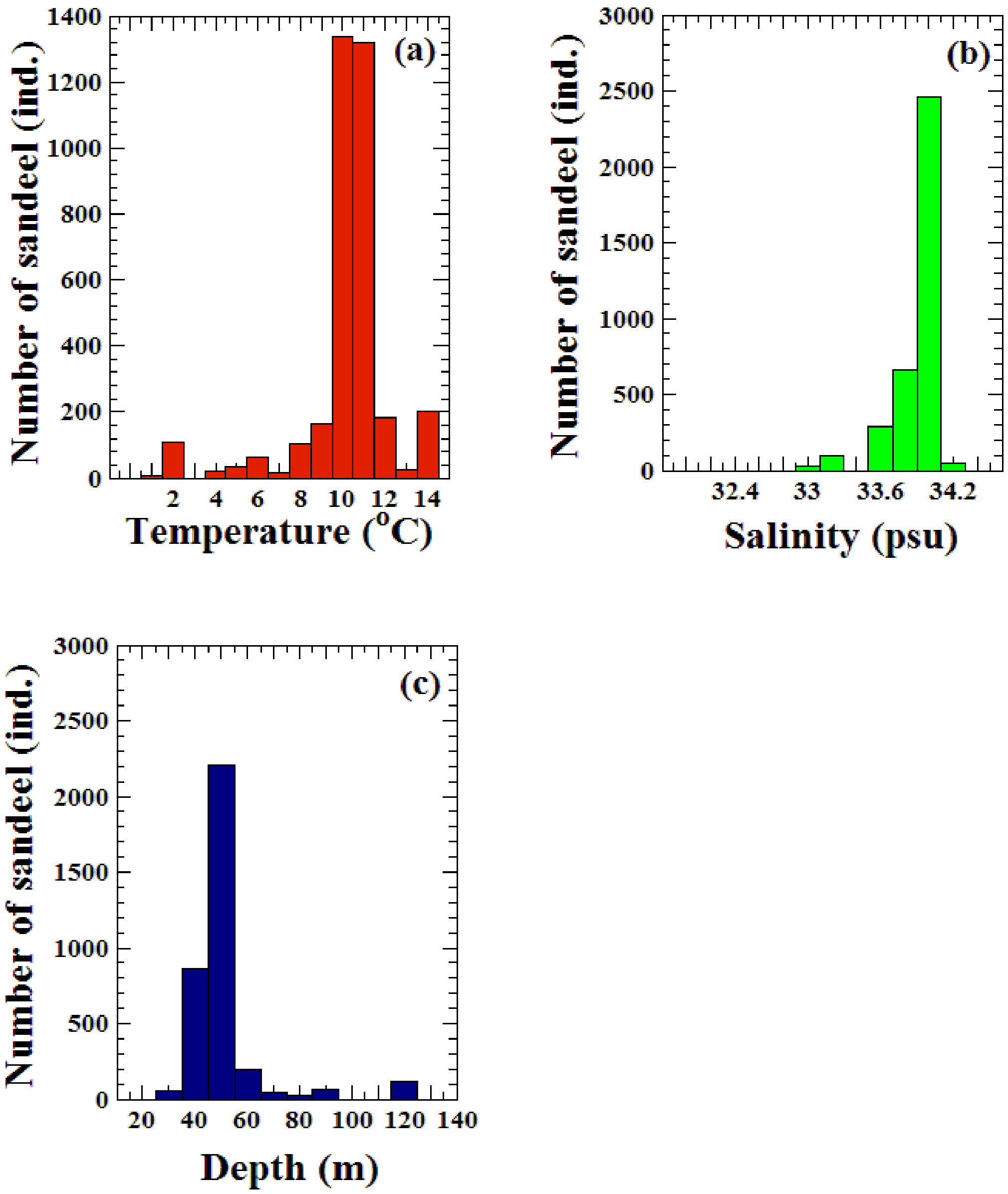

Figure 4.4 Preferences of oceanographic conditions; (a) temperature, (b) salinity, (c) depth for Japanese sandeel. All datasets from 2010 to 2012 were used.

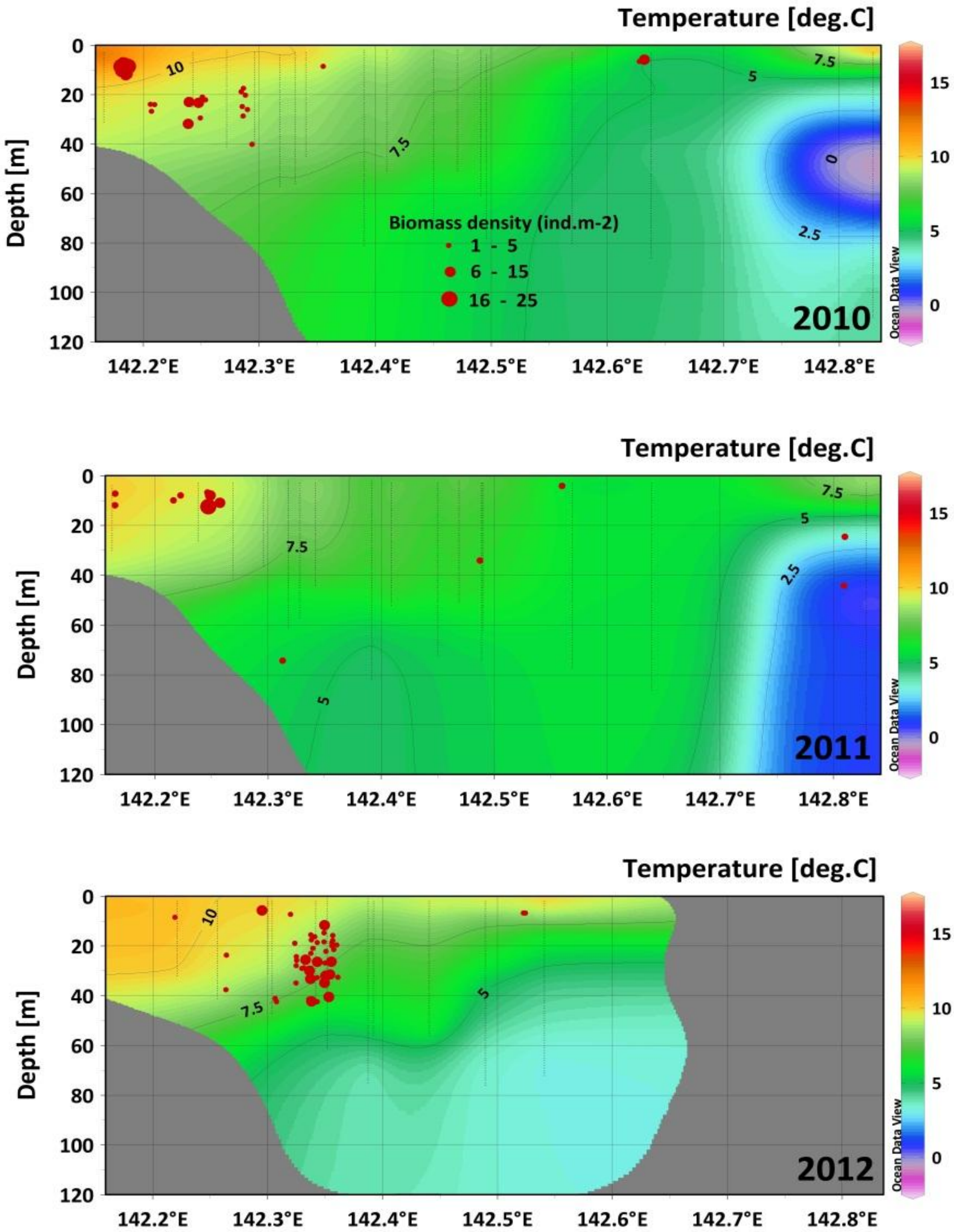

Figure 4.5 Sandeel distributions were recorded by acoustical overlain with vertical and horizontal profiles of temperature; (a) 2010, (b) 2011, and (c) 2012. Sandeel biomass density is also shown.

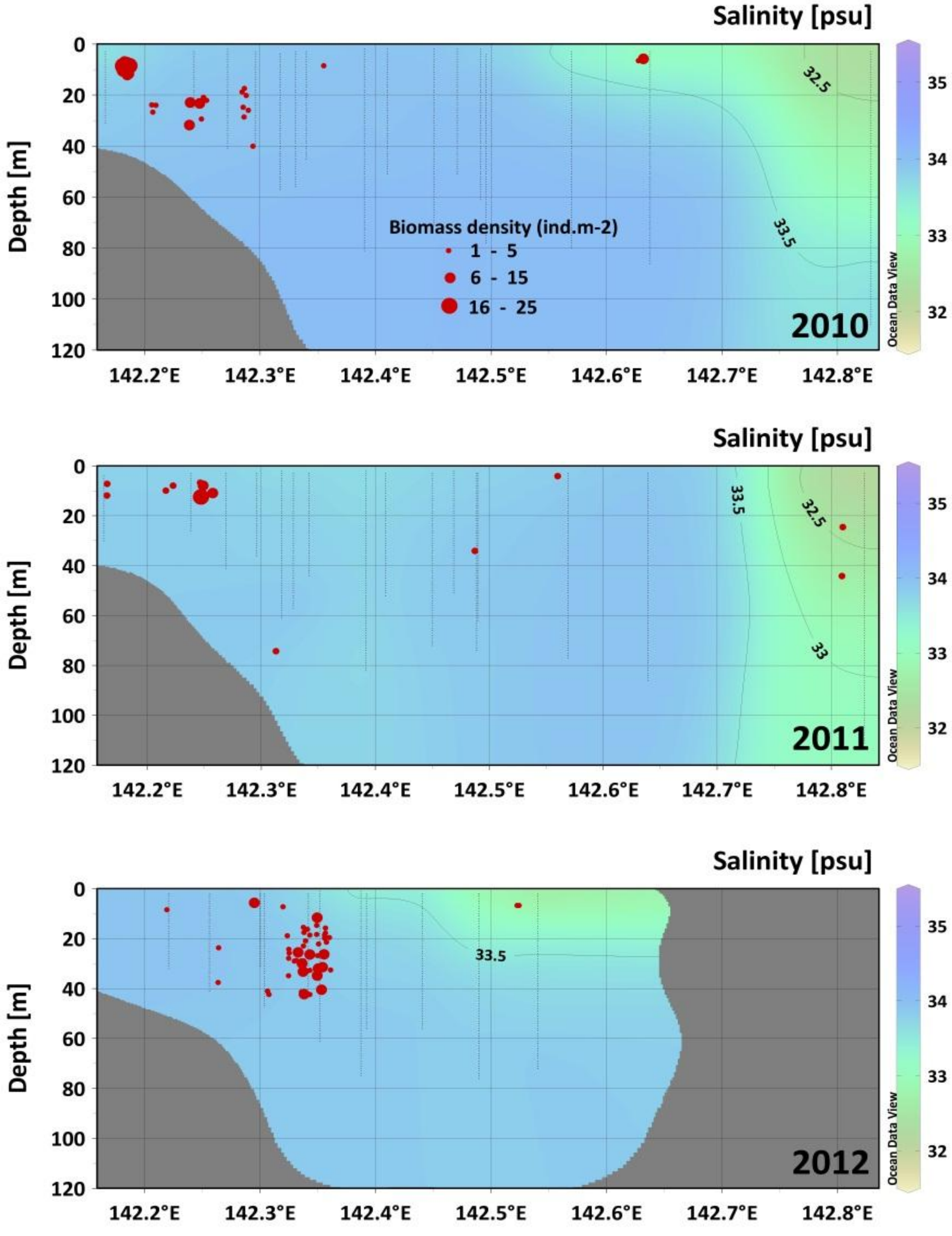

Figure 4.6 Sandeel distributions were recorded by acoustical overlain with vertical and horizontal profiles of salinity; (a) 2010, (b) 2011, and (c) 2012. Sandeel biomass density is also shown.

3.2 Effects of oceanographic factors on sandeel distribution

In the current study, the oceanographic condition on each school was used for display and further analysis. Tables 4.1–4.4 present the models constructed from predictor factors such as temperature, salinity, depth on the sandeel biomass density in presence/absence (Tables 4.1 & 4.2) and in present (Tables 4.3 & 4.4) scenarios using GAMs/GLMs.

The results for each of the 7 models constructed of GAMs and GLMs are presented in Tables 4.1–4.4. The Tables 4.1 & 4.2 show each of the models constructed from one predictor, two predictors and the last, three predictors. Over all, for each model the predictor factor (s) had a significant factor on the school density in $p<0.05$ reference levels except temperature as a single predictor, and absent in a combination with salinity in two model predictor and three model predictor in GLMs although it were not had a significant contribution. The final model combination of temperature, salinity and depth had highest cumulative deviance explained (CDE), 15.400% (GAMs) and 1.163% (GLMs), respectively. Tables 4.1 & 4.2 suggested that the effects of oceanographic factor might be taken into account for variability in sandeel distribution. Further, GAMs with highest CDE were suitable to explain the effect of oceanographic factor in presence/absence of sandeel distribution.

The resulted GAMs were constructed as listed in Tables 4.3 & 4.4, were single parameter models had the lowest deviance explained, especially for salinity. The temperature showed the highest deviance explained among the single parameter models followed by depth. Combination of salinity and depth explained relatively higher variability in sandeel biomass, according to AIC and deviance explained (15.500%). The three parameter models also had the lowest AIC value and high deviance explained (15.700%) and as the best model predictor. For GLMs, salinity as single predictor model had the lowest AIC and the highest deviance explained and also found in combination of two parameter models for salinity and depth. Overall, the three parameters model had the lowest AIC and the highest deviance explained (7.841%). All the results obtained from the addition of predictor factors at different levels showed increase or decrease in CDE and the AIC value varied.

GAM plots with the effects of each predictor on school density could be interpreted and the results given as in Figures 4.7a–d (presence/absence) and Figures 4.8a–d (presence), respectively. Rug plot on the horizontal axis represent observed data points while the fitted function is shown by the think line and the grey shade shows the 95% confidence interval (Mugo *et al*., 2010).

Table 4.1 Summary statistic of the GAMs: oceanographic variables effects on the Japanese sandeel distribution (n=2016). The significant factor, Akaike information criterion (AIC) value and percent cumulative deviance explained (CDE) are also shown.

No.	Model	Variable	*p*-value	AIC	CDE (%)
1.	Temperature	Temperature	9.2×10^{-6} ***	2305.766	2.300
2.	Salinity	Salinity	$<2\times 10^{-16}$ ***	2190.416	6.940
3.	Depth	Depth	$<2\times 10^{-16}$ ***	2170.803	7.880
4.	Temperature + Salinity	Temperature	0.000124 ***	2166.101	8.670
		Salinity	$< 2\times 10^{-16}$ ***		
5.	Temperature + Depth	Temperature	1.2×10^{-8} ***	2113.173	11.100
		Depth	$< 2\times 10^{-16}$ ***		
6.	Salinity + Depth	Salinity	1.5×10^{-10}***	2088.670	12.100
		Depth	$< 2\times 10^{-16}$ ***		
7.	Temperature + Salinity + Depth	Temperature	8.46×10^{-11}***	2027.827	15.400
		Salinity	2.55×10^{-14}***		
		Depth	$<2 \times 10^{-16}$ ***		

Significant codes: 0.001 '***' 0.01 '**' 0.05 '*'

Table 4.2 Summary statistic of the GLMs: oceanographic variables effects on the Japanese sandeel distribution (n=2016). The significant factor, Akaike information criterion (AIC) value and percent cumulative deviance explained (CDE) are also shown.

No.	Model	Variable	*p*-value	AIC	CDE (%)
1.	Temperature	Temperature	0.00746 **	2426.232	0.035
2.	Salinity	Salinity	2.01×10^{-6} ***	2410.783	1.116
3.	Depth	Depth	0.104	2430.759	0.131
4.	Temperature + Salinity	Temperature	0.763151	2412.692	1.120
		Salinity	8.19×10^{-5} ***		
5.	Temperature + Depth	Temperature	0.0294 *	2428.006	0.366
		Depth	0.6346		
6.	Salinity + Depth	Salinity	4.89×10^{-6} ***	2411.843	1.162
		Depth	0.333		
7.	Temperature + Salinity + Depth	Temperature	0.887	2413.823	1.163
		Salinity	5.86×10^{-5} ***		
		Depth	0.352		

Significant codes: 0.001 '***' 0.01 '**' 0.05 '*'

Table 4.3 Summary statistic of the GAMs: oceanographic variables effects on the Japanese sandeel distribution (n=536). The significant factor, Akaike information criterion (AIC) value and percent cumulative deviance explained (CDE) are also shown.

No.	Model	Variable	*p*-value	AIC	CDE (%)
1.	Temperature	Temperature	4.27×10^{-8} ***	3163.944	8.900
2.	Salinity	Salinity	5.38×10^{-8} ***	3159.076	10.400
3.	Depth	Depth	1.01×10^{-9} ***	3157.953	8.930
4.	Temperature + Salinity	Temperature	0.00407 **	3144.479	15.300
		Salinity	0.00040 ***		
5.	Temperature + Depth	Temperature	0.0035 **	3147.073	11.800
		Depth	6.91×10^{-8} ***		
6.	Salinity + Depth	Salinity	6.28×10^{-5} ***	3134.466	15.500
		Depth	2.33×10^{-5}***		
7.	Temperature + Salinity + Depth	Temperature	0.668018	3137.73	15.700
		Salinity	0.002450 ***		
		Depth	0.000562 ***		

Significant codes: 0.001 '***' 0.01 '**' 0.05 '*'

Table 4.4 Summary statistic of the GLMs: oceanographic variables effects on the Japanese sandeel distribution (n=536). The significant factor, Akaike information criterion (AIC) value and percent cumulative deviance explained (CDE) are also shown.

No.	Model	Variable	*p*-value	AIC	CDE (%)
1.	Temperature	Temperature	0.048617 *	3188.484	3.331
2.	Salinity	Salinity	0.0358	3187.098	3.580
3.	Depth	Depth	0.000124 ***	3177.569	5.279
4.	Temperature + Salinity	Temperature	0.000138 ***	3174.451	6.179
		Salinity	06.68 $\times 10^{-5}$***		
5.	Temperature + Depth	Temperature	0.3293	3178.609	5.449
		Depth	0.0006 ***		
6.	Salinity + Depth	Salinity	0.000199 ***	3165.610	7.714
		Depth	1.39 $\times 10^{-6}$***		
7.	Temperature + Salinity + Depth	Temperature	0.393	3166.874	7.841
		Salinity	2.3$\times 10^{-5}$***		
		Depth	0.002079 **		

Significant codes: 0.001 '***' 0.01 '**' 0.05 '*'

Figure 4.7 shows the effect of oceanographic factor on sandeel distribution. Temperature had positive effect on sandeel schools clearly over 10.0 ^{o}C (Figure 4.7a). Due to fewer data points at 2.0–3.0 ^{o}C, hence, the confidence intervals are wider. The plot on salinity (Figure 4.7b), a positive effect on school distribution was observed in the ranges of the salinity from 33.8–34.0 psu. For depth (Figure 4.7c), a positive effect on sandeel distribution of 20– 50 m occurred.

Presence sandeel school is as shown in Figure 4.8. Here, temperature had a positive effect of 10.5–13.8 ^{o}C (Figure 4.8a). Highest sandeel school concentrations were found in ranges of the temperature from 10.0–11.0 ^{o}C, and salinity of 33.6 – 33.7 psu (Figure 4.8b). In relation to depth, a positive effect on sandeel distribution of less than 45 m occurred (Figure 4.8c). The study also provided the best model prediction for the two predictor models with combination of salinity and depth (Figures 4.7d & 4.8d).

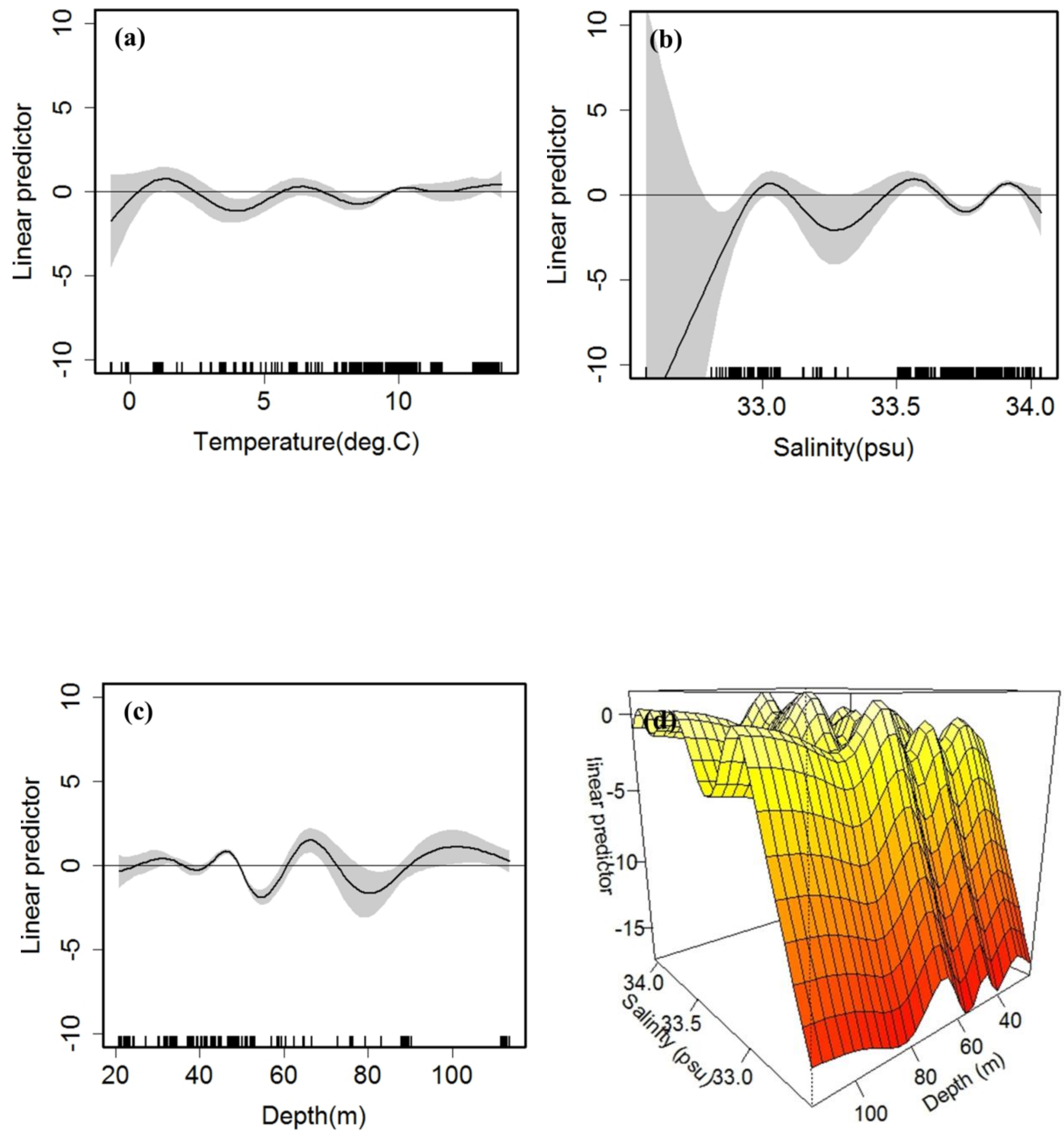

Figure 4.7 Responsive shapes of oceanographic factors effects in presence/absence of sandeel schools; (a) temperature, (b) salinity, (c) depth, and (d) best model predictor of two variables.

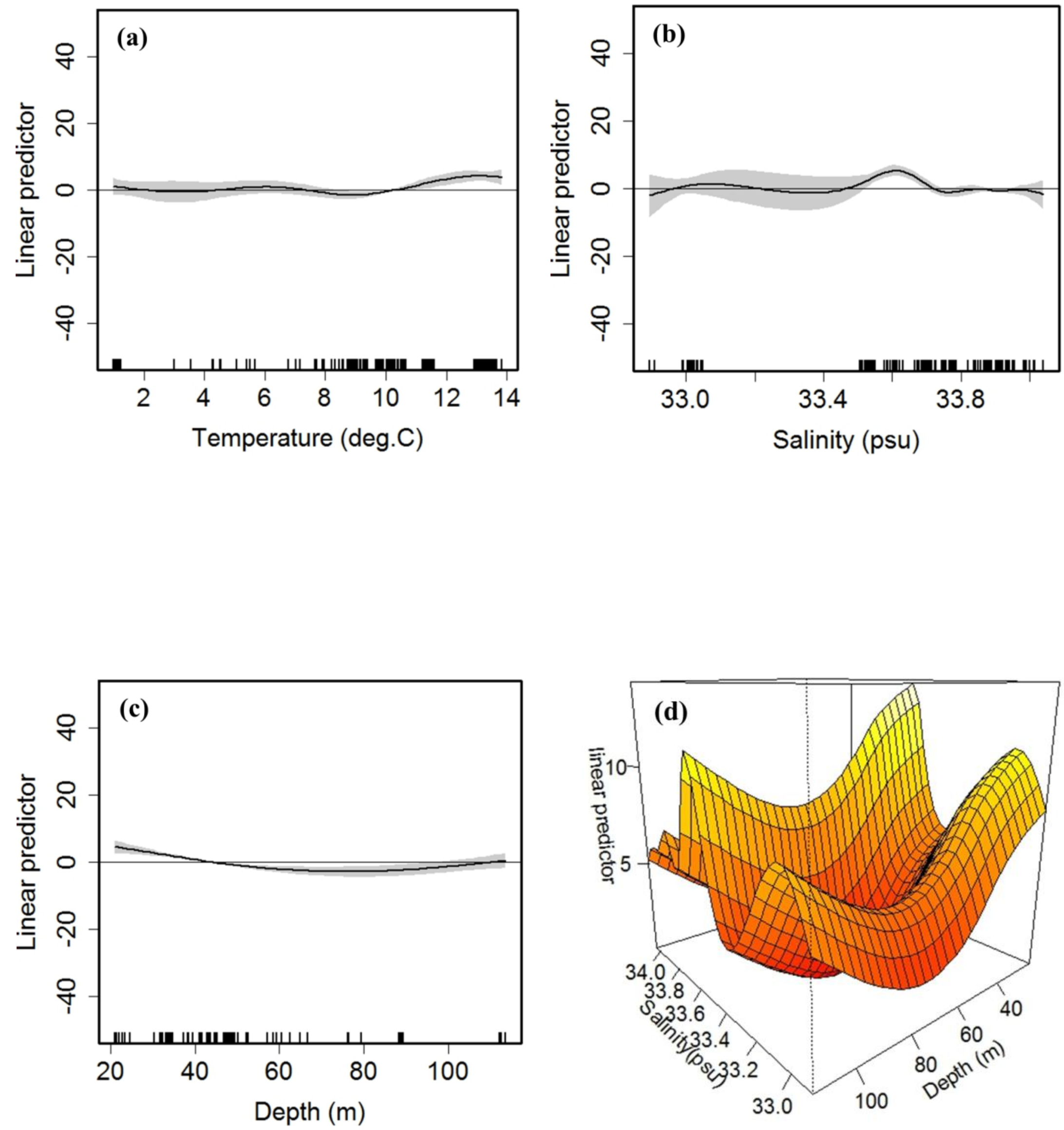

Figure 4.8 Responses shapes of oceanographic factors effects in presence of sandeel schools; (a) temperature, (b) salinity, (c) depth, and (d) best model predictor of two variables.

IV.4 Discussion

Variations in oceanographic conditions play a key role in natural fluctuations of Japanese sandeel stocks, such as sea surface temperature (SST) that have the greatest impact on larval fish stages and fish distribution. Thus SST is a good indicator for fishing areas and has been used for decades by fishermen and researchers. Moreover, changes on oceanographic factor (physical and biological) may have profound effects on migration patterns and growth of fish (Murase *et al*., 2009).

As temperature may vary across the survey area, measurements should be taken regularly. Consideration should be given as to how the oceanographic data will be used in analyses (e.g., correlation with density distribution and analysis cell of school), as a greater number of samples may be needed to meet this objective. Although water column profiles are necessary, continuous sea surface temperature measurements could be useful in areas lacking oceanographic sampling (Figures 4.1a–d). Sea surface temperature plays important role in fish physiology, and temperature variations are often linked with the biological richness of an oceanic area. Intrusion of warm waters into The Sea of Okhotsk is a good indicator for effective passive transport of sandeel from their nursery area to the harvesting grounds during summer periods.

Conductivity-temperature-depth (CTD) provided the oceanographic condition in a vertical way and unlimited by depth ranges and also could be used to understand oceanographic processes in water column (Figures 4.5 & 4.6), contrary to satellite remote sensed data even though it provided information in large area of interest. The oceanographic condition such as temperature, salinity and bottom depth on sandeel position for three years datasets were used; showing in scatter plots and preference ranged to suggest possible relationship among all variables observed as indicated in Figures 4.2–4.4. Oceanographic data are also required for the calculation of sound speed and the acoustic absorption coefficient in the water column (Miyashita and Tetsumura, 2001).

Distribution of sandeel is predominantly confined to coastal regions, sometimes making the largest populations and especially occurring in upwelling regions. In this section, the study presented the detail of relationship between sandeel and their physical environment at different time and spatial scales in an attempt to understand the various processes involved and how it can be possibly used for modeling their dynamics and forecasting their abundance. Watanabe (2009) reported that the contrasting responses of the fish populations to the SST rise can be explained by different temperature preference in terms of growth rate in larval and early juvenile stages such as cool temperatures are preferred by sardine and warm temperatures are preferred by saury and anchovy.

Knowing the oceanographic conditions is crucial for estimating the abundance of sandeel in the NCH, because they influence the distribution of sandeel in their natural habitat. The sandeel distribution was investigated during the daytime which was linked to the dynamic of oceanographic condition. As shown in Tables 4.1–4.4 and Figures 4.7 & 4.8, the effects of oceanographic factors on sandeel distribution and biomass in the water column were noted. The influences of oceanographic condition changes on the number of school density could be evaluated based on the *p*-value, AIC and CDE values. Thus, the oceanographic factors related to sandeel distribution become a matter of great importance to understand their habitat preference. Cury *et al*. (2005) reported that pelagic fish can also modify their aggregation level under certain conditions, although this is not always fully understood, but commonly attributed to environmental changes.

The acoustic measurements on the longitude scale were mapped. The survey track is high-lighted by individual school along the track and each school being denoted as a red single point as shown in Figures 4.5 & 4.6. Map contours were identified as those with high temperature and more saline, or *vice versa*. Itoh and Ohshima (2000) noted that regarding the seasonal variation of SWC water, in the surface layer exists only near the Soya Strait from May to June, while it gradually extends southeastward along the Hokkaido coast from July to October.

The temperature and salinity were highest in July than June (Figures 4.5 & 4.6) since the peak for summer period occurred in August each year. In summer, the SWC water lies near the coast, but in winter the ESC water predominates, except near the sea bottom which has SWC water (Takizawa, 1982; Ishizu *et al*., 2006). Sandeel were least abundant at the coolest area and the fresh waters (Figures 4.5 & 4.6) and highest at the warmest area as a result of rising waters temperature transported by the Soya Warm Current. Thus might be a strategy in biological process under oceanographic conditional changes related to growth of the fish. Growth rate of *A. hexapterus* within stock (between years) was positively correlated with temperature (Robards *et al*., 2002).

The differences of water properties assembled in the NCH were made by the oceanographic processes such as frontal oceanic zones, eddies, and gyres that often occurred (Talley and Nagata, 1995; Ohshima *et al*., 2001), could be influenced the existence of the Japanese sandeel horizontal and vertical distribution and in the water column. In summer and autumn periods, SWC water flows along the coast of northeastern Hokkaido and brings warm and saline subtropical water from the Japan Sea. In contrast, winter season, ESC water flows southward from Sakhalin Island to

Hokkaido, while SWC water weakens. ESC water is characterized by salinity less than 32.0 (Takizawa, 1982; Oguma *et al*., 2011).

The present study revealed that the oceanographic conditions of sandeel schools tend to concentrate at ranges of temperature between 10.0 –11.0 ^{o}C and salinity range of 33.7–34.0 psu, respectively, (Figures 4.2–4.4). Even though the study area was influenced by SWC water and ESC water (Aota and Matsuyama, 1987; Ohshima *et al*., 2001; Matsuyama *et al*., 2006; Ishizu *et al*., 2006), they could be found in the optimum habitat. Temperature of SWC water changes considerably depending on the season, while salinity of SWC does not change much and remains higher than 33.6–34.2 psu from April to October throughout the year. Low salinity water of 31.0–32.0 psu which is dominant in December corresponds to ESC water (Itoh and Ohshima, 2000). Therefore, sandeels migrating in the northern coast of Hokkaido could have followed the interruption of SWC water during summer months which they occupied in the warmer and saline waters.

Others species, lesser sandeel (*A. marinus*) had both temperature and salinity optimum between 8.3–9.0 ^{o}C and 34.9 –35.0 psu, respectively (Kooij *et al*., 2008). The results of the present study supported the findings by Mosteiro *et al.* (2004), who noted that sandeel schools were found mainly in shallow area about of 50 m depth.

GAMs as a nonlinear model was more robustly used than GLMs which had the lowest AIC and the highest deviance explained, for understanding effect of oceanographic factors on sandeel distribution and biomass in water column (Tables 4.1 –4.4). Previous study reported GAMs model to be very useful for investigating the effects of oceanographic factors on the fish abundance and distribution in the water column such as sandeel distribution and abundance in the Dogger Bank (Kooij *et al*., 2008); for many pelagic fish including Japanese sandeel (Murase *et al*., 2009).

Statistical models such as generalized additive models (GAMs) succeeded to identify the effects of oceanographic factors on the sandeel distribution in presence/absence and in presence (revealed by the shape of smoothes among predictor factors). These results suggest that the oceanographic factors play an important role in explaining the abundance and distribution of this species in the study area.

This study suggested that sandeel schools prefer and tend to concentrate in the specific range of oceanographic factors such as temperature, salinity and depth. These suitable conditions may represent the optimal habitat of the Japanese sandeel especially in the study area during the summer periods.

CHAPTER V. GENERAL DISCUSSION, FURTHER CONSIDERATIONS, RECOMENDATIONS AND SUMMARY

V.1 General Discussion

This work was the fundamental study to document the swimming angle of Japanese sandeel (*A. personatus*) in the experimental tank and in the application of the theoretical scattering model such as a DWBA model. Swimming angle for swimbladderless fish such as sandeel was the main factor influencing the accuracy of TS. Hence, the present study considered the swimming angle distribution in TS estimates. Bimodal distribution of the swimming angle of sandeel was found. It may have occurred due to small sample size in the measurements (n=95). If more images were analyzed, the result might have become a normal distribution as presented by Kubilius and Ona (2012) who measured the swimming angle of lesser sandeel in small on-board fish tank and found a monomodal distribution of the swimming angle (n=534). The current study was used a monomodal distribution that was normalized by PDF to calculate the average target strength pattern as shown in the results herein. Measurements of swimming angle are required for the accurate estimates of the TS of sandeel. It had larger effect on TS variation than fish length and frequencies responses, and the variation with angle changes was quite large (Hasen and Horne, 2003).

The TS variation as a function of swimming angle on the theoretical backscattering model at 38 kHz is more fluctuating on the side lobe (Figure 2.6). However, the TS values for both frequencies at 38 and 120 kHz are tended to be consistent on the near main lobe especially for small fish length. Similar to the findings of Yasuma *et al.* (2009) for the TS of Japanese sandeel, the present study found that the TS was higher at low frequency for larger fish. The discrepancy in the TS results was not only due to frequencies responses used in the theoretical model, but also caused by fish length that seemed to have a contribution in the variability of the TS. This study revealed that there was good agreement between the experimental and theoretical TS although the measured TS were higher than those calculated from the theoretical measurements. TS difference method at 38 and 120 kHz was applied to identify the echo trace of sandeel school that was successful in the separation of the sandeel schools and unwanted target. Since the interference patterns caused by two or more dominant scatters in the organism vary with frequency, single frequency measurements are not sufficient to accurately characterize the scattering physics (Reeder, 2011).

The acoustic survey and associated otter trawling catches data were obtained from a suitable aggregation of sandeel population off Sarufutsu waters, northern coast of Hokkaido. The results indicated that sandeel distribution and biomass varied for every year, probably because biomass migrating were varied every year. Besides that, the acoustic surveys were carried out in different times and sampling designs. The current study applied acoustic measurements (Maclennan and Simmonds, 1992; Miyashita and Tetsumura, 2001) to improve sandeel distribution and biomass estimates for describing the real abundance of fish in the study area. The study result will be strengthened based on the previous study that acoustic method is reliable to estimate the fish distribution and biomass in the field.

Conductivity-temperature-depth (CTD) profile provided the oceanographic condition in a vertical way and were unlimited by depth ranges. In addition the CTD could be used to understand oceanographic processes in the water column (Figures 4.5 & 4.6) contrary to satellite remote sensed data even though it provided information in a large area of interest (Figure 4.1). The sandeel distribution and biomass were investigated during daytime which was linked to the dynamic of oceanographic condition. Thus, the oceanographic factors related to sandeel distribution become a matter of great importance to understand their habitat preference. Cury *et al*. (2005) reported that pelagic fish can also modify their aggregation level under certain conditions, although this is not always fully understood, hence commonly attributed to environmental changes.

Temperature and salinity were the highest in July than June (Figures 4.5 & 4.6) since the peak for summer period occurred in August each year. In summer, the SWC water lies near the coast, but in winter the ESC water predominates, except near the sea bottom which has SWC water (Takizawa, 1982; Ishizu *et al*., 2006). Sandeel were the least abundant at the coolest area and the highest at the warmest area as a result of rising waters temperature transported by the Soya Warm Current.

The present study noted that the oceanographic conditions of sandeel schools tend to concentrate at ranges of temperature between 10.0–11.0 ^{o}C and salinity range from 33.8–34.0 psu, and depth of 40–50 m, respectively (Figure 4.4). These suitable conditions may represent the optimal habitat of the Japanese sandeel especially in the study area during the summer periods. Even though the study area was influenced by SWC water and ESC water (Aota and Matsuyama, 1987; Ohshima *et al*., 2001; Matsuyama *et al*., 2006; Ishizu *et al*., 2006), they could be found in the optimum habitat. Temperature of SWC water changes considerably depending on the season, while salinity of SWC does not change much and remains higher than 33.6–34.2 psu from April to October throughout the year. Low salinity water of 31.0–32.0 psu which is dominant in December corresponds to ESC water (Itoh and Ohshima, 2000). Therefore, sandeels migrating in the northern coast of Hokkaido could have followed the interruption of SWC water during summer months which they occupied in the warmer and saline waters.

Others species, lesser sandeel (*A. marinus*) had both temperature and salinity optimum between 8.3–9.0 ^{o}C and 34.9–35.0 psu, respectively (Kooij *et al*., 2008). The results of the present study supported the findings by Mosteiro *et al.* (2004), who noted that sandeel schools were found mainly in shallow area about of 50 m depth.

V.2 Further considerations

The study presented here represented some attempts such as observation of Japanese sandeel swimming behavior; target strength estimates; and estimates of sandeel distribution and biomass in the field by acoustical method. Further, this study also investigated the environmental condition changes in relation with sandeel distribution and biomass in each school detected by acoustic surveys and the results were showed by statistical models. Towards accurate application of fisheries acoustics, some works to be considered were discussed below.

2.1 Measurements of swimming angle

For a downward looking transducer, operating at geometric scattering frequencies, swimming angle is generally considered the primary influence on TS of sandeel, swimblanderless fish. The study measured the swimming angle in the experimental tank and analyzed the pitch angles. Thus, in the future, it is very important to design the observations by using two cameras. The other one will be used to collect dorsal aspect imagery (yaw angles). This information could measure the fish body movement during swimming (Kubilius and Ona, 2012) and to confirm that the fish has to be perpendicular to the camera (Ito *et al*., 2011). For more reliable result, *in-situ* measurement is required. Also the TS of a fish varies with its orientation relative to the acoustic axis in the field survey, due to absence of the measurement of pitch and roll angles, the TS estimates of fish should be measured in a three-dimensional.

Sandeel forms compact schools in the water column during the day, thus it is difficult to detect this fish as an individual target in the water column using acoustic methods. Therefore, information from the *in-situ* and *ex-situ* TS measurement experiments on enclosed populations of freely swimming sandeel is needed. The *in-situ* measurement of swimming angle is required to provide information on the natural swimming orientation of sandeel and it could help to understand the observed TS variability. This information is required in the theoretical TS model (Yasuma *et al*., 2009) and for interpreting the observed variability in the multi-frequency response of sandeel schools (Johnsen *et al*., 2009; Kubilius and Ona, 2012).

2.2 Measurements of target strength

Hydro-acoustics applied to estimate fish abundance in the water column could be attempting to give accurate and precise values through scrutiny of TS of various fish. Although in this study some successfully documented factors affecting TS such swimming angle, fish length, and frequency responses are investigated, the results might not be representative of the characteristics of live fish. For the advancement of the acoustic method such as increasing availability of multi-beam transducer to derive reliable information of fish stock, in the near future program, measurements of fish TS could includes laboratory measurement and advanced analysis, modeling of acoustic scattering and *in-situ* measurements using broadband signals and advanced analytical algorithms could be required. Further analysis and modeling TS will continue to push the science forward to provide robust methods to extract meaningful biological information from acoustic backscattered signals.

The study on the dorsal aspect TS of sandeel is very important (Foote, 1980), which is applicable to downward-looking echosounders, to convert acoustic data obtained from field survey. The present study provided information on the TS of Japanese sandeel that was derived from theoretical and experimental TSs.

For theoretical TS, DWBA model (Groska *et al*., 2005; Ito *et al*., 2011) was applied to know the back-scattering strength of fish, by the examination of the length of body sizes in narrow ranges. Thus, the relationship between TS and fish length were founded in lower correlations. More large fish samples in larger differences of length of the body sizes are required for obtaining more reliable results. Besides that, measurements of acoustic material properties of Japanese sandeel such as sound speed and density contrasts are needed and should be adjusted in a different condition (i.e. area and season). Yet, the measured fish TS in the water tank experiment used frozen samples. Therefore, significant changes may have occurred in the material conditions, such as changes on the water content and tissue composition of fish (Yasuma *et al*., 2009). Although, the fish samples frozen quickly at low temperature (e.g. $\leq -40^{o}$C). Strictly speaking, fresh fish samples are required for more precise sandeel TS value. However, it can be done in the present study because the fishing ground was located far from the experimental place.

2.3 Estimates of sandeel distribution and biomass

To avoid a depletion of the Japanese sandeel stock in the northern coast of Hokkaido, the Sea of Okhotsk, accurate biomass estimates are essential. To improve the understanding of this situation, the information on the status of fish stock was based on scientific advices, such as monitoring acoustic surveys and sampling gear (otter trawling) (Simmonds and MacLennan, 2005), were performed in this area. However, the problem of determining the fraction of the population remaining in the sediment during acoustic survey and thus inaccessible to acoustics (Mackinson *et al*., 2005) even if the acoustic monitoring is done in daytime and may have source errors in sandeel stock estimates. In addition there could be a challenge in the future to get better real abundance in the field. Future developments and improvements in the application of echosounder to commercial fisheries and fisheries research are suggested.

It is very difficult to forecast natural fluctuations of sandeel stocks in the northern coast of Hokkaido. This was due to the fish stock that was influenced by fish migrating in each year as fish recruitment from nursery area in the bay around Japan waters (Tomiyama *et al*., 2005; Yamada, 2009). Furthermore, little is known about the juvenile transport mechanism from the nursery area and the especially in the whole middle of Japan to the northern coast of Hokkaido. Therefore fisheries scientists together with fisher and fisheries managers must seek more effective ways of monitoring sandeel stocks to utilize them more rationally for sustainable resources such as continued acoustic monitoring of the resource in comparison with the condition in the other areas in order to explain the population dynamics of fish in the field.

Sandeel distribution within different regions should be considered in acoustic survey designs. The survey area should be extended to the eastern coast part of Hokkaido. Also it should be routine surveys during summer periods. This is because the information is required to understand the sandeel migration patterns in this area and the effect of fisheries on sandeel stock fluctuation after fishing season.

2.4 Optimal habitat

The oceanographic condition in the northern coast of Hokkaido was changed since mixed water of the SWC water originate from the Sea of Japan through the soya strait, which flows toward the southeast along the coast of Hokkaido, in the Sea of Okhotsk (Aota and Matsuyama, 1987; Ohshima *et al*., 2001; Matsuyama *et al*., 2006; Ishizu *et al*., 2006) and ESC water brought cool water those assembled around the coast of Hokkaido. The ESC was found to play a key role in the water change between the Sea of Japan and the sea of Okhotsk (Kantakov and Shevchenko, 1999). Itoh and Ohshima (2000) noted that in regard to the seasonal variation of SWC water, in the surface layer exists only near the Soya Strait from May to June, while it gradually extends southeastward along the Coast of Hokkaido from July to October.

The habitat of sandeel can be changed rapidly in response to the dynamics of their environmental conditions. To explain the condition preferences of sandeel, long term annual datasets are required to simulate their habitat condition by simulating statistical models (Hastie and Tibshirani, 1990; Faraway, 2006; Wood, 2006) to predict the relationship between variables. This could also be done by comparing the model results to generate the best model predictor for explaining their abundance and distribution. Moreover, climate changes may impact upon sandeel abundance and distribution and thus it should be considered. Besides, survey design (sampling effort) should be extended to be a representative area of the northern coast of Hokkaido and sampling period of acoustical monitoring should be done every month (for several months) during summer season for more reliable results.

Other factors that may contribute on the pattern of Japanese sandeel abundance and distribution but not incorporated in this study include the availability of food, concentration of zooplankton, as main prey associate with school positions in the water column. Sandeel abundance and distribution during the daytime were linked to zooplankton densities (Robards and Piatt, 1999c; Kooij *et al*., 2008) and only limited to the spatial interrelationship of fish and zooplankton in the open ocean (Swartzman *et al*., 1999). Another factor that should also be taken into consideration is the sediment types as habit selection for sandeel distribution which is important because sandeel distribution is highly influenced by the substrate composition. Acoustic seabed classification should be used to characterize features of the seabed substrata to infer their habitat type.

V.3 Recommendations

The most specific issues in Ecosystem Approach to Fisheries (EAF) is the relation to the impact of fisheries on the environment including biodiversity and habitat, and the impact of the environment on fisheries such as natural variability and climate change (Garcia and Cochrane, 2005). Makino (2011) noted that there are three principal measures for sandeel resource conservation: establishment of an opening day fishing juveniles, protection of spawning stock, and establishment of protected areas for estivation. Sandeel management developed in Ise Bay is a good example of Japanese adaptive fisheries management. Community-based unions play an important role in enforcing these management measures (Tomiyama *et al*., 2005). Since, sandeel that were found in the studied area were adult fish, it is possible to manage the regulation for the fishing season such as estimation of fish stock that should be done earlier and at end of the fishing seasons. Fishing gear should be used as well as fishing ground that should to be applied to ensure sustainable stock level of sandeel.

To get a better understanding, the information on the distribution pattern of sandeel in the area of interest, data visualization plays a vital role in developing integrated approaches to fishery management and stock assessment as a keystone technology for working with high dimensional regional ecosystems and also to play a major role in integrated studies of marine ecosystems and their relationship to evolving environmental condition changes needed. It facilitates the efforts of the study to improve the understanding of Japanese sandeel stock assessments in the marine environment, thus helping efforts to build sustainable fisheries.

V.4 Summary

This thesis had explored and examined several methods, which could be improved in the acoustic estimates of Japanese sandeel biomass and distribution in the northern coast of Hokkaido. Step by step procedures of the study were run. Firstly, the study explored the swimming angle distribution of sandeel in experimental water tank, *ex-situ* measurements, which was the mainly factor that influenced the variability target strength (TS) for swimbladderless fish such as sandeel species. This study revealed that the Japanese sandeel intended to display positive angle as indicated in the mean and standard deviation values of 20.38 ± 18.5^{o}, respectively.

The next step measured the dorsal aspect TS of sandeel at two frequencies responses (38 and 120 kHz), as the frequencies commonly used for scientific echosounders for fish abundance estimates to obtained true TS. The distorted-wave born approximation (DWBA) model was applied to estimate theoretical TS and the swimming angle distribution were substituted in TS calculation. Also, the experimental TS were performed on dead fish using a large water tank in the laboratory experiment. The resultant TS could be significant improve the precision and accuracy of the TS. The TS of sandeel information is needed to estimate the abundance and distribution of sandeel in the field using a quantitative echosounder, which is dominantly used on many commercial fishing vessels in Japan.

The study expanded the results by developing acoustic identification on the echogram information using mean volume backscattering strength (SV) difference method ($\Delta SV = SV_{120kHz} - SV_{38kHz}$). TS values of sandeel were influenced by frequency responses that were ranged of –5 to +3 dB between at lower frequency (38 kHz) and at higher frequency (120 kHz) were required to identify acoustically monitored sandeel schools and in the estimation of their biomass. The acoustic data were collected annually from 2009 to 2012 and the information was visualized through the map formed for each year. This study gave a good insight regarding the distribution patterns and biomass of sandeel in northern coast of Hokkaido.

To get a better understanding of the quantitative distribution of sandeel in relation to oceanographic condition changes, the study also investigated the oceanographic condition changes in the northern coast of Hokkaido especially in summer months (in June and July) which were influenced by Soya Warm Current (SWC) and East Sakhalin current (ESC) waters. At this step, it was interesting to reveal the dynamics of oceanographic factors on sandeel distribution characteristics. The statistical models such as generalized linear models (GLMs) and generalized additive models (GAMs) were employed to characterize the effect of oceanographic factors on the distribution and biomass of sandeel. These models are more reliable than traditional regression, in the contexts of investigating dynamic of oceanographic condition on habitat selection of fish. The current study recommended that GAMs were more reliable to apply for understanding the effects of oceanographic factors on sandeel distribution and biomass. This study was a fundamental attempt in providing the basic information to investigate the preferred condition of Japanese sandeel in the field in order to apply better management of sandeel for sustainable marine resources.

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APPENDIX

Appendix 1 Algorithms for modeling acoustic scattering from Japanese sandeel, *Ammmodytes personatus*.

```
******************************fbsvsangle.m***************************

global rposvec avec hvec gvec k1 fbsvector k fbs

g=1.032;        %density contrast. Input the value.
h=1.018;        %sound speed contrast. Input the value.
freq=38;      %frequency (kHz). Input the value.
rposvec=[]*10;    %rposvec (mm). Input the value.
avec=[]*10;      %avec, radius (mm). Input the value.
[n,m]=size(avec);
gvec=ones(n,1)*g;
hvec=ones(n,1)*h;
rposvec=rposvec*.001;
avec=avec*.001;
fbsvector=zeros(360,1);
phivector=zeros(360,1);
sigmabs_ave=0;

k=2*pi*freq/1.5;
for phi=0:359
    phi
    fbsvector(phi+1)=phi;
    phirad=phi*pi/180;
    k1=k*[cos(phirad);sin(phirad);0];
    findfbs;
    fbsvector(phi+1)=fbs;
end
sigmabsvector=(abs(fbsvector)).^2;
TSvector=10*log10(sigmabsvector)
```

```
global rposvec avec hvec gvec k1 fbsvector k fbs

g=1.032;        %density contrast. Input the value.
h=1.018;        %sound speed contrast. Input the value.
freq=38;         %frequency (kHz). Input the value.
rposvec= ]*10;      %avec, radius (mm). Input the value.

[n,m]=size(avec);

gvec=ones(n,1)*g;
hvec=ones(n,1)*h;
rposvec=rposvec*.001;
avec=avec*.001;

fbsvector=zeros(360,1);
phivector=zeros(360,1);
sigmabs_ave=0;

k=2*pi*freq/1.5;
for phi=0:359
    phi
    fbsvector(phi+1)=phi;
    phirad=phi*pi/180;
    k1=k*[cos(phirad);sin(phirad);0];
    findfbs;
    fbsvector(phi+1)=fbs;
end
sigmabsvector=(abs(fbsvector)).^2;
TSvector=10*log10(sigmabsvector)
```

****

```
*******************************findfbs.m*****************************
global k1 a1 a2 rpos1 rpos2 g1 g2 h1 h2 betatilt
[n,m]=size(avec);
fbs=0;
for p=1:n-1;
    a1=avec(p);
    a2=avec(p+1);
    rpos1=(rposvec(p,:))';
    rpos2=(rposvec(p+1,:))';
    g1=gvec(p);
    g2=gvec(p+1);
    h1=hvec(p);
    h2=hvec(p+1);
    alphatilt=acos(k1'*(rpos2-rpos1)/(norm(k1)*norm(rpos2-rpos1)));
    betatilt=abs(alphatilt-pi/2);
    fbs=fbs+quadL(@DWBAintegrand,0,1);
end
****************************DWBAintegrand.m************************
function [integrand] = DWBAintegrand(s)
global k1 rpos1 rpos2 a1 a2 betatilt g1 h1 g2 h2 bessy;
i=sqrt(-1);
rposx=s.*(rpos2(1,1)-rpos1(1,1))+rpos1(1,1);
rposy=s.*(rpos2(2,1)-rpos1(2,1))+rpos1(2,1);
rposz=s.*(rpos2(3,1)-rpos1(3,1))+rpos1(3,1);
rpos=[rposx;rposy;rposz];
a=s.*(a2-a1)+a1;
g=s.*(g2-g1)+g1;
h=s.*(h2-h1)+h1;
gamgam=1./(g.*h.^2)+1./g-2;
if abs(abs(betatilt) - pi/2) < 1e-10
    bessy=norm(k1)*a./h;
else
    bessy=bessel(1,2*norm(k1)*a./h*cos(betatilt))/cos(betatilt);
end
integrand=norm(k1)/4*gamgam.*exp(2*i*k1'*rpos./h).*a.*bessy*norm(rpos2-rpos1);
*******************************************************************
```