Estimation of prey preference of common minke whales (*Balaenoptera acutorostrata*) in a coastal component (off Sanriku) of JARPNII in 2005 and 2006

HIROTO MURASE[1], SHIGEYUKI KAWAHARA[2], HIROSHI NAGASHIMA[3], KEIICHI ONODERA[3], TSUTOMU TAMURA[1], RYOSUKE OKAMOTO[4], SHIROH, YONEZAKI[1], RYUICHI MATSUKURA[5], KENJI MINAMI[5], KAZUSHI MIYASHITA[6], HIDEYOSHI YOSHIDA[7], MUTSUO GOTO[1], TAKEHARU BANDO[1], DENZO INAGAKE[8], MAKOTO OKAZAKI[8], HIROSHI OKAMURA[7] AND HIDEHIRO KATO[4]

[1]*The Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo, 104-0055, Japan*
[2]*National Research Institute of Far Seas Fisheries, 5-7-1, Orido, Shimizu, Shizuoka, Shizuoka, 424-8633, Japan*
[3]*Miyagi Prefecture Fisheries Technology Institute, 97-6 Sodenohama, Watanoha, Ishinomaki, Miyagi 986-2135, Japan*
[4]*Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato-ku, Tokyo, 108-8477, Japan*
[5]*Graduate School of Environmental Science, Hokkaido University, 3-1-1 Minato-cho, Hakodata, Hokkaido 041-8611, Japan.*
[6]*Field Science Center for the Northern Biosphere, Hokkaido University, 3-1-1 Minato, Hakodate, Hokkaido, 041-8611, Japan*
[7]*National Research Institute of Far Seas Fisheries, 2-12-4 Fukuura, Kanazawa, Yokohama, Kanagawa 236-8648, Japan*
[8]*National Research Institute of Fisheries Science, 2-12-4 Fukuura, Kanazawa, Yokohama, Kanagawa 236-8648, Japan*

ABSTRACT

Prey preference of common minke whales in the coastal water off Sanriku, Japan, was studied to examine how they interacted with target species of local commercial fisheries. This was the first report of prey preference of minke whales in this region. To estimate the prey preference, sampling surveys of minke whales and their prey surveys were conducted in the same area at the same timing (April). The surveys were conducted as a part of a coastal component of JARPN II in 2005 and 2006. A local fisheries science institute, Miyagi Prefecture Fisheries Technology Institute, took part in the surveys. A prey preference index, Manly's α, was used in the analysis. Sum of Manly's α for all prey species is 1 and prey species with large values of Manly's α indicates preference for it. Minke whales fed on North Pacific krill, Japanese anchovy and Japanese sand lance (adult) during the surveys. These are important species of local commercial fisheries. Estimated average values of Manly's α for krill, anchovy and adult sand lance in 2005 and 2006 were 0.02 (se=0.02), 0.09 (se=0.08) and 0.89 (se=0.09), respectively. Minke whales showed preference for adult sand lance. As previously reported in other regions, krill was not preferred prey of minke whales. Ecosystem modelling work (Okamura *et al.*, 2009) suggested that change in a functional response form had substantial effect on predation impact on sand lance by minke whales. Functional response form can be estimated if long term prey preference data are available. Continuation of JARPN II will provide data to develop reliable ecosystem models for fisheries management.

INTRODUCTION

Removal of large whales from marine ecosystem as the results of commercial harvesting demonstrates that these whales play important role in marine trophic dynamics. Krill surplus, prey release due to removal of large whales by harvesting in the Antarctic, led increase in number of other krill predators such as Antarctic minke whales (*Balaenoptera bonaerensis*) and crabeater seal (*Lobodon carcinophaga*) (Laws, 1985), is well known example. In the North Pacific, it was postulated that decline of populations of seals, sea lions and sea otters was derived from prey switching of killer whales from large whales after post world war II commercial harvesting (Springer *et al.*, 2003) though opposite views were also presented (DeMaster *et al.*, 2006; Mizroch and Rice, 2006; Trites *et al.*, 2007; Wade *et al.*, 2007). After the ban of commercial harvesting of large whales, these populations show increasing trends worldwide in recent years. In tern, potential of competition between whales and commercial fisheries has been postulated (Tamura, 2003). However, those studies on trophic role of whales in ecosystem were conducted at large scale (e.g. ocean basin scale) and effect of whales on local scale (e.g. coastal fisheries area) is rarely studied. Study of effect of whales on local fisheries is important for fisheries management because it is expected that interaction between fisheries and whales is intense at local level and it would directly affect the livelihoods of fishermen.

Sendai Bay is located in the north-eastern region of Japan (Fig. 1). The bay is belonging to Sanriku region and it is an important fishing ground of local communities. A wide variety of species are harvested by local fishermen in the bay. The seasonal effect of changes in the location of the subarctic western boundary current with cold low-salinity water (Oyashio) and the subtropical western boundary current with warm high-salinity water (Kuroshio) is strong in the bay. Distribution patterns of biological organisms in Sendai Bay drastically change as the season progresses as the result of the changes in the oceanographic conditions. In springtime, North Pacific krill (*Euphausia pacifica*) and Japanese sand lance (*Ammodytes personatus*) are major target species of commercial fishing (Nagashima, 2000; Taki, 2002) Japanese anchovy (*Engraulis japonicus*) starts migration from south to north in springtime and some earlier migrants are observed in the bay in spring. Anchovy is also target of commercial fisheries (Nagashima, 2007). The bay is a part of the migration corridor of common minke whales (*B. acutorostrata*) and they are distributed in there in spring. Commercial whaling of minke whales by small-type whaling boats had been also one of the important local fisheries but it has been banned by the International Whaling Commission since 1986 without scientific justification. Past records suggested that minke whales mainly fed these commercially important species in this region (Kasamatsu and Tanaka, 1992). Though the impact of predation by minke whales on these preys could be large at the local scale, no systematic survey was conducted to assess the magnitude in the past.

The second phase of the Japanese Whale Research Program under Special Permit in the North Pacific (JARPN II) has been conducted since 2000. The research activity of JARPN II is legal according to Japanese national regulation and the International Convention for the Regulation of Whaling (ICRW). The overall goal of JARPN II is to contribute to the conservation and sustainable use of marine living resources including whales in the western North Pacific, especially within Japan's EEZ. One of the main objectives of JARPN II is estimation of prey preference of cetaceans. To estimates prey preference of cetaceans, cetacean sampling and prey surveys have been conducted simultaneously as a part of JARPN II. The surveys were conducted as feasibility studies in the first two years (2000 and 2001). Prey preferences of common minke and Bryde's (*B. edeni*) whales were estimated using data sets collected in the feasibility studies and results were reported to IWC/SC (Government of Japan, 2002) and published in peer reviewed scientific journal (Murase *et al.*, 2007). Based on the success of feasibility studies, JARPN II was expanded to full scale in 2002. In the full scale survey, JARPN II is divided into offshore and coastal components. Coastal component of JARPN II has been conducted off Kushiro and off Sanriku. Coastal component of JARPN II was conducted by the National Research Institute of Far Seas Fisheries and the Institute of Cetacean Research in cooperation with the Tokyo University of Marine Science and Technology. In addition, a local fisheries science institute, Miyagi Prefecture Fisheries Technology Institute, took part in the survey because of interests in feeding impact of minke whales on local fisheries.

It was planned that the results of full scale JARPNII will be review every six years. First six years period was 2002-2007. This paper presented the results of estimation of prey preference of minke whales off Sanriku in 2005 and 2006 using data collected by simultaneous cetacean sampling and prey surveys. Though survey was also conduced in 2007, the results were not presented because analysis was not completed. This was the first attempt to estimate prey preference of minke whales off Sanriku especially in Sendai Bay. In this paper, preference is defined as the animal choosing a resource irrespective of amount of resources.

MATERIALS AND METHODS

Survey area, timing of survey and vessels

Prey survey

The simultaneous cetacean sampling and prey surveys were conducted around Sendai Bay in April in 2005 and 2006 as a part of the coastal component of the JARPN II. For prey species surveys, the survey area was stratified into 7 blocks (A-G block) based on bottom depth and administrative boundary (Fig. 1). A zigzag trackline was set to cover each block. According to Aglen (1989), accurate biomass estimation will be expected if the index of survey distance (surveyed distance divided by square root of survey area) is larger than 6. The distance index in each survey block was at least 6 in this survey. Acoustic and oceanographic surveys were conducted using trawler-type RV, "Takuyo maru" (Miyagi prefecture, 120 GT). The RV steamed at 9 knots on tracklines. A quantitative echosounder, Simrad EK500 (Norway), with operating frequencies at 38 and 120 kHz was used for the acoustic survey. The data were recorded with the aid of Echoview (Myriax,, Australia). Calibrations were carried out prior to the survey every year using the copper sphere technique described in the EK 500 manual which was based on Foote (1982). A trawl net (mouth opening of 7 m (width) * 3.5 m (height) with 3mm liner cod end) was used to examine species compositions of representative echosigns in the survey area. Targeted trawls were conducted in the blocks where densities of species of interest were high. Representative echosigns were selected based on our previous knowledge. Because acoustic surveys using EK500 have been conducted in the survey area since 1999, we have qualitative information on the echosigns in the survey area. Details of prey survey methods were also described by Yonezaki *et al.* (2009).

Cetacean survey

Four small-type whaling catcher boats were engaged in sampling of minke whales in April and May from 2005 to 2006. Stomach contents of sampled minke whales were initially examined at the land station. The land station was established at Ayukawa port area in Miyagi prefecture. Details of cetacean surveys were described by Kishiro *et al.* (2009).

Oceanographic observation

Oceanographic conditions from sea surface to 1m above bottom were recorded by CTD. Sea surface temperature was recorded every 1 minute while RV steamed on the trackline. Contour maps of water temperature at surface and bottom were drawn based the ordinary Kriging method.

Stomach content analysis

Baleen whales have a four-chambered stomach system. Among them, the stomach contents remain in the forestomach (1st. stomach) and fundus (2nd. stomach) were used in this study. Details of stomach contents analysis were described in Tamura *et al*. (2009). Though sampling survey of minke whales conducted in April and May, samples collected in April were used in the analysis because prey surveys were conducted only in April.

Biomass estimation of prey species

Species identifications of echosigns were conducted based on the differences of mean volume backscattering strength between 120 kHz and 38 kHz (ΔMVBS120-38) and the mean of volume backscattering strength ($\overline{s_v}$) at 38 kHz and at 120 kHz. $\overline{s_v}$ and ΔMVBS120-38 were calculated based on the results of targeting trawl hauls. Ranges of $\overline{s_v}$ and ΔMVBS120-38 for three species were as follows; krill: -70 - -45 dB and 10 - 20 dB, anchovy (adult): -50 - -35 dB and -10 - 5 dB, sand lance (adult): -70 - -50 dB and -10 - 10 dB. We verified the results of the species identifications by visual inspection of echogram based on our previous knowledge. Nautical area scattering coefficient (s_A) by species for every 0.1 n.mile of survey transect from sea surface to bottom was calculated with a aid of Echoview. Theoretical target strength (TS) of krill and sand lance at 120 kHz were calculated based on the Distorted Wave Born Approximation (DWBA) model (Stanton and Chu, 2000 for review). Calculated length-TS (dB) relationships of krill and sand lance at 120 kHz based on DWBA were TS=50.7log(TL, mm)-150.4 and TS=49.3log(SL, mm)-160.2, respectively (Matsukura unpublished data). Length-TS relationship of anchovy was TS=20log(TL, cm)-72.5 (Iversen, *et al.*, 1993). Biomass densities ($\bar{\rho}$, t/n.mile2) of three species were estimated as $\bar{\rho} = \sum (s_A / \sigma_{bs}) f_i W_i$ where σ is acoustical scattering cross section (4π10^(0.1*TS)), *fi* was the frequency distribution of *i*th length class and *Wi* was weight of *i*th length class. Biomasses and the variances of three species were estimated based on a stratified random sampling method as described by Jolly and Hampton (1990). Because sand lance is capable to move vertically between pelagic water and bottom substrates where it buries itself during daytime (Robards and Piatt, 1999), sand lance detected by echosounder considered as not absolute biomass but as available biomass for minke whales for feeding.

Estimation of prey preference

The standardized form of Manly's selection index called Manly's α (Manly *et al.*, 1972), also known as Chesson's index (Chesson, 1978), was used in the study as in the cases of Lindstrøm and Haug (2001) and Murase *et al.* (2007). Selection index is calculated as follows.

Sample proportion of number of individuals with dominant prey species *i* in their stomach (n_i) in survey year *j* is

$$o_i = n_{ij} / \sum_{i=1}^{I} n_{ij} \ .$$

If more than two prey species is found in the stomachs, we only considered dominant species (e.g. if 100 kg of anchovy and 10 kg of krill are found in a stomach, the individual is treated that it consume only anchovy). It was assumed that each individual consumes the average daily prey consumption weight of dominant prey species *i* in the stomach. Thus, o_i is equal to sample proportion of prey species *i* by weight used by all animals. Sample proportion of available units (biomasses in survey block) in prey *i* in survey year *j* is

$$p_{ij} = m_{ij} / \sum_{i=1}^{I} m_{ij}$$

where m_{ij} is an amount of available units in prey *i* in survey year *j* in a sample of available resource units. Manly's selection index is

$$w_{ij} = o_{ij} / p_{ij} \ .$$

Standardized Manly's selection index, Manly's α is written as;

$$B_i = \frac{w_i}{\sum_i w_i}$$

If $\hat{B}_i$ is equal to $1/I$ (I is total number of prey species utilized by a predator species), species i is randomly selected. If B_i greater than $1/I$, species i is actively selected. If B_i is less than 1/I, species i is avoided.

The log-likelihood function based on a multinomial distribution is given by

$$\sum_{i=1}^{I}\sum_{j=1}^{J} n_{ij} \log\left(\frac{B_i a_{ij}}{\sum w_k a_{kj}}\right)$$

where a_{ij} is the density of prey i in the survey year j. Our objective is to estimate the B_i parameters by maximizing the above equation. Data in 2005 and 2006 were used to estimate average B_i in two years. Each density, a_{ij}, has its uncertainty in the form of CV. To account for the variation in estimation of selection indices, we used a Monte Carlo simulation technique with 1000 permutations. When $a_{ij}^* \sim LN(log(a_{ij}), CV_{ij}^2)$, we calculate the B_i^*s for each a_{ij}^*. Then the variance of B_i is given by $var(B_i) = E(var(B_i^*)) + var(E(B_i^*))$ where $var(B_i^*)$ is calculated by a Hessian matrix. Variance of B_i in each year is also estimated using same methods.

RESULTS

Oceanographic conditions

Contour maps of surface and bottom temperature were shown in Fig. 2. These maps suggested that oceanographic condition in the survey area was different in each year.

Distribution patterns and stomach contents of whales

Sighting effort and sighting positions by small-type whaling catcher boats were shown in Fig 3. Sighting positions and stomach contents of sampled minke whales were also shown in Fig. 3. Minke whales were sampled in B, C, E and F blocks. Summary of stomach contents in these blocks were shown in Table 1. Krill, anchovy and adult sand lance (≥ 10 cm) were only species found in the stomachs.

Distribution patterns and biomasses of prey species

Distribution patterns of krill, anchovy and adult sand lance were shown in Fig. 4. Krill was mainly distributed in offshore and northern region (A, D and G blocks). Distribution patterns of anchovy were varied year to year according to change in sea surface temperature. Adult sand lance was distributed in nearshore region (B, C, E and F blocks). Biomasses of these species were summarized in Table 2.

Prey preference of minke whales

Prey preference of minke whales in each year and average values in two years (2005 and 2006) was summarized in Table 3. Because minke whales were mainly sampled in B, C, E and F blocks, data in these blocks were pooled to estimate the prey preference. Minke whales showed preference for sand lance in each year. Krill and anchovy were avoided. Average value of Manly's α in 2005 to 2006 indicated that minke whales preferred firstly sand lance, secondary anchovy and thirdly krill in the survey area in April.

DISCUSSION

This was the first report of prey preference of minke in Sendai Bay. As in the cases of studies in the Norwegian water (Harbitz and Lindstrøm, 2001; Haug *et al.*, 1996; Lindstrøm and Haug, 2001; Skaug *et al.*, 1997; Sivertsen *et al.*, 2006) and in the western North Pacific (Murase *et al.*, 2007; Muraase *et al.* 2009), minke whales showed preference for pelagic shoaling fishes while they avoided krill in this study. Previous studies suggested that minke whales showed preference for anchovy in the western North Pacific in summer (Murase *et al.*, 2007; Muraase *et al.* 2009). In contrast, they showed preference for sand lance in Sendai Bay in spring. Biomass estimates of sand lance were higher than anchovy in all years in this study. The results indicated that minke whales could show preference for abundant pelagic shoaling fishes if more than two pelagic shoaling fish are presented. Krill was mainly distributed in offshore and northern region (A, D and G blocks). Few minke whales were sighted in these blocks (Hakamada *et al.*, 2009). Though prey preference in these blocks could not be estimated in this analysis, few minke whales sightings in these blocks indicated that krill was not preferred prey for them.

Sand lance is distributed in the central region of Sendai Bay where the water depth was 40-70m with medium to large gravel bottom substrate (Kobayashi *et al.*, 1995). Adult sand lance in the 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 rest of season. Because of their unique life history, sand lance is resident species in the bay in contrast to other migrant pelagic fish such as anchovy. Sand lance in Sendai bay in spring would be highly predictable prey for minke whales. This could be one of the reasons why minke whales are distributed in the bay in spring. It was reported that lesser sandeel (*A. marinus*) was an important prey in a local region (the eastern North Sea) of the northeastern Atlantic (Windsland *et al.*, 2007). A small scale habitat study in the coastal water of Scotland suggested that seasonal movement of minke whales could be related to availability of lesser sandeel (Macleod *et al.*, 2004). Together with the results of this study, it can be concluded that *Ammodytes* spp. are locally and temporally important species for minke whales. Windsland *et al.* (2007) reported that minke whales could switch their prey from sandeel to haddock in the eastern North Sea when the recruitment of sandeel was poor. It is expected that such prey switching might occur in Sendai Bay when biomass of sand lance is low.

Commercial fishing of sand lance is operated in Sendai Bay in spring. Traditionally, juvenile (≤ 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 effect of bottom trawling on abundance of sand lance was devastated, local fishing associations abstained trawl fisheries and set fishing quota for lift net fishing in 1990 (Nagashima, 2004). The abundance of sand lance increased after 1990. Sand lance in Sedai 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 minke whales is expected to be high. 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). It was strongly recommended that effort be focused on appropriate data collection and/or experiments to develop the most appropriate functional response form to represent feeding behaviour (Pláganyi, 2007). Multispecies functional response of common minke whales in the southern Barents Sea was estimated at micro scale (Smout and Lindstrøm, 2007). For fisheries management purpose, ecosystem model at meso to macro scale is required. Functional response form at different scales could be different. Functional response form required by ecosystem model for fisheries model needs long term collection of prey preference data. It was suggested that biomass of lesser sandeel could be controlled by both top-down and bottom-up processes in the North Sea (Frederiksen *et al.*, 2007). To model interactions between marine mammal and fisheries, it is important to be able to investigate the long term dynamics of a system (Matthiopolos *et al.*, 2008). Continuation of JARPN II is important to develop appropriate functional response form for minke whales.

ACKNOWLEDGMENTS

Authors express thank you to the crews and the researchers who dedicated to collect data in the field. Special thanks are given to Ms. Tomoko Hasegawa who supported the handling of huge amount of data set. This survey was supported by Fisheries Agency of Japan, Fisheries Research Agency of Japan, Miyagi Prefecture and the Institute of Cetacean Research. We thank these institutions for their support.

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Table 1. Summary of stomach contents of minke whales in B, C, E and F blocks. Number of individuals with dominant prey species in their stomach was summarized. If two prey species were found in the stomach, only a dominant species in wet weight was counted.

Year	Krill	Japanese anchovy	Sand lance
	# of ind.	# of ind.	# of ind.
2005	2	0	25
2006	0	1	17

Table 2. Biomasses of preys in B, C, E and F blocks.

Year	Krill		Japanese anchovy		Sand lance	
	Biomass (10^3t)	CV	Biomass (10^3t)	CV	Biomass (10^3t)	CV
2005	22.78	0.36	1.32	0.33	7.61	0.19
2006	3.03	0.11	9.06	0.19	28.34	0.07

Table 3. Values of Manly's α as a means of indications of prey preferences of minke whales in B, C, E and F blocks. Standard error (se) is also shown. If Manly's α is equal to 1/*I*, species *i* is randomly selected. If Manly's α is greater than 1/*I*, species *i* is actively selected. If Manly's α is less than 1/*I*, species *i* is avoided. *I* is total number of species consumed by minke whales.

Year	Krill		Japanese Anchovy		Sand Lance	
	Manly's α	se	Manly's α	se	Manly's α	se
2005	0.03	-	0.00	-	0.97	-
2006	0.00	-	0.16	0.14	0.84	0.14
Average	0.02	0.02	0.09	0.08	0.89	0.09

*Standard error in 2005 couldn't be estimated.

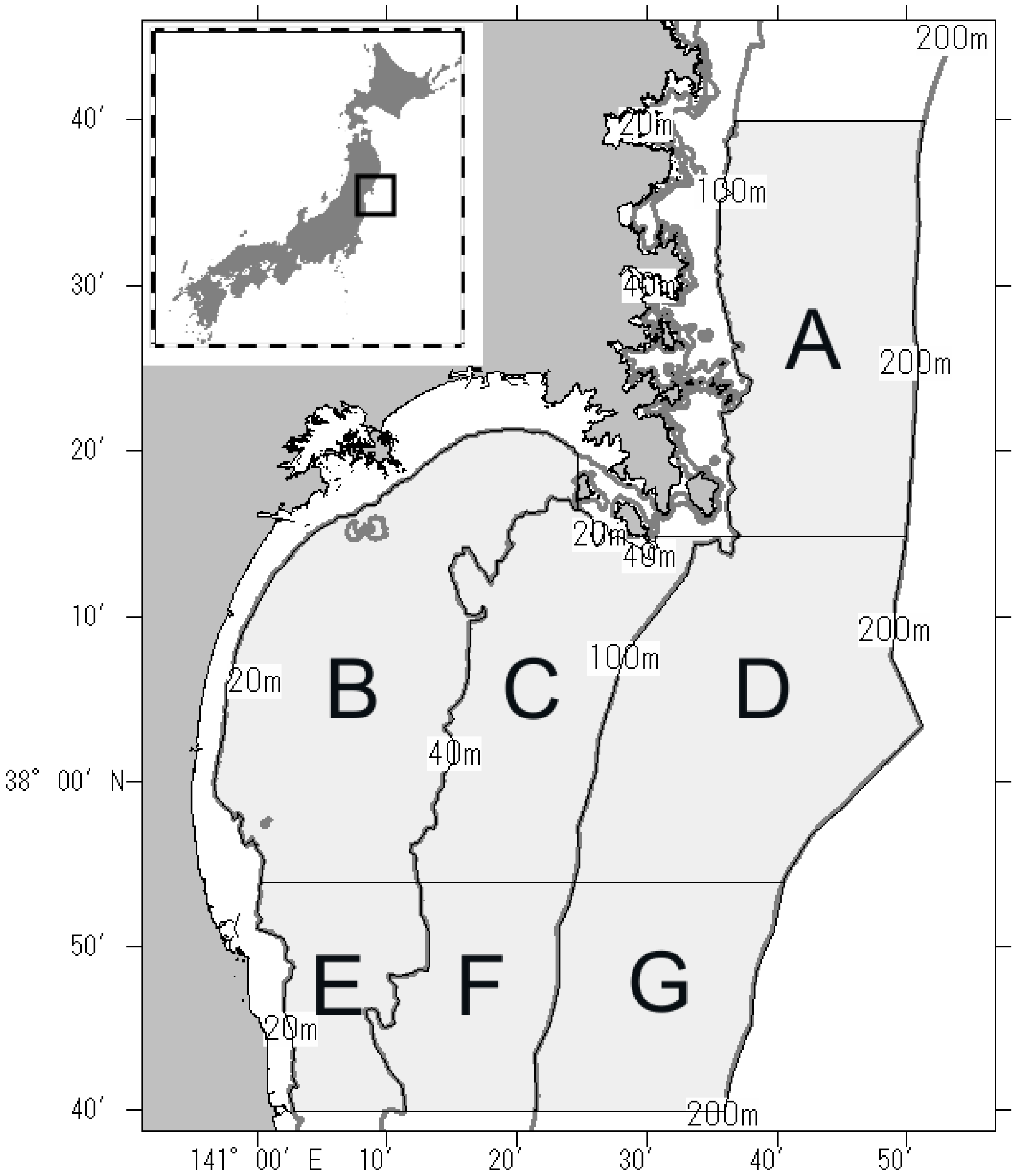

Fig. 1. Map of the survey area in Sendai Bay, Japan. The survey area was stratified into 7 blocks (A-G) for the purpose of a stratified random sampling to estimate biomass of krill, Japanese anchovy and sand lance.

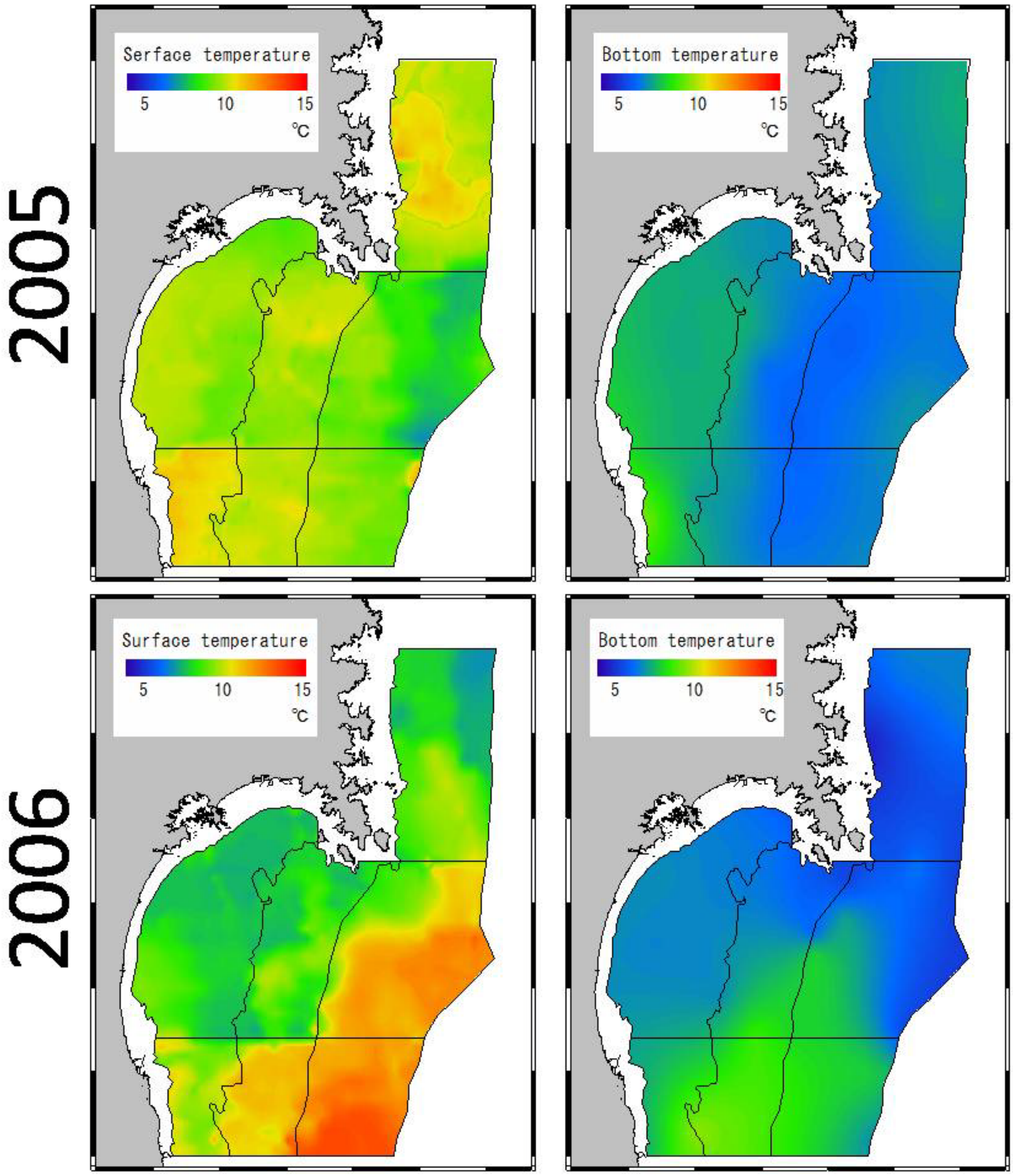

Fig. 2. Contour maps of surface (left) and bottom (right) temperature in the survey area.

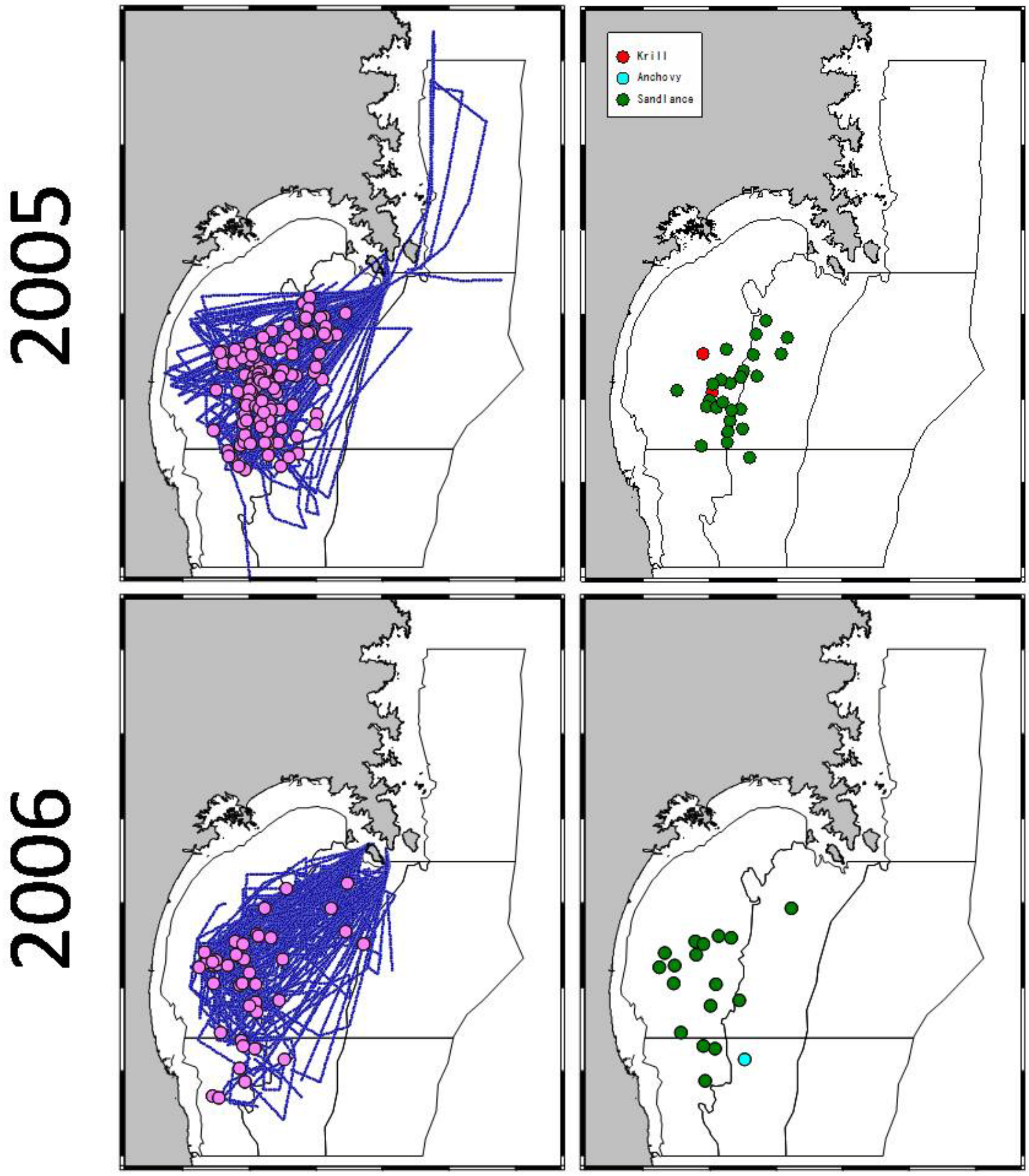

Fig 3. Cruise tracks and sighting positions of minke whales (left) and sighting positions of animals and their dominant stomachs contents of sampled minke whales (right). Blue line: cruise tracks; pink circle: sighting positions; red circle: stomach with krill; sky blue circle: stomach with Japanese anchovy; green circle: stomach with adult sand lance.

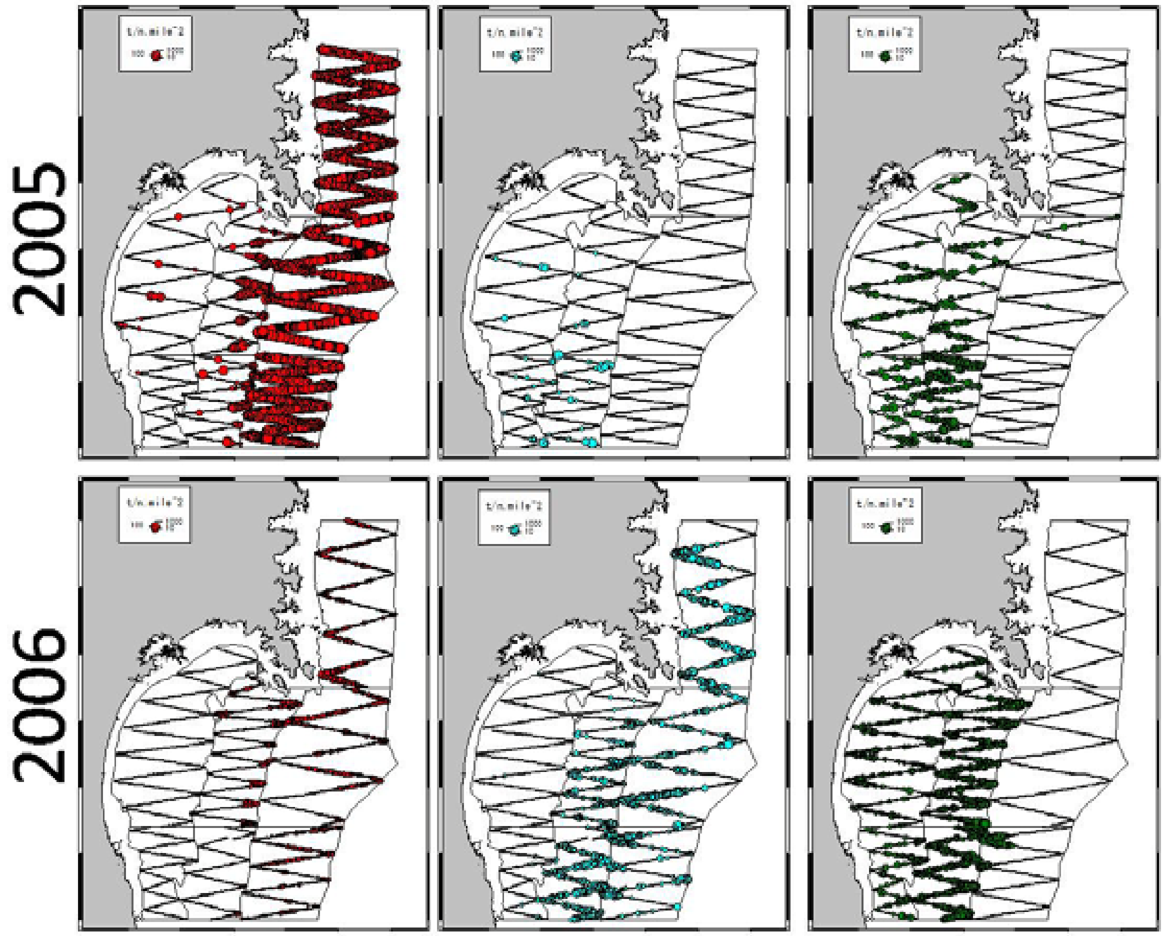

Fig. 4. Distribution patterns of krill (left), Japanese anchovy (middle) and adult sand lance (right) in the survey area detected by the echosounder.