Estimation of prey species biomass in the Sanriku region based on 2008 and 2009 JARPNII acoustic surveys

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ABSTRACT

Prey species surveys were conducted in the coastal region off Sanriku, north eastern Japan in spring 2008 and 2009 as a part of JARPNII coastal component off Sanriku. The surveys were conducted concurrently with a sampling survey of common minke whales. Two stratified blocks were analysed. Zigzag tracklines were set in the blocks. The surveys were conducted by a trawler type RV, *Takuyo-maru*. Acoustic data were recorded continuously along the tracklines by a quantitative echosounder. Samplings using a midwater trawl net were conducted at some stations to identify species and size compositions of acoustic backscatterings. Vertical oceanographic conditions were recorded by using a CTD. Subsurface oceanographic conditions were recorded continuously along the tracklines. In 2008 the total biomass estimation of sand lance adult was 8,076tons, while that of sand lance juvenile was 1,237tons. The estimations of biomass of Japanese anchovy were 0.18 tons in blocks B and C, respectively. In 2009 the total biomass estimation of sand lance adult was 2,512tons, while that of sand lance juvenile was 315tons. The estimation of biomass of Japanese anchovy were 0.64 tons in block B and C, respectively. Biomass estimates of sand lance were higher than Japanese anchovy in 2008 and 2009 in this study. This result suggested that seasonal movement of common minke whales could be related to availability of sand lance in Sendai Bay during spring season. These data would be useful as input data for the development of ecosystem models in this area.

KEYWORDS: FOOD/PREY, ACOUSTICS; MODELLING; SCIENTIFIC PERMITS; SANRIKU

INTRODUCTION

JARPNII was designed to contribute to conservation and sustainable use of marine living resources including whales in the western North Pacific, especially within Japan's EEZ (Government of Japan, 2000; 2004). One of the major objectives of JARPN II is to advance feeding ecology and ecosystem studies, involving studies of prey consumption by cetaceans, prey preference of cetaceans and ecosystem modeling. To accomplish the goal, sampling survey of common minke whales (*Balaenoptera acutorostrata*) and survey on biomass estimation of their prey species have been conducted concurrently off Sanriku, Japan since 2003 as a JARPNII coastal component. Prey species surveys were conducted in the coastal region off Sanriku, independently from the coastal sampling surveys for common minke whale since 2003 (except 2004, 2011) as a part of JARPNII.

The sand lance (*Ammodytes personatus*) and Japanese anchovy (*Engraulis japonicas*) are key prey species in the Sanriku ecosystem supporting different species of baleen whales, pinnipeds, birds and fish. Changes in its abundance could affect the biology and abundance on its predators as well the whole ecosystem. For this reason JARPNII considered it important to conduct yearly monitoring of sand lance and Japanese anchovy biomass in the research area.

This paper presents the results of the sand lance and Japanese anchovy biomass estimation based on the echo sounder data collected in 2008 and 2009 seasons. It was not possible to evaluate any trend in these abundance with just two surveys conducted. However the sand lance and Japanese anchovy biomass estimates obtained in the present study are useful to evaluate the impact of these consumption by common minke whales in the research area, and as input data for the development of the ecosystem models.

MATERIALS AND METHODS

Survey area

The Sanriku region is northeastern part of the Japanese Main Island that was known to be major grounds of the past commercial whaling of common minke whales in spring season (Hatanaka and Miyashita, 1997). This region is one of the most productive waters in the world ocean due to the mixing of Kuroshio and Oyashio currents. Generally, the Oyashio water dominates in the survey area in the investigation period (Hanawa and Mitsudera, 1987). Therefore, this region was an important fishing ground for commercial species such as Japanese sand lance (Nagashima, 2007), Japanese anchovy (Nagashima, 2007), and Pacific krill (*Euphausia pacifica*) (Taki *et al*., 1993; Taki, 2002). The possible competition between the whales and the fisheries in this area was suggested by the JARPN and the JARPNII feasibility study (Tamura and Fujise, 2002a, b).

The sampling survey of minke whale was conducted in the coastal waters within the 50 n.miles (mainly within 30 n.miles) from Ayukawa, Miyagi prefecture, Japan. In 2003, the prey survey was conducted in a wider area off the Pacific coast of the northern Japanese Main Island, preliminary. This survey area divided into two parts. To avoid the conflict with nets in the coastal waters, the waters within 10 miles from the coast were excluded in principle. Since 2005, the prey survey area was divided into nine blocks (A, B, C, D, E, F, G, H, I, and J) based on bottom depth (20, 40, 100, and 200m) and prefectural boundary (boundary between Miyagi and Fukushima prefecture) (Figure 1). Because of logistical constraint, the number of blocks changed in each year (Table 1). In 2008 and 2009, 5 blocks (B, C, E, D, E and F) were surveyed. The details of previous prey surveys (from 2003 to 2007) around Sanriku region were described by Yonezaki *et al.* (2009).

Track-line design and timing
Saw tooth type zigzag lines were used in each survey. If there was any fishing equipment, track line was cancelled. The survey was conducted during the daytime from an hour after sunrise to an hour before sunset.

Survey vessels
In 2008 and 2009 surveys, the research vessel (RV) used was a trawler-type RV, "*Takuyo maru* (TKY)" (Miyagi prefecture Fisheries Technology Institute, 120 GT) (Figure 2). Net sampling, acoustic data recording using quantitative echosounders and oceanographic surveys were conducted by *Takuyo maru*.

Net sampling and quantitative echosounder
In 2008 and 2009, midwater trawl was used. The trawl net was a mouth opening of 7m width / 3.5m height and a 3mm liner cod end. Towing speed of the trawl nets was 2-4knots. The depth and the height of the mouth of the net were monitored with a net recorder. All samples were identified to the species as much as possible and weighted aboard the vessels. For the major species (ex. Japanese anchovy, Japanese sand lance, Pacific krill), a sample of 100 animals was taken, and lengths and weights were measured. Scaled and standard lengths were used to Japanese anchovy and adult / juvenile Japanese sand lances, respectively.

The distribution and abundance of the prey species were investigated with the quantitative echo sounder (EK 500; Simrad, Norway) on board *Takuyo maru*. Echo sounder data were recorded continuously while the vessel steamed on predetermined track line. The nominal steaming speeds on the track line was 9-10knots. Quantitative echo sounder EK500 with frequency at 38 and 120kHz were used to collect data for the acoustic survey. Acoustic data were acquired with Echoview version 3.00 (Sonar Data Pty Ltd, Australia). The copper sphere technique described in EK 500 operation manual (Simrad, 1997) was applied for the calibrations. Acoustic data were stored with an aid of software, Echoview (Sonar Data, Australia). Species/size compositions of echo signs were identified by targeting mid-water trawling. Water temperature and salinity profiles were recorded using Conductivity Temperature Depth profiler (CTD, Seabird, USA).

Data analysis methodology of quantitative echosounder
We applied the same acoustic data analysis described by method of 2009 JARPNII Review paper (Murase *et al.*, 2009), because it was appropriate for comparison purposes.

The wet weight (*wt*) of sand lance and Japanese anchovy were calculated with the following formula. Where, *SL* was standard length, *TL* was total length of prey species. In each stratum that 5% of the upper and lower values were not included in the analysis.

Sand lance adult	$\log_{10} wt(\mathrm{g}) = 2.7288 \times \log_{10}(SL, cm) - 2.0371$	(Murase, *per com*)	(1)
Sand lance Juvenile	$\log_{10} wt(\mathrm{g}) = 3.0572 \times \log_{10}(SL, cm) - 2.4885$	(Murase, *per com*)	(2)
Japanese anchovy	$wt\ (\mathrm{g}) = 0.004 \times (SL, cm)^{3.09}$	(Anonymous, 1990)	(3)

Each backscattering cross section area (σ) was calculated with the following formula based on prey species target strength:

$$\sigma = 4\pi 10^{TS(L)/10} \tag{4}$$

where, *TS(L)* were Target Strength (*TS*) of sand lance (juvenile and adult) and Japanese anchovy.

Sand lance adult	$\mathrm{TS} = 21.4 \times \log_e(SL, mm) - 170.2$	(Murase, *per com*)	(5)
Sand lance juvenile	$\mathrm{TS} = 22.3 \times \log_e(SL, mm) - 160.2$	(Murase, *per com*)	(6)
Japanese anchovy	$\mathrm{TS} = 20.0 \times \log_e(TL, cm) - 72.5$	(Iversen *et al*., 1993)	(7)

Mean backscattering area per square n.mile of survey transect (S_A) attributed to prey species for every 1n.mile of survey transect over 15 to 150m depth was calculated by following formula;

$$s_A = 4\pi r_0^2 1852^2 \int_{r_1=15}^{r_2=150} s_V dr \left(\frac{m^2}{n.mi^2}\right) \tag{8}$$

where, r is depth from the surface, $r0$ = 1m representing the reference range for backscattering strength and S_V = 0 if 10 log (S_V)≦–80dB, because threshold backscattering was set at –80dB. $\Delta MVBS$ was calculated quantitatively using Echoview.

Average area prey species biomass density (ρ_i) was calculated as follows;

$$\rho_i = S_A \frac{w}{\sigma} \tag{9}$$

With this formula mean prey species biomass of each transect in each stratum was calculated. Weighted mean of (ρ_k) of each block was;

$$\rho_k = \frac{\sum(\rho_i \times n_i)}{\sum n_i} \tag{10}$$

where, ρ_k = mean S_A in kth block, n_i = number of transects in kth block, Then variance of ρ_k was calculated with the formula;

$$Var(\rho_k) = \frac{N}{N-1} \frac{\sum(\rho_i - \rho_k)^2 n_i^{\,2}}{\left(\sum n_i\right)^2} \tag{11}$$

Biomass was estimated as;

$$B_k = A \times \rho_k \tag{12}$$

where, B_k is density biomass in kth block and A is area of kth block. Variance of B_k was calculated with following formula;

$$Var(B_k) = A^2 \times Var(\rho_k) \tag{13}$$

Coefficient of variation of B_k was calculated as;

$$CV(B_k) = \frac{\sqrt{Var(B_k)}}{B_k} \tag{14}$$

In this study, biomass estimation of prey species were estimated in blocks B and C. Because, main distribution of sand lance is also covered in blocks B and C.

RESULTS

Survey distance of each block

Track design is shown in Figure 3. The number of transects and survey distance of each block are shown in Table 2. In 2008 season, total survey distance in blocks B and C were 99.7 and 91.8n.miles, respectively. In 2009 season, total survey distance in blocks B and C were 70.1 and 92.4n.miles, respectively.

Sizes of the prey species sampled

The sample size and average length of sand lance and Japanese anchovy by trawl survey in 2008 and 2009 are shown in Table 3. Body length of sand lance (adult and juvenile) ranged from 80 to 162mm, from 25 to 70mm, respectively. Body length of Japanese anchovy ranged from 65 to 106mm (Table 3). Results of the size distribution of sand lance and Japanese anchovy in 2008 and 2009 are shown in Figures. 4, 5 and 6.

Biomass estimation of prey species by each block

The results of the density and biomass estimation of sand lance and Japanese anchovy in each block are shown in Tables 4 and 5. In 2008 season, total biomass estimations of sand lance adult in blocks B and C were 2,718 and 5,358tons, respectively; those of sand lance juvenile were 82 and 1,155tons, respectively. The biomass estimations of Japanese anchovy were 0.14 and 0.05tons, respectively. In 2009 season, total biomass estimations of sand lance adults in block B and C were 790 and 1,722tons, respectively; those of sand lance juvenile were 8 and 307 tons, respectively. The biomass estimations of Japanese anchovy were 0.39 and 0.24tons, respectively.

The mean densities in each prey were from 0.7 to 7.1g/m^2 in sand lance adult from 0.01 to 1.5g/m^2 in sand lance juvenile. The mean densities in Japanese anchovy were from 0.0001 to 0.0003g/m^2.

DISCUSSION

Biomass estimates of sand lance were higher than Japanese anchovy in the 2008 and 2009 surveys. This result was similar to those of a previous study (Murase *et al*., 2009).

Sand lance is distributed in the central region of the Sendai Bay where the water depth was 40-70m with medium to large gravel bottom substrate (Kobayashi *et al.*, 1995). Adult sand lance (local name: Meroudo) in the Sendai Bay bury themselves in the substrate and estivate without feeding during summer while their feeding occur in pelagic water from late winter to early summer (Kobayashi *et al.*, 1995; Kodama, 1980). Their spawning occur during the rest of season. Because of their unique life history, sand lance is a resident species in the Sendai Bay in contrast to other migrant pelagic fish such as Japanese anchovy. Sand lance in Sendai Bay in spring would be a predictable prey species for common minke whales. This could be one of the reasons why common minke whales are distributed in the Sendai bay in spring.

It was reported that lesser sand eel (*A. marinus*) was an important prey for common minke whale in a local region (the eastern North Sea) of the eastern North Atlantic (Windsland *et al.*, 2007). A small scale habitat study in the coastal water of Scotland suggested that seasonal movement of common minke whales could be related to availability of lesser sand eel (Macleod *et al*., 2004). Based on the results of this study, it can be concluded that the sand lance is a locally and temporally important species for common minke whales in Sendai Bay. Windsland *et al*. (2007) reported that common minke whales could switch their prey from sand eel to haddock in the eastern North Sea when the recruitment of sand eel was poor. It is expected that such prey switching might occur in Sendai Bay when biomass of sand lance is low. Tamura *et al* (2016: SC/F16/JR17), however, suggested that prey switching do not occur in Sendai Bay.

Commercial fishing of sand lance operates in Sendai Bay in spring. Traditionally, juvenile (body length ≤ 10 cm) and adult sand lance are captured by lift net with light and large dip net, respectively. Bottom trawl fishing boats participated in adult sand lance fishing from 1984 to 1989 (Nagashima, 2004). Because the negative effects of bottom trawling on abundance of sand lance, local fishing associations abstained of conducting trawl fisheries and they set a fishing quota for lift net fishing in 1990 (Nagashima, 2004). The abundance of sand lance increased after 1990 again. Sand lance in Sendai Bay is considered as a distinctive stock based on biological and morphological characteristics (Kodama, 1980). Though they are distributed in coastal waters around Japan. Because both commercial fishing and minke whales target on the single stock of sand lance in the small area, effect of commercial catch and feeding by common minke whales is expected to be high.

Similar acoustic surveys were conducted in JARPNII in 2005 and 2006 (Appendix 2: Murase *et al*. 2009). In 2005 and 2006 season, in blocks B, C, E and F, biomass of sand lance were reported 7,610 and 28,340tons, respectively. In 2005 and 2006 seasons, in blocks B, C, E and F, biomass of Japanese anchovy were reported 1,320 and 9,060tons, respectively. A direct comparison of those surveys with the present study is complicated, because differences in the blocks surveyed. Although the densities were similar between both studies, difficulties experienced in the comparison of prey species abundance derived from echo sounder surveys should be recognized. Factors that should be considered in the comparisons include differences in survey coverage, differences in design and timing of surveys and differences in the methods for estimating biomass of prey species.

There are some general limitations to the interpretation of the result of abundance estimation of prey species using echo sounder: 1) background prey species could not be detected by echo sounder because of low density, 2) surface prey species which meant could distribute shallower than the transducers. These limitations would contribute to an underestimation of prey species biomass. Overall, the results presented here provided general distribution and biomass patterns of prey species in the survey area. The following points should be considered to improve the echo sounder survey in future: 1) survey should be conducted in peak abundance season to minimize seasonal effect on abundance estimation, 2) survey should be conducted in same area and survey timing to interpret yearly changes, and 3) prey survey should be conducted concurrently with cetacean samplings.

However, these results of estimates of sand lance by echosounder could be useful for comparing to the prey consumption by common minke whales (Tamura *et al*, 2016: SC/F16/JR17).

Results of preliminary ecosystem modelling work suggested that feeding of minke whales had substantial impact on MSY of sand lance but the magnitude was depended on shape of functional response (relationship between consumption by predator and prey availability) (Okamura *et al*., 2009). See updated results of the ecosystem modelling work in Kitakado *et al.* (2016: SC/F16/JR29).

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Table 1. Summary of prey surveys in Sanriku region from 2003 to 2013 excluding 2004 and 2011.

Season	Date	Area (Block)	Vessel	Gross Tonnage (t)	Midwater trawl	Bongo net	Sabiki	IKMT	Echosounder	Frequency (kHz)
2003	9-28 Apr.	35N-41N I,II	*Kaiyo-Maru No.7*	499	22	4	-	17	EK500	38,120,200
2004	No survey									
2005	11-27 Apr.	38.21N-37.54N-37.40N A,B,C,D,E,Fand G	*Takuyo-Maru*	120	14	-	-	-	EK500	38,120,200
2006	11-27 Apr.	38.21N-37.54N-37.40N A,B,C,D,E,F,G,H, I and J	*Takuyo-Maru*, *Syunyo- MAru*	120 887	11	1	2	-	EK500	38,120,200
2007	9-27 Apr.	38.21N-37.54N-37.40N B,C,D,E,F and G	*Takuyo-Maru*	120	10	-	-	-	EK500	38,120,200
2008	9-24 Apr.	38.21N-37.54N-37.40N B,C,D,E and F	*Takuyo-Maru*	120	9	-	-	-	EK500	38,120,200
2009	20 Apr.-1 May	38.21N-37.54N-37.40N B,C,D,E and F	*Takuyo-Maru*	120	9	-	-	-	EK500	38,120,200
2010	16-27 Apr. 13-22 May	38.21N-37.54N-37.40N B,C,E and F	*Takuyo-Maru*	120	12	-	-	-	EK500	38,120,200
2011	Cancelled (Effects of the Great East Japan Earthquake)									
2012	16-21 Apr. 14-18 May	38.40N-38.15N-37.54N A,B,C and D	*Takuyo-Maru*	120	12	-	-	-	EK500	38,120,200
2013	16-24 Apr. 21-23 May	38.40N-38.15N-37.54N A,B,C and D	*Takuyo-Maru*	120	8	-	-	-	EK500	38,120,200

Table 2. Detail of prey survey in Sanriku region in 2008 and 2009.

Block	2008		2009	
	Number of transect	Survey distance (n.miles)	Number of transect	Survey distance (n.miles)
B	9	99.7	8	70.1
C	9	91.8	13	92.4

Table 3. The number of individuals of samples, minimum, maximum and average of body length of sand lance and Japanese anchovy sampled by trawl surveys in 2008 and 2009

Species	Numbers	Average (mm)	Minimum (mm)	Maximum (mm)
Sand lance (Adult)	201	105	80	162
Sand lance (Juveile)	507	41	25	70
Japanese anchovy	33	85	65	106

Table 4. Mean density and biomass of sand lance and Japanese anchovy in blocks B and C in 2008.

(Block B)

Species	Mean density (g/m^2)	Biomass (t)	CV (%)
Sand lance (Adult)	2.4	2,718	4.9
Sand lance (Juveile)	0.07	82	4.7
Japanese anchovy	0.0001	0.14	4.0

(Block C)

Species	Mean density (g/m^2)	Biomass (t)	CV (%)
Sand lance (Adult)	7.1	5,358	8.2
Sand lance (Juveile)	1.5	1,155	6.0
Japanese anchovy	0.0001	0.05	5.0

Table 5. Mean density and biomass of sand lance and Japanese anchovy in blocks B and C in 2009.

(Block B)

Species	Mean density (g/m^2)	Biomass (t)	CV (%)
Sand lance (Adult)	0.7	790	3.6
Sand lance (Juveile)	0.01	8	3.9
Japanese anchovy	0.0003	0.39	6.3

(Block C)

Species	Mean density (g/m^2)	Biomass (t)	CV (%)
Sand lance (Adult)	2.3	1,722	3.4
Sand lance (Juveile)	0.4	307	5.5
Japanese anchovy	0.0003	0.24	4.2

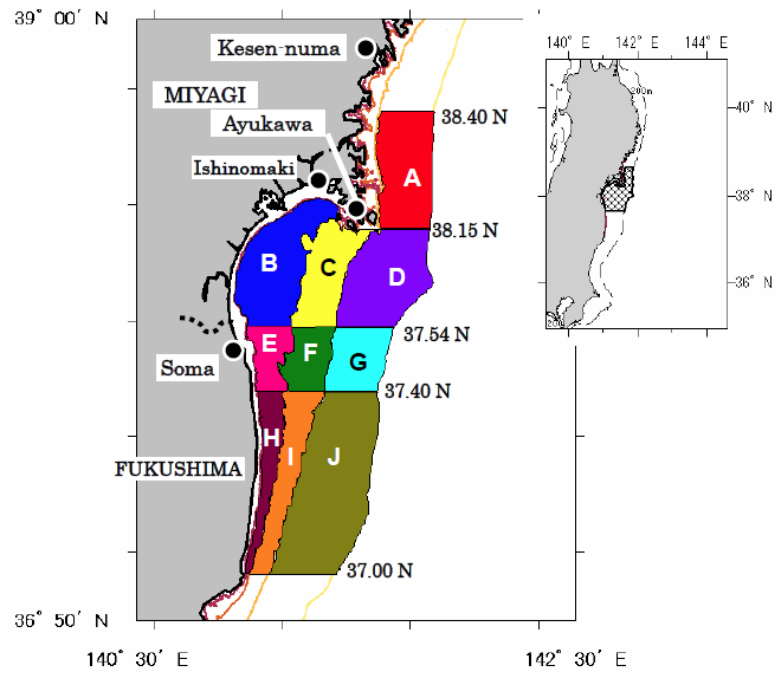

Figure 1. The survey area and nine blocks of prey species surveys of Sanriku region since 2005. Blocks H, I and J were investigated in 2006 only.
In 2008 and 2009, five Blocks (B, C, D, E and F) were investigated

Figure 2. Prey surveys vessel, *Takuyo-maru* (TKY) in 2008 and 2009.

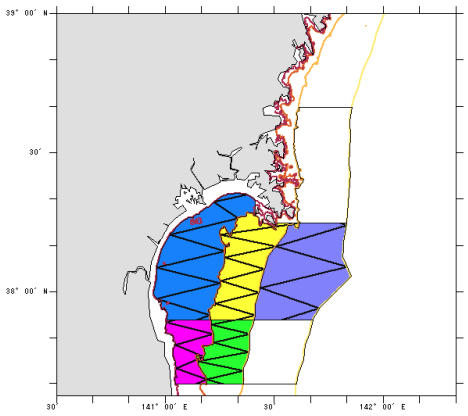

Figure 3. The track line of prey surveys in 2008 and 2009.

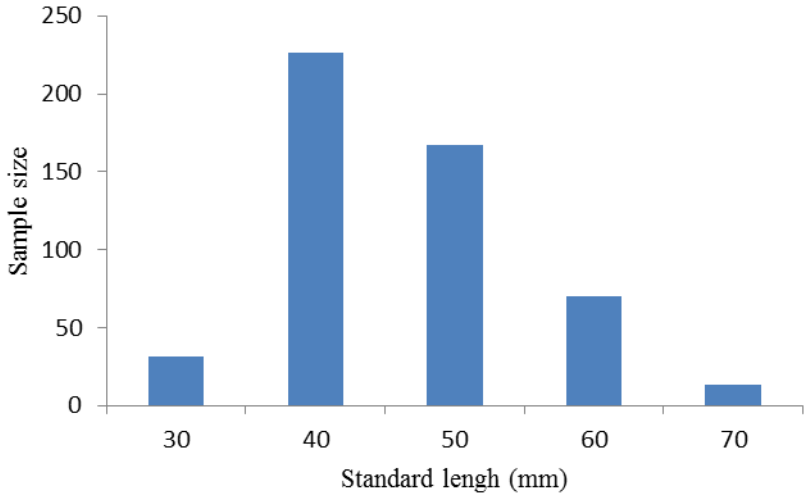

Figure 4. Body length distribution of sand lance juvenile sampled by trawl survey in 2008 and 2009.

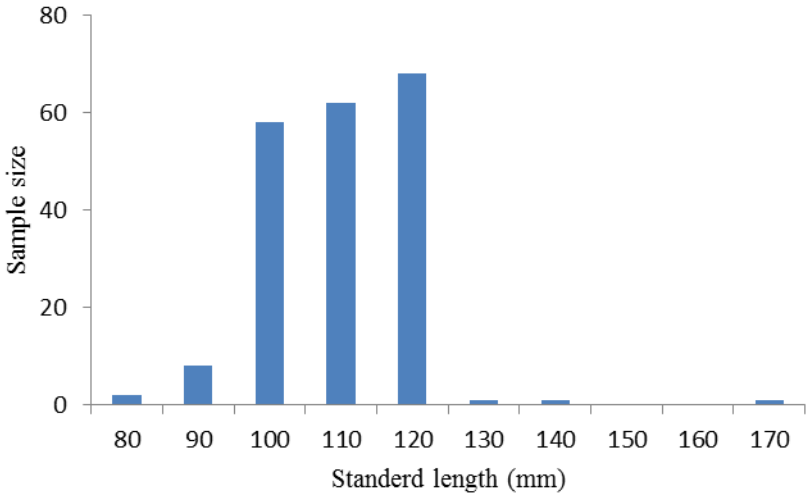

Figure 5. Body length distribution of sand lance adult sampled by trawl survey in 2008 and 2009.

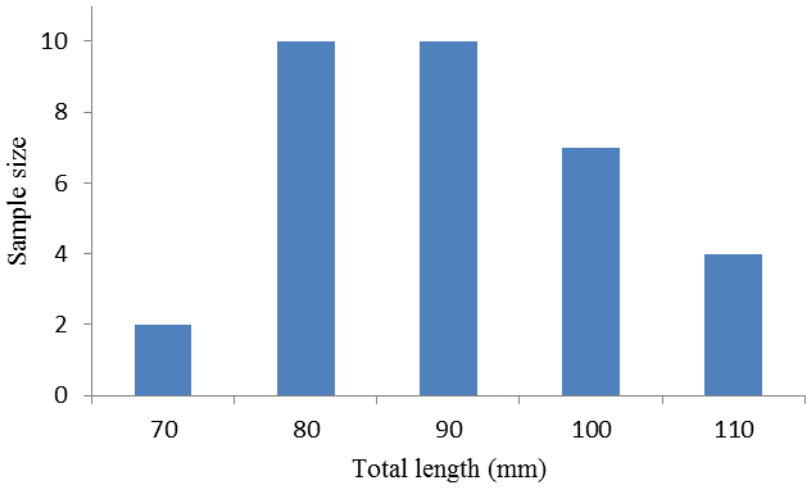

Figure 6. Body length distribution of Japanese anchovy sampled by trawl survey in 2009.

Appendix 1. Information of prey species in the coastal waters off Sanriku.

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Japanese sand lance

R/V *Takuyo Maru* (120GT), Miyagi Prefecture Fisheries Technology Institute

Research period: every year in January

Research area: Sendai Bay

Methods: Bongo net by *Takuyo Maru* (120GT)

Index: CPUE (no. of individuals per m^3)

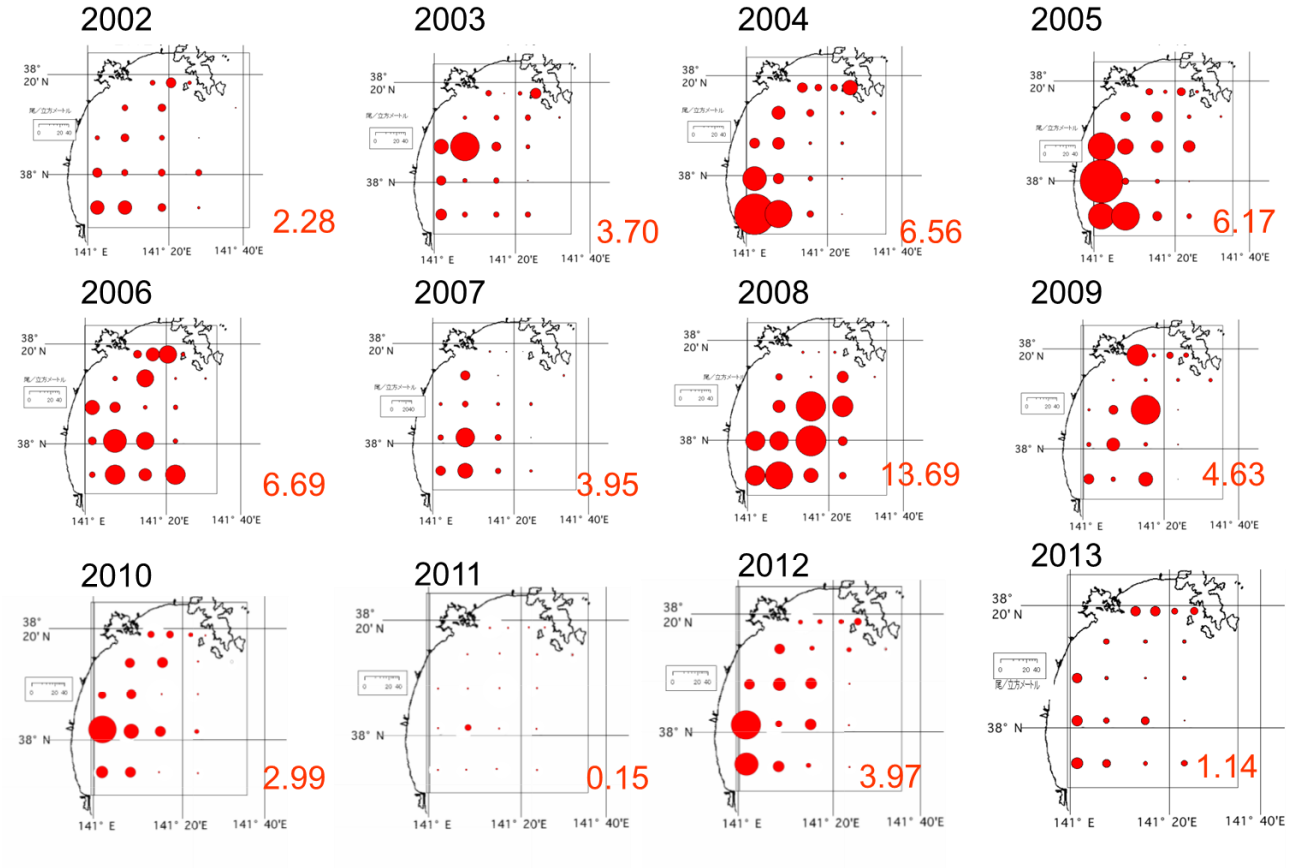

Figure 1. Occurrence of sand lance (juvenile) in January around Sendai Bay (ind./m^3)

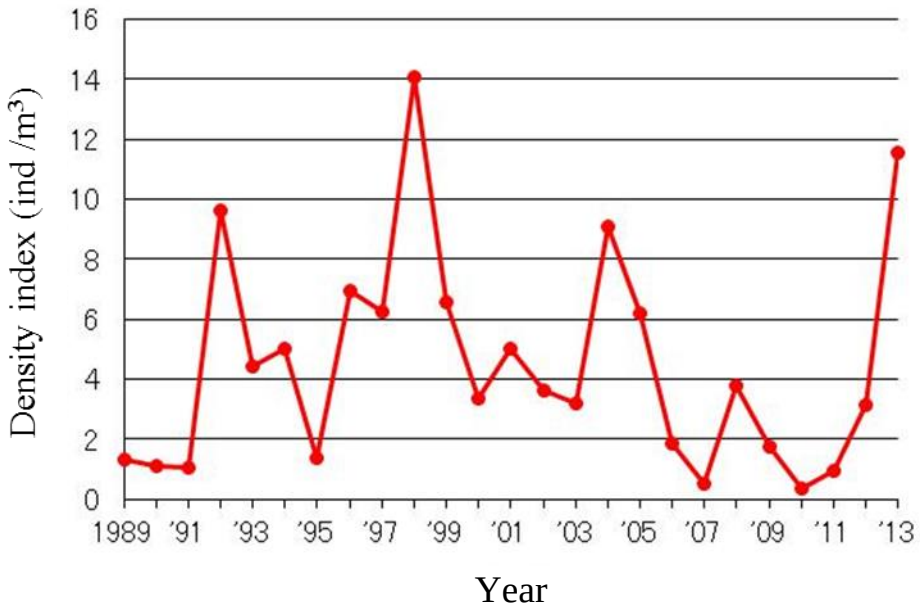

Figure 2. Yearly change of Density Index (ind./m^3) of sand lance in the estivation period around Sendai Bay

Appendix 2. Estimation of prey species biomass based on acoustic surveys.

(Adapted from Murase *et al*., 2009)

Table 1. Summary of the results of estimation of prey species biomass based on Echosounder.

Sand lance

Year	Analyzed blocks	Biomass (10^3 t)	Remarks
2005	B, C, E and F	7.61	Murase *et al*. 2009
2006	B, C, E and F	28.34	Murase *et al*. 2009
2008	B, C	9.31	This study
2009	B, C	2.83	This study

Japanese anchovy

Year	Analyzed blocks	Biomass (10^3 t)	Remarks
2005	B, C, E and F	1.32	Murase *et al*. 2009
2006	B, C, E and F	9.06	Murase *et al*. 2009
2008	B, C	0.0002	This study
2009	B, C	0.0006	This study