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ABSTRACT

Prey preferences of common minke, Bryde's and sei whales at meso scale were estimated using data from the cooperative surveys of cetacean sampling and prey of cetaceans. The surveys were conducted as a part of the offshore component of JARPNII from 2002 to 2007. This was the first report of prey preferences of minke, Bryde's and sei whales in the offshore region of the western North Pacific. Prey preferences of sei whales have not been reported in any part of world in the past. The preferences were estimated as input parameters for a minimum realistic type ecosystem model. A prey preference index, Manly's α, was used in the analysis. The 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. For minke whales, Manly's α of krill, Japanese anchovy and Pacific saury were 0.05 (se=0.03), 0.36 (se=0.19) and 0.59 (se=0.17), respectively. Minke whales showed preference toward pelagic fishes as previously reported. For Bryde's whales, Manly's α of krill and anchovy were 0.05 (se=0.04) and 0.95 (se=0.04), respectively. For sei whales, Manly's α of copepods, krill, anchovy and saury were 0.41 (se=0.10), 0.13 (se=0.04), 0.25 (se=0.10) and 0.20 (se=0.08), respectively. Though preys of three baleen whale species overlapped, Manly's α suggested their trophic niches were different from each other. Minke and sei whales coexisted in same survey blocks but their prey utilization patterns were different. For example, distribution of minke and sei whales was overlapped in block A in 2003. In this block, minke whales showed preference toward saury while sei whales showed preference toward copepods. Accumulation of prey preference data for long periods provides the basis for appropriate choice of functional response form which is required by ecosystem models for fisheries management. Continuation of long term research such as JARPN II is important to develop reliable ecosystem models.

INTRODUCTION

Study on the ecological niche theory is one of the most active fields of ecology (Hirzel *et al.*, 2008). Estimation of prey preference is one of the study methods to define a trophic niche of a species. Aside from such a pure scientific interest, prey preference plays important role in applied science. It is one of the key parameters in the ecosystem model developed for a purpose of fisheries management. The ecosystem approach to fisheries management is widely accepted concept worldwide and many international organizations require its application (Morishita, 2008). The International Whaling Commission (IWC) unanimously decided to make the study of interactions between whales and fish stocks matter of priority in 2001

(IWC, 2002). The IWC held the Modelling Workshop on Cetacean-Fishery Competition in 2002 (IWC, 2004). The Scientific Committee of the IWC (IWC/SC) created working group on Ecosystem Modelling with recognition of the importance of this matter. In response to the requests from the international community, scientists have developed a wide variety of ecosystem models (Pláganyi, 2007 for review). Some ecosystem models such as MULTISPEC (Bogstad *et al.*, 1997) and GADGET (Begley, 2008) require prey preference of predator as one of key parameters. A mathematical model for functional response of predator (relationship between consumption by predator and prey availability) is key function in other ecosystem models such as Ecopath with Ecosim (EwE) (Christensen *et al.*, 2005). Functional response required by such models can only be estimated using long term prey preference data. Prey preference of predators can only be studied to compare species compositions of prey in stomachs of predators with species compositions of prey in a field.

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, concurrent cetacean sampling and prey surveys have been conducted 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 (*Balaenoptera acutorostrata*) 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. Sei whale (*B. borealis*) was added as a target cetacean species in addition to minke and Bryde's whales.

There are three spatiotemporal scale to link feeding ecology of cetaceans with distribution pattern of them and the definitions are follows; at the macro scale, cetaceans migrate seasonally between feeding and breeding grounds; at the meso scale, cetaceans move over days and weeks in search of preferred local abundance of food; and at the micro scale, whales dive and search for food within localised areas (IWC, 2003). In JARPN II, prey preference of whales is considered as one of the input parameter of ecosystem models not at individual level but at population level in the feeding area.

It was planned that the results of full scale JARPNII will be review every six years. First six years period was 2002-2007. In the full scale survey, JARPNII has three components (three regional survey areas) namely off Sanriku, off Kushiro and offshore. In this paper, results of estimation of prey preferences using data sets obtained by the offshore components in first six years period were reported. Specifically, prey preferences of minke, Bryde's and sei whales were estimated as a parameter for minimum realistic type ecosystem models developed by Kawahara (2009). This was the first report of prey preference of sei whales worldwide. Although prey preferences of common minke and Bryde's whales in the western North Pacific were estimated using data obtained feasibility studies of JARPN II (Murase *et al.,* 2007), areal coverage was limited to the west of 150°E. Prey preferences of common minke and Bryde's whales to the east of 150°E were also studied in the full scale survey where no results had been reported in the past. 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

The survey area of the cetacean prey surveys in JARPN II offshore component was in the western North Pacific (Fig 1). Southern, northern, eastern and western boundaries of the survey area were 35°N, boundary of economic exclusive zone (EEZ) claimed by a foreign country, 170°E and eastern coast line of Japan, respectively. Continental shelf region of Japan (shallower than 200 m water depth) was not included. The survey area corresponds to Sub-areas 7, 8 and 9 which are set for the Implementation Simulation Trials of common minke whale in the North Pacific (IWC, 1994). Although the most of survey area of offshore component of JARPNII is out of EEZ of Japan, the area is migration corridors for many pelagic fish such as Japanese anchovy *(Engraulis japonicus*), Japanese pilchard (*Sardinops melanostictus*), Pacific saury (*Cololabis saira*) and chub mackerel (*Scomber japonicus*). Because those pelagic fishes show seasonal migration between inside and outside of Japanese EEZ, investigation of feeding impact of cetaceans on those species is important. Within the survey area, one to three small blocks were set for cooperative whale and prey surveys every year. Locations and timing of surveys of these small blocks were shown in Table 1 and Fig. 1. Both whale and prey surveys were conducted simultaneously in the survey blocks so that data were collected at same spatiotemporal scale. Ideally, the cooperative survey should be conducted in entire the survey area. However, because availability of fisheries research vessel for prey survey was limited, small blocks were established within the survey area. Small blocks were set considering potential influence from the oceanographic conditions, such as positions of fronts and water masses as well as anticipated distribution pattern of the target cetacean species so that the defined small blocks could be treated as representations of the entire survey area. The survey blocks were poststratified based on observed in-situ oceanographic conditions and distribution patterns of target species. The cooperative whale sampling and prey surveys were conducted from 2002 to 2007 (except 2006). Three sighting and sampling vessels (SSVs) were engaged in the whale survey consisting of sighting and sampling of whales. Stomach contents of sampled minke, Bryde's and sei whales were initially examined on the research base ship, *Nisshin-Maru*. In addition to those whale survey vessels, one trawler type fisheries research vessel was engaged in prey surveys every year. Details of Survey area and timing of prey survey were summarized in Murase *et al.* (2009). Concurrent surveys were conducted in daytime from 30 minutes after sunrise to 30 minutes before sunset. Details of whale surveys were summarized in Tamura *et al.* (2009(b)).

Oceanographic observation

Oceanographic observation was conducted using CTD and XCTD to examine position of oceanographic front in each block. Positions of the Subarctic Front (SAF, temperature front defined by 4°C at 100 m), the boundary of warm side of the cold water (10°C isotherm at 100 m (the boundary of cold side is 5°C at 100 m)) and the Kuroshio extension axis (14°C isotherm at 200 m) were estimated by the ordinal Kriging method using observed data. Area between the boundary of warm side of the cold water and the Kuroshio extension axis is defined as the warm water.

Cetacean sighting survey

Distribution patterns of minke, Bryde's and sei whales were examined by using cetacean sighting data recorded by SSVs. Zigzag tracklines were designed in survey blocks. SSVs steamed on tracklines at a nominal speed of 10.5 knots. Sighting survey was terminated when either Beafout scale was higher than 4 or visibility was less than 2 n.miles. Primary observers were allocated to the top barrel (3 observers) and the upper bridge. (2 observers). Once sightings were made, SSVs approached them to confirm species and number of individuals within a school.

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 was described in Tamura *et al.* (2009(a)).

Biomass estimation of prey species
Stomach contents analysis revealed main preys for minke, Bryde's and sei whales (Tamura *et al.*, 2009(a)). Minke whales mainly fed on Japanese anchovy and Pacific saury. Bryede's whales mainly fed on Japanese anchovy. Sei whales mainly fed on Japanese anchovy, copepods and krill. Japanese anchovy and Pacific saury were abundant small pelagic fishes in the Japanese water according to the recent stock assessment report by Government of Japan. Based on these a priori information, four main prey species of three baleen whales, copepods, krill, Japanese anchovy and Pacific saury, were considered in this analysis as well as in the MRM developed by Kawahara (2009). In accordance with this, biomasses of these four species were estimated in this study. We assumed that feeding of these three baleen whale species took place upper 150 m water depth given known distribution patterns of preys. Thus, biomasses of preys were estimated from 0 to 150 m water depth.

Biomass estimation using net data
Biomass of Pacific saury was estimated using a surface trawl developed by Ueno *et al.* (2004) because it is distributed near sea surface and can not be detected by an echosounder. The surface trawl was towed at 0-30 m water depth layer. The trawl was 86.3 m long with a mouth opening of. 900 m^2 and a 6.0 m cod end with a 17.5 x 17.5 mm mesh inner. Floats were attached to the bridle so that the trawl could be towed at the surface. Towing duration was either 30 or 60 minutes per haul. The surface trawl was towed at predetermined sampling stations. Surface trawl samples collected by Tohoku National Fisheries Research Institute (TNFRI) in special block A in 2002 and block A in 2003 were also used in the analysis. TNFRI samples were collected almost same timing of the prey survey. Biomass of Pacific saury was estimated based on a swept-area method (Mackett, 1973).

Biomass of copepods was estimated either using MOCNESS (Multiple Opening / Closing Net and Environmental Sampling System) or NORPAC (North Pacific standard net). MOCNESS was used in 2003, 2004 and 2005 while NORPAC was used in the rest of years (2002 and 2007). Biomass of copepods in 0-150 m water depth layer was estimated. The mouth opening size and mesh size of MOCNESS were 1 m^2 and 0.33 mm^2, respectively. At the predetermined station, following depth layers were towed by MOCNESS; 0-20m, 20-40m, 40-60 m, 60-80 m, 80-100 m, 100-150 m, 150-200 m and 200-250 m. The mouth opening and mesh size of NORPAC are 45 cm and 0.35 mm, respectively. NORPAC was towed from 150m to surface. Filtered water volumes were recorded by using flow meters except 2002. Density of copepods was estimated 1 m^2 divided by 0.159 m^2 (area of mouth opening of NORPAC). NORPAC samples collected by TNFRI in block A in 2002 were also used in the analysis. TNFRI samples were collected almost same timing of the prey survey. Details of sampling methods using trawl, NORPAC and MOCNESS were described in Murase *et al.* (2009).

Biomass estimation using echosounder data

Biomasses of Japanese anchovy and krill were estimated by using quantitative echosoudners. Quantitative echosounders, either Simrad EK500 or EK60, equipped on a trawler type fisheries research vessel were used to collect acoustic data. Acoustic data were recorded with 38 and 120 kHz transducers. Echosounders were calibrated every year based on the copper sphere technique (Foote, 1982). Acoustic data were analyzed with the aid of Echoview (Myriax Software Pty. Ltd.) software at the laboratory. Nautical area scattering coefficient (s_A, m^2/n.mile^2) by species for every 1 km of survey transect over defined depth interval (10-150 m) was calculated by following formula;

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

where r is depth from the sea surface, r_0 = 1m representing the reference range for backscattering strength. Average area biomass density ($\bar{\rho}$) for each species was calculated as follows;

$$\bar{\rho} = \frac{s_A}{\bar{\sigma}} \bar{w} \text{ .}$$

W is wet weight of individual. The acoustic cross section (σ) was converted from target strength (TS) as followed;

$$\sigma = 4\pi 10^{0.1TS}$$

The TS of krill at 38 and 120 kHz was estimated by using the Distorted Wave Born Approximation (DWBA) model (Tojo *et al.* 2008):

$$TS_{38kHz} = 60.6 \log_{10}(TL) - 177.2$$

$$TS_{120kHz} = 50.7 \log_{10}(TL) - 150.4$$

Backscattering from krill can be identified if the difference of mean volume backscattering strength between 120 and 38 kHz (ΔMBVS$_{120\text{-}38}$) fells in a specific range (Miyashita *et al.*, 1997; Kang *et al.*, 2002). ΔMBVS$_{120\text{-}38}$ is equivalent to the difference of TS between 120 and 38 kHz (ΔTS$_{120\text{-}38}$). Length frequency data of krill were sampled by the Isaacs-Kidd Midwater Trawl (IKMT) in 2002. Ranges of ΔMBVS$_{120\text{-}38}$ for krill in blocks A and B in 2002 were 15.4 – 17.5 and 14.5 – 17.0 dB, respectively. Mean TS$_{120}$ of krill in blocks A and B in 2002 were -94.6 and 90.3 dB, respectively. Mean wet weights of individual krill correspond to mean TS were 11.1 and 17.0 mg, respectively. The range of ΔMBVS$_{120\text{-}38}$, mean TS and mean wet weight in block A in 2002 were applied to block A in 2003, block "offshore" in 2004, Eastern block in 2005 and blocks 1 and 2 in 2007. The range of ΔMBVS$_{120\text{-}38}$, mean TS and mean wet weight in block B in 2002 were applied to block B in 2003, western block in 2005 and block 3 in 2007.

Japanese anchovy, sardine and mackerels (including both Chub and Blue (*Scomber australasicus*) mackerels) were only small pelagic fish species to form dense schools in the survey area. Pelagic fishes were distinguished from the other backscatterings based on the shape and auxiliary acoustic characteristics though the species compositions in the schools could not be identified. To add the species composition information to the acoustic data, proportion of species composition by number of individuals was obtained using trawl data. Both targeting and predetermined trawl hauls were used to calculate the proportion. The proportion was calculated by SST in 1°C increments. Mean length of Japanese anchovy is calculated by SST in 1°C increments in each block and then they are converted to TS using following formula (Foote, 1987);

$$TS = 20 \log TL - 71.9$$

Mean wet weights of Japanese anchovy corresponded to mean length were also calculated in each block.

Following procedures were adopted from Jolly and Hampton (1990). Weighted ρ of each block was;

$$\overline{\rho_k} = \frac{\sum_{i=1}^{N_k} \overline{\rho_{ki}} (n_{k_i})}{\sum_{i=1}^{N_k} n_{k_i}}$$

where $\overline{\rho_k}$ = mean ρ in kth block, N_k = number of transects in kth block, $\overline{\rho_{ki}}$ = mean ρ on the ith transect in kth block and n_{k_i} = number of 1 km averaging intervals on the ith transect in kth block. In this formula, each transect was regarded as a single biomass density sample. Then variance of $\overline{\rho_k}$ was calculated with the formula (Jolly and Hampton, 1990);

$$Var(\overline{\rho_k}) = \frac{N_k}{N_k - 1} \frac{\sum_{i=1}^{N_k} (\overline{\rho_{k_i}} - \overline{\rho_k})^2 n_{k_i}{}^2}{\left(\sum_{i=1}^{N_k} n_{k_i} \right)^2}$$

Biomass was estimated as;

$$B_k = A_k \rho_k$$

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

$$\mathrm{var}(B_k) = A_k{}^2 \, \mathrm{var}(\overline{\rho_k})$$

Coefficient of variation of B_k was calculated as;

$$CV(B_k) = \frac{\sqrt{\mathrm{var}(B_k)}}{B_k}$$

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 block j is

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

The results of stomach contents analysis indicated that 88.4 % of sampled minke whales in JARPN II from 2000 to 2007 fed on single species (Tamura *et al.*, 2008(a)). Likewise, 92.3 and 89.2 % of sampled Byrde's and sei whales fed on single species. Based on the information, we assume that each individual consumes the average daily prey consumption weight of dominant prey species i in the stomach. 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 as it consume only anchovy). 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 block 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 block 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 block j. Our objective is to estimate the B_i parameters by maximizing the above equation. Data from 2002 to 2007 were used to estimate B_i as average values in the JARPN II offshore component survey area in summer from 2002 to 2007. 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 block in each year is also estimated using same methods.

RESULTS

Poststratification of survey blocks

Predefined survey blocks were poststratified based on the position of the SAF (Figs. 2 - 11). Poststratified blocks were set either around the SAF (about 2 latitudes from the SAF in north and south directions) or south of these blocks (mainly areas consisted of cold and warm waters).

Distribution patterns and stomach contents of whales

Sighting positions and stomach contents of sampled common minke, Bryde's and sei whales in the poststratified blocks were shown in Figs. 2 - 11. As indicated in the figures, whales were sampled randomly within the poststratified blocks. Summary of stomach contents in the poststratified blocks were shown in Table 2. Prey species of minke, Bryde's and sei whales showed some overlap but their main preys were different. Sei whales fed on copepods, krill, anchovy and Pacific saury. Bryde's whales only fed on krill and anchovy. Minke whales fed on krill anchovy and Pacific saury. Copepodite stage 5 (C5) of *Neocalanus* spp. was only copepods identified to the species level in the stomach of sei whales sampled during cooperative surveys. Several species of krill were identified in the stomachs of minke, Bryde's and sei whales. They were treated as krill in our analysis, because their species could not be identified by echosounders.

Distribution patterns and biomasses of prey species.

Distribution patterns of preys of common minke, Bryde's and sei whales in the poststratified blocks were shown in Figs. 2 - 11. Biomasses of preys were summarized in Table 3. Because Copepodite stage 5 (C5) of *Neocalanus* spp. was only copepods identified to the species level in the stomach of sei whales, biomass of *Neocalanus* spp.(C5) was estimated in the analysis.

Prey preferences of minke, Bryde's and sei whales

Prey preference of minke, Bryde's and sei whales in each block in each year was summarized in Table 4. Minke whales showed preference for fishes regardless of blocks and years (Table 4(a)). Bryde's whales showed preference for anchovy except block B in 2003 (Table 4(b)). Prey preferences of sei whales were variable among blocks (Table 4(c)).

Minke and sei whales co-exited in block A-N in 2002 (Fig. 2), block A-S in 2003 (Fig. 4) and block E-N in 2005 (Fig. 7) but they showed different prey preferences. Minke whales showed preference for Pacific saury while sei whales showed preference for anchovy in block A-N in 2002. Minke whales showed prey preference for Pacific saury and achovy while sei whales showed preference for copepods in block A-S in 2003. Minke whales showed prey preference for Pacific saury and anchovy while sei whales showed prey preference for krill and Pacific saury in block E-N in 2005.

Table 5 showed the average Manly's α of three baleen whale species in the JARPN II offshore component survey area in summer from 2002 to 2007. Minke whales showed preference for anchovy and suary while they avoided krill. Bryde's whales showed preference for anchovy while they avoided krill. Sei whales showed preference for copepods and anchovy while they avoided krill and Pacific saury.

DISCUSSION

This was the first report of prey preferences of minke, Bryde's and sei whales in the offshore region of the western North Pacific. Prey preference of sei whales have not been reported in any part of world in the past. During a period from 2002 to 2007, Manly's α indicated that sei whales preferred firstly copepods, secondary Japanese anchovy, thirdly Pacific saury and fourthly krill. Data collected during commercial whaling operation from 1952 to 1972 indicated that sei whales mainly fed on copepods in the north of 40°N while they fed on pelagic fishes in the south of 40°N (Nemoto, 1957; 1959; Kawamura, 1973). Prey preference of sei whales in this study was mainly estimated from 35°N to 45°N. Our results generally agreed with past findings. It was suggested that sei whale possibly switch its prey depending on the abundance of preys as in the case of minke whales as reported by Kasamatsu and Tanaka (1992). In the past studies, mackerels were mainly observed in the stomachs of sei whales in 1970's (Kawamura, 1973; 1982), but Japanese anchovy were majority of the stomach content in the this study. Catch statistics of pelagic fishes indicated that abundance of mackerels was high in 1970's, and Japanese anchovy became more abundant in 2000's (Yatsu *et al.*, 2005 and updated by Takasuka *et al.* 2008). Though change in abundances of *Neocalanus* spp. were reported from 1970's to 1990's (Chiba *et al.*, 2006; Tadokoro *et al.*, 2005), no data regarding these copepods was available for 2000's at the time of the present study. Presumably, proportion of copepods in stomachs of sei whales may change as change in abundance of copepods in our survey area. No information was available on decadal change in abundance of krill in the offshore region of the western North Pacific. Continuation of the cooperative surveys on cetacean sampling and prey of cetaceans is necessary to detect how prey preference of sei whales changes in response to change in availability of preys.

Murase *et al.* (2007) reported that minke whales showed preference for anchovy in the water south of 42°N and west of 150°E from June to August in 2000 and 2001. The results of this study suggested minke whales showed preference for Pacific saury in addition to anchovy in water south 46°N and around 157°E. The study by Murase *et al.* (2007) was conducted June-August and no Pacific suary was observed in their survey area. Pacific saury migrates from south to north in the offshore region in summer and then it returns to south along the coast of Japan in autumn (Sugisaki and Kurita, 2004). Minke whales fed on northern migrants of Pacific saury in the offshore region in summer (Tamura and Fujise, 2002). Present study demonstrated that change in diet of minke whales reflected availability of preys as suggested by Tamura *et al.* (1998) and Tamura and Fujise (2002). 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, Windsland *et al.*, 2007) and in the western North Pacific (Murase *et al.*, 2007), minke whales showed preference for pelagic shoaling fishes while they avoided krill in this study. Bryde's whales showed preference for krill and anchovy depended on blocks but they showed preference for anchovy as indicated by average Manly's α value in the JARPN II offshore component survey area in summer from 2002 to 2007. Preference for anchovy could be general tendency of Bryde's whales in the western North Pacific but it seems that prey switching of Bryde's from krill to anchovy (or vice versa) could occurred irrespective of prey biomass. Further study is required to dismantle the mechanism.

Minke and sei whales are co-existed in some blocks but they showed different prey preferences. The results suggested that prey species identification using stomach contents is critically important to estimate prey preference when more than two species which potentially feed on same preys are co-existed in same area. Several studies were conducted to examine whale-prey relationships without using stomach contents. Piatt and Methven (1992) investigated threshold foraging behavior of humpback (*Megaptera novaeangliae*), fin (*B. physalus*) and minke whales on capelin in Witless Bay Newfoundland Canada. However, because they did not confirm actual prey of baleen whales, it was obscure whether they fed on capelin or not. Friedlaender *et al.* (2006) suggested that Antarctic minke whales showed preference for larger individual krill and smaller aggregation area than humpback whales in the Antarctic water. However, because they just investigated spatial relationships between baleen whales based on a sighting survey and distribution of krill based on an echosounder survey, it was uncertain whether Antarctic minke whales actually fed on larger size krill than humpback whales or not. Witteveen *et al.* (2008) attached acoustic tags to humpback whales to investigate prey preference. They concluded that humpback whales showed preference for capelin. However, because they just investigated relationships between swimming behaviour of humpback whales and distribution pattern of preys detected by an echosounder, there was no evidence whether humpback whales actually fed on capelin or not. To study and quantify estimate prey preference of baleen whales, prey species identification using stomach contests is required.

Prey biomass estimations in selected survey blocks were used as an indicative of prey availability to whales at meso scale. In JARPN II, prey preference of whales is considered as one of the input parameter of ecosystem models not at micro scale (individual level) but at meso scale (population level) in the feeding area. Thus our prey preference estimation methods is satisfactory met the goal of the survey. Study on prey preference at micro scale might help the interpretation of prey preference at meso scale. At the micro scale, prey preference of whales can be related not only biomasses of prey but also to other factors such as shapes and behaviour of schools of preys. Conventional quantitative echosounders such as Simrad EK500 and EK60 can not collected such data fully. Newly developed fisheries multibeam echosounder can record these detailed data (Trenkel *et al.*, 2008). If the new technology is used along with conventional study methods, it will enhance our knowledge on prey preference of whales.

As an initial attempt, constant prey preference was assumed in the MRM developed by Kawahara (2009). Some ecosystem models such as EwE require functional response of predator. Though functional response form is important in the EwE (e.g. Mori *et al.*, 2009), it has not been estimated for baleen whales using actual data because of lack of long term data collection for it. Pláganyi (2007) strongly recommended that effort be focused on appropriate data collection and/or experiments to assist in shedding light as to the most appropriate form to represent feeding behaviour. 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 at different scales could be different. Functional form required by ecosystem model for fisheries model needs long term collection of prey preference data. Continuation of JARPN II is important to develop appropriate functional response form for baleen whales.

We estimated biomasses of preys from 0 to 150 m water depth based on known main distribution depth of them: copepods (*Neocalanus* spp. (C5)) = 100 m (Murase unpublished data), anchovy = <100 m (Murase *et al.*, 2007) and Pacific saury = <10 m (Ueno *et al.*, 2004). Main distribution depth of krill is deeper than 150 m (Murase *et al.*, 2007). Because all whale species considered in this study avoid krill, inclusion of biomass of krill deeper than 150 m water depth would not reverse the results of our findings. Feeding depths of minke, Bryde's and sei whales in the western North Pacific have not been reported. It was reported that maximum dive depth of fin and blue whales were 470 m at least (Panigada, *et al.*, 1999) and 204 m (Croll *et al.*, 2001), respectively. Measurement of actual feeding depth of minke, Bryde's and sei whales using time depth recorder will be useful to define their feeding depth ranges.

Biomass data of copepods and Pacific saury were spatially sparse because nets were used. If their biomass can be estimated using echosounders, one will be able to study more detailed prey preference of cetaceans in both spatial and temporal scales. Biomass of copepods can be estimated by using echosounders (Beardsley *et al.*, 1996; Coyle, 1998; 2005) if high frequency such as 200 and 420 kHz can be used in the survey. However, because of small body size of copepods, estimation of target strength as well as development of acoustical species identification methods are critically important. These points will be studies in future JARPN II. Because Pacific saury is distributed mainly near ocean surface layer (e.g. <10m), surface trawling technique developed by Ueno *et al.* (2004) is only way for estimation of biomass. Up looking echosounder mounted on Autonomous Underwater Vehicle (AUV) (Fernandes *et al.*, 2003) can be used for alternation of trawling. However, development and deployment of such new equipment will take time and they will not take place in immediate future. To sample prey species, use of MOHT (Matsuda-Oozeki-Hu-Trawl) net in addition to nets used in JARPN II will enhance sampling efficiency as suggested by Oozeki *et al.* (2004). Biomass estimation using echosounders in this study adopt up to date techniques used as standard in worldwide. There are several sources of biases associated with biomass estimation using echosounder. Demer (2004) pointed out that following potential sources of biases may be appreciable components of measurement uncertainty: stemming from uncertainties in the target strength model, the length-weight model, the species classification methods, bubble attenuation, signal thresholding and survey area definition. Though study of details of acoustics is not main objective of this study, these technical points will be investigated as much as possible because biomass estimation of preys is very important for estimation of prey preferences.

It is recognized that both climatic and biological regime shifts occurred in the North Pacific Ocean and their effect on fisheries and ecosystem were actively investigated by North Pacific Marine Science Organization (PICES). In the western North Pacific, commercial catch histories of pelagic fishes have shown drastic fluctuation and quasi-decadal species alterations so-called species replacement since the 1950's (Yatsu *et al.* 2001). Species replacement is a form of a biological regime shift. Although there are many definition of regime shift, the study group of fisheries and ecosystem responses to recent regime shift under PICES defined regime shift as "a relative rapid change from one decadal-scale period of a persistent state to another decadal-scale period of persistent state" (King, 2005). Climate indices such as the Pacific Decadal Oscillation (PDO) indicated that significant climatic regime shifts were occurred around 1976, 1989 and 1998 in recent decades (Overland *et al.*, 2008). Responses of pelagic biological organisms to climatic regime shifts were reported including copepods (Tadokoro *et al.*, 2005), Japanese anchovy, Japanese sardine, Pacific saury and mackerel (Takasuka *et al.*, 2008; Tian *et al.*, 2004; Yatsu *et al.*, 2008). Some analysis provided simple interpretation of interaction between climatic and biological regime shifts based on spawning temperature optima theory (e.g. Takasuka *et al.*, 2008) but the interpretation is difficult in other cases because of complexity of interactions (Yastu *et al.*, 2008). In this study, Manly's α suggested that trophic niches of minke, sei and Bryde's were different from each other. However, a wide variety of prey species found in their stomachs (Tamura *et al.*, 2009) suggested that they could have capability to switch their prey in response to regime shifts. Stomach contents collected by commercial harvesting indicated that common minke whales switched their preys according to biological regime shift of prey abundances (Kasamatsu and Tanaka, 1992). However, effects of both biological and climatic regime shifts on baleen whales in the western North Pacific are still largely open to question because of lack of data collected through systematic surveys. The ecosystem structure of the western North Pacific is "wasp-waist" (Bakun, 2006). In wasp-waist ecosystem, many species exist at the top and the bottom but a few dominant species (mostly small planktivorous fishes) occupied the middle (analogous to body shape wasp in terms of number of species in an ecosystem) (Bakun, 2006). Pelagic fishes such as sardines and anchovies occupy the middle level of the ecosystem in the North Pacific. Bakun (2006) suggested that feeding by predators could cause population collapse (but not extinction) of prey at the middle level of ecosystem if the predation rate by predator exceeds the production rate of the prey. Once climatic regime shift negatively affect the production rate of the prey, predation by predators accelerate the rate of collapse of prey population. Thus, predation by baleen whales could also affect regime shifts in other organisms especially small planktivorous fishes. So far, regime shift have not been reported during JARPN II from 2002 to 2007. To detect effect of regime shifts on cetaceans as well as effect of predation by cetaceans on biological regime shifts, long term cetacean prey survey program is critically important.

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Table 1. Timing of the cooprative whale and prey surveys from 2002 to 2007.

Year	Block	(Abbreviation)	Poststratified blocks	Prey Survey			Whale Survey	
				Vessel	Start	End	Start	End
2002	Special Block A	2002-A	2002-A-N	SYO	17-Jul	26-Jul	18-Jul	1-Aug
	Special Block B	2002-B	-	SYO	2-Aug	9-Aug	7-Aug	17-Aug
2003	Block A	2003-A	2003-A-S	SYO	15-Jun	25-Jun	10-Jun	22-Jun
	Block B	2003-B	-	SYO	1-Jul	9-Jul	26-Jun	29-Jun
							1-Jul	7-Jul
2004	Offshore	2004-O	2004-O-C	SYO	14-Sep	19-Sep	5-Sep	8-Sep
2005	Western Block	2005-W	-	SYO	12-Jul	25-Jul	8-Jul	15-Jul
	Eastern Block	2005-E	2005-E-S	SYO	27-Jul	11-Aug	25-Jul	4-Aug
			2005-E-N					
2007	Block 1	Jan-07	2007-1-S	KK1	7-Jul	26-Jul	9-Jul	22-Jul
			2007-1-N					
	Block 2	Feb-07	2007-2-C	KK1	28-Jul	21-Aug	23-Jul	2-Aug
	Block 3	Mar-07	2007-3-C	KK1	24-Aug	4-Sep	11-Aug	13-Aug

Table 2. Summary of stomach contents of minke (a), Bryde's (b) and sei (c) whales in the poststratified 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.

(a) Minke whales

Year	Block	Krill	Japanese Anchovy	Pacific saury
		# of ind.	# of ind.	# of ind.
2002	A-N	6	0	11
2003	A-S	0	3	10
2005	E-N	1	1	7

(b)Bryde's whales

Year	Block	Krill	Japanese Anchovy
		# of ind	# of ind
2002	B	0	1
2003	B	13	1
2005	W	9	12
2007	1-S	0	18
2007	3-C	0	10

(c) Sei whales

Year	Block	Copepods	Krill	Japanese Anchovy	Pacific saury
		# of ind	# of ind	# of ind	# of ind
2002	A-N	1	8	1	0
2003	A-S	8	2	1	1
2004	O-C	4	0	1	0
2005	E-S	2	7	0	0
2005	E-N	1	4	0	2
2007	1-S	0	0	5	0
2007	1-N	5	0	0	0
2007	2	10	0	0	3

Table 3. Biomasses of preys in the poststratified blocks.

Year	Block	Copepods		Krill		Japanese Anchovy		Pacific saury	
		Biomass (million t)	CV	Biomass (million t)	CV	Biomass (million t)	CV	Biomass (million t)	CV
2002	A-N	0.48	0.12	0.978	0.2	0.007	0.2	0.32	0.15
	B	-	-	0.231	0.3	0.201	0.5	-	-
2003	A-S	0.38	0.70	0.843	0.2	0.206	0.9	0.34	0.17
	B	-	-	0.459	0.4	0.296	0.5	-	-
2004	O-C	0.01	0.38	0.048	0.3	0.003	1.0	0.00	0.27
2005	E-S	0.000	0.7	0.44	0.38	0.08	0.47	0.00	0.50
	E-N	0.42	0.21	0.31	0.17	0.03	0.50	0.14	0.38
	W	-	-	0.11	0.45	0.00	0.44	-	-
2007	1-S	0.00	0.28	0.45	0.20	0.24	0.68	0.00	0.00
	1-N	0.85	0.19	0.51	0.31	0.08	0.42	0.02	0.44
	2-C	0.47	0.17	0.13	0.55	0.08	0.59	0.10	0.47
	3-C	-	-	0.12	0.11	0.06	0.88	-	-

Table 4. Values of Manly's α as a means of indications of prey preferences of minke (a), Bryde's (b) and sei whales (c) in the poststratified 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.

(a) Minke whales

Year	Block	Krill		Japanese Anchovy		Pacific saury	
		Manly's α	se	Manly's α	se	Manly's α	se
2002	A-N	0.15	0.07	0.00	-	0.85	0.07
2003	A-S	0.00	-	0.33	0.23	0.67	0.23
2005	E-N	0.04	0.04	0.41	0.28	0.55	0.27

(b) Bryde's whales

Year	Block	Krill		Japanese Anchovy	
		Manly's α	se	Manly's α	se
2002	B	0.00	-	1.00	-
2003	B	0.89	0.14	0.11	0.14
2005	W	0.02	0.02	0.98	0.02
2007	1-S	0.00	-	1.00	-
2007	3-C	0.00	-	1.00	-

(c) Sei whales

Year	Block	Copepods		Krill		Japanese Anchovy		Pacific saury	
		Manly's α	se	Manly's α	se	Manly's α	se	Manly's α	se
2002	A-N	0.01	0.02	0.06	0.06	0.93	0.07	0.00	-
2003	A-S	0.67	0.23	0.08	0.07	0.16	0.22	0.10	0.11
2004	O-C	0.44	0.32	-	-	0.56	0.32	0.00	-
2005	E-S	1.00	-	0.00	-	0.00	-	0.00	-
2005	E-N	0.08	0.09	0.44	0.21	0.00	-	0.48	0.22
2007	1-S	0.00	-	0.00	-	1.00	-	0.00	-
2007	1-N	1.00	-	0.00	-	0.00	-	0.00	-
2007	2	0.42	0.19	0.00	-	0.00	-	0.58	0.19

Table 5. Estimated average values of Manly's α of minke, Bryde's and sei whales α in the JARPN II offshore component survey area in summer from 2002 to 2007 using the log-likelihood function based on a multinomial distribution.

Species	Copepods		Krill		Japanese anchovy		Pacific sauey	
	Manly's α	se	Manly's α	se	Manly's α	se	Manly's α	se
Minke whale	-	-	0.05	0.03	0.36	0.19	0.59	0.17
Bryde's whale	-	-	0.05	0.04	0.95	0.04	-	-
Sei whale	0.41	0.10	0.13	0.04	0.25	0.10	0.20	0.08

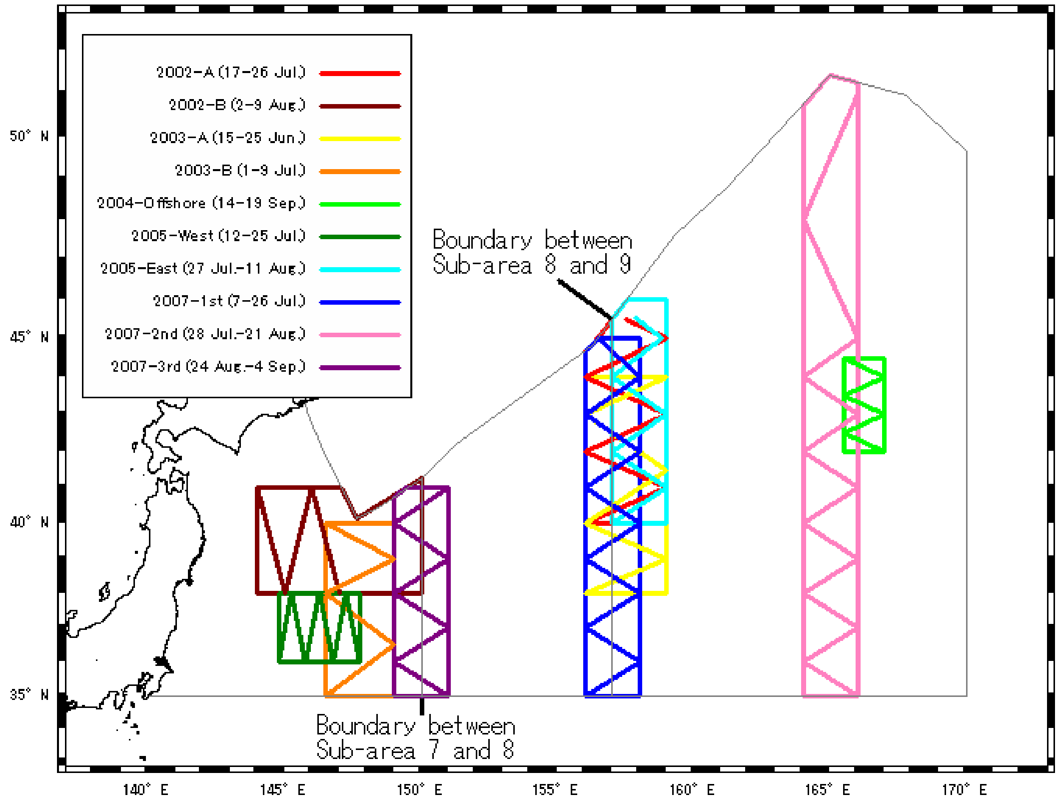

Fig. 1. Predefined survey blocks for the cooperative whale and prey surveys in JARPN II offshore component from 2002 to 2007. Each colour represents boundary of surveyed blocks. These blocks were poststratified based on observed oceanographic conditions. Zigzag line within each block represent planned trackline of prey surveys.

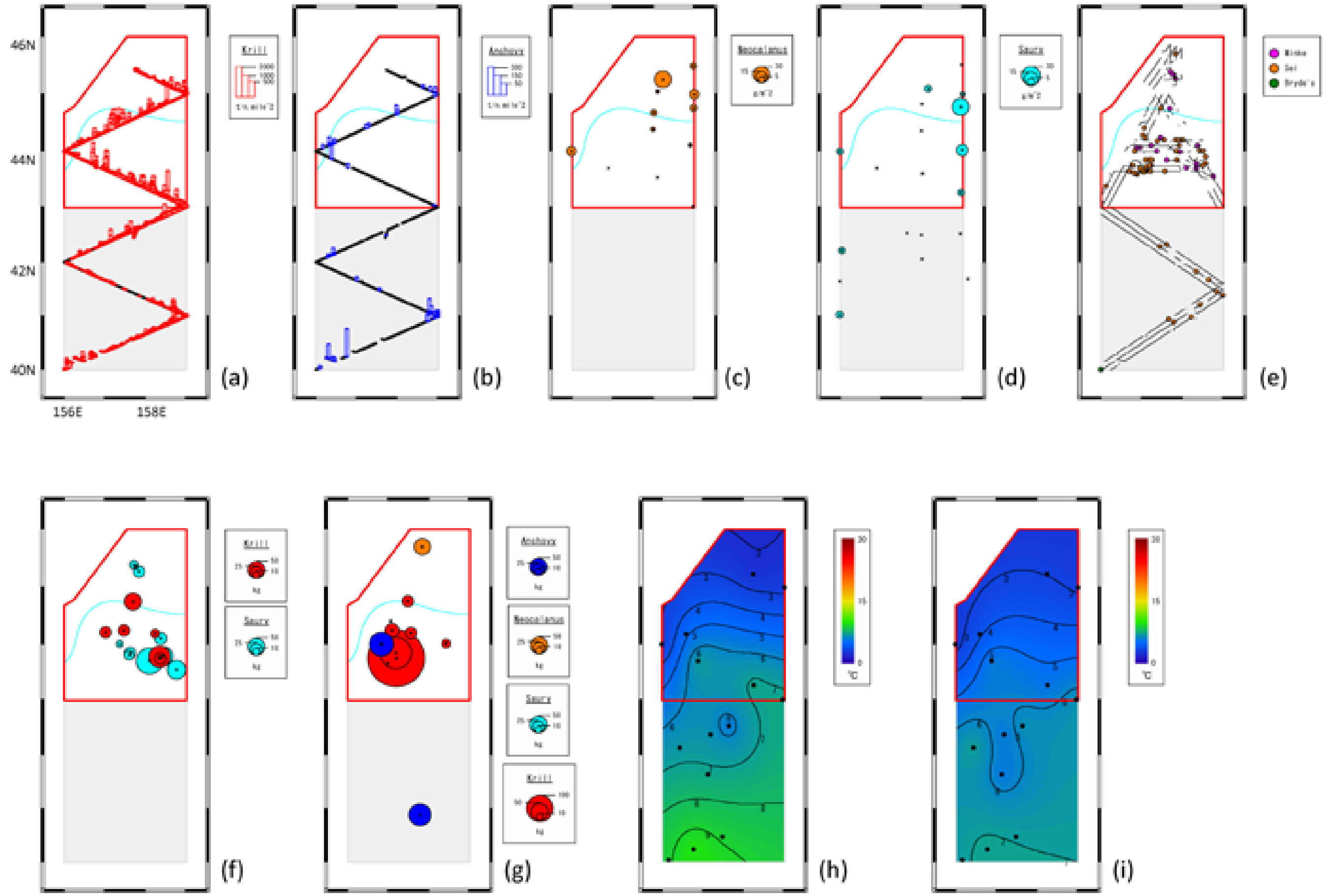

Fig.2. Maps in block A in 2002: Distribution patterns of krill (a), Japanese anchovy (b), copepods (*Neocalanus* spp. (C5)) (c) and Pacific suary (d). Sighting effort and sighting positions of common minke and sei whales (e). Sampled positions and stomach contents of minke (f) and sei (g) whales. Water temperature at 100 m (h) and at 200 m (i) water depth. Encircled area by red line is the poststratified area, A-N. Light blue line in maps (a)-(f) represents 4°C isotherm at 100 m water depth.

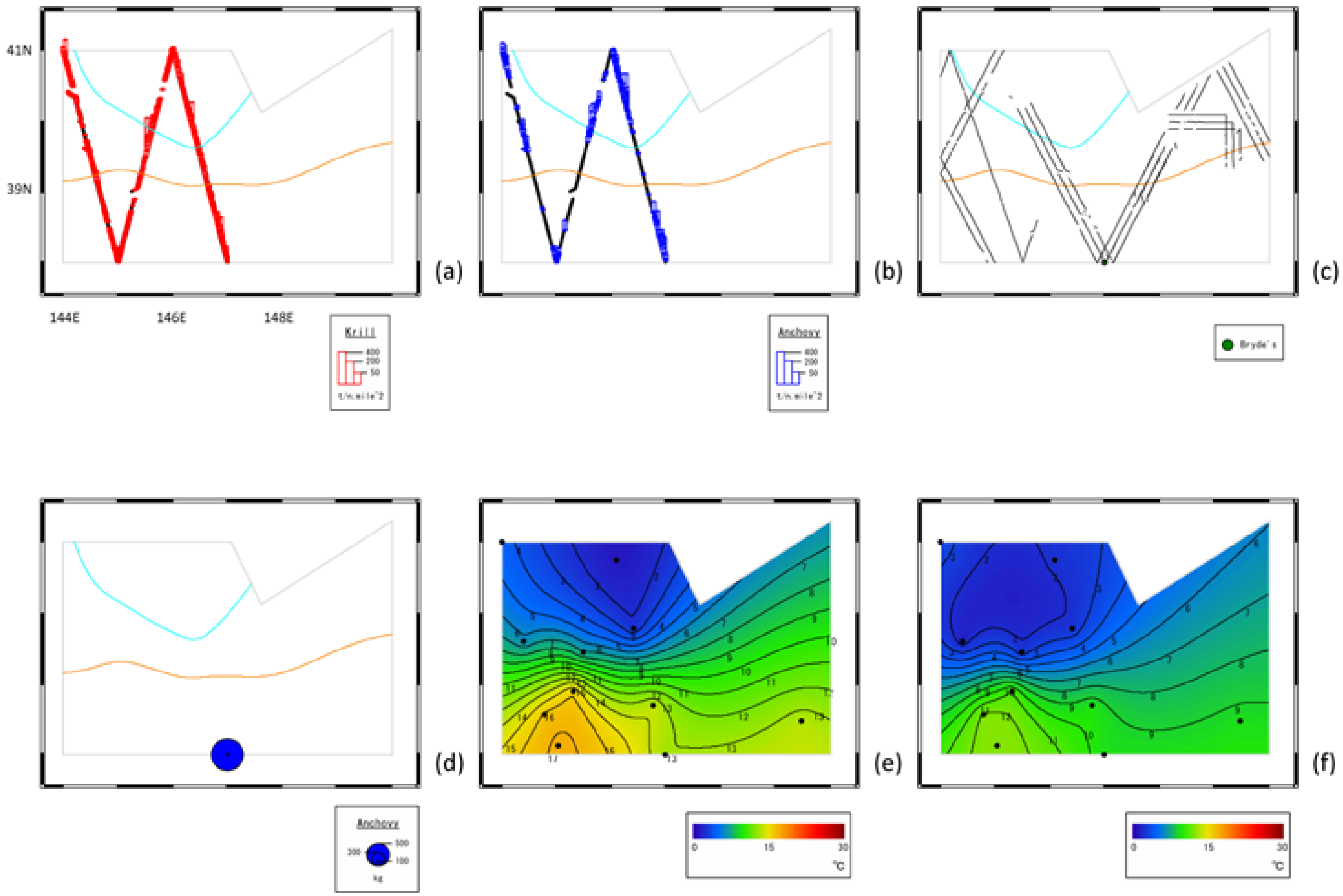

Fig.3. Maps in block B in 2002: Distribution patterns of krill (a) and Japanese anchovy (b). Sighting effort and sighting positions of Bryde's whales (c). Sampled positions and stomach contents of Bryde's whales (d). Water temperature at 100 m (e) and 200 m (f) water depth. Light blue and orange lines in maps (a)-(d) represents 4°C and 10°C isotherm at 100 m water depth, respectively.

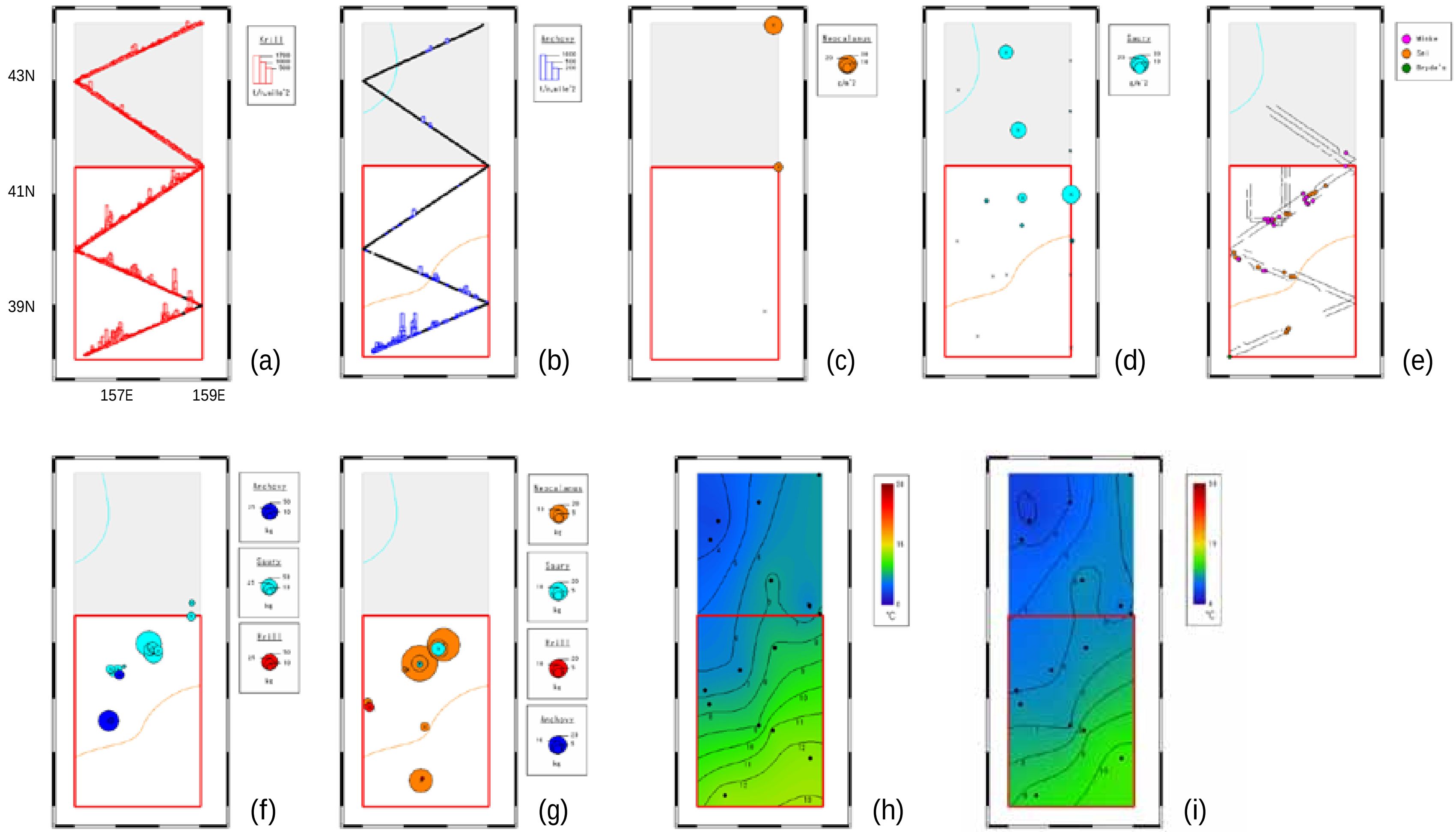

Fig.4. Maps in block A in 2003: Distribution patterns of krill (a), Japanese anchovy (b), copepods (*Neocalanus* spp. (C5)) (c) and Pacific suary (d). Sighting effort and sighting positions of common minke and sei whales (e). Sampled positions and stomach contents of minke (f) and sei (g) whales. Water temperature at 100 m (h) and 200 m (i) water depth. Encircled area by red line is the poststratified area, A-S. Light blue and orange lines in maps (a)-(g) represent 4°C and 10°C isotherm at 100 m water depth, respectively.

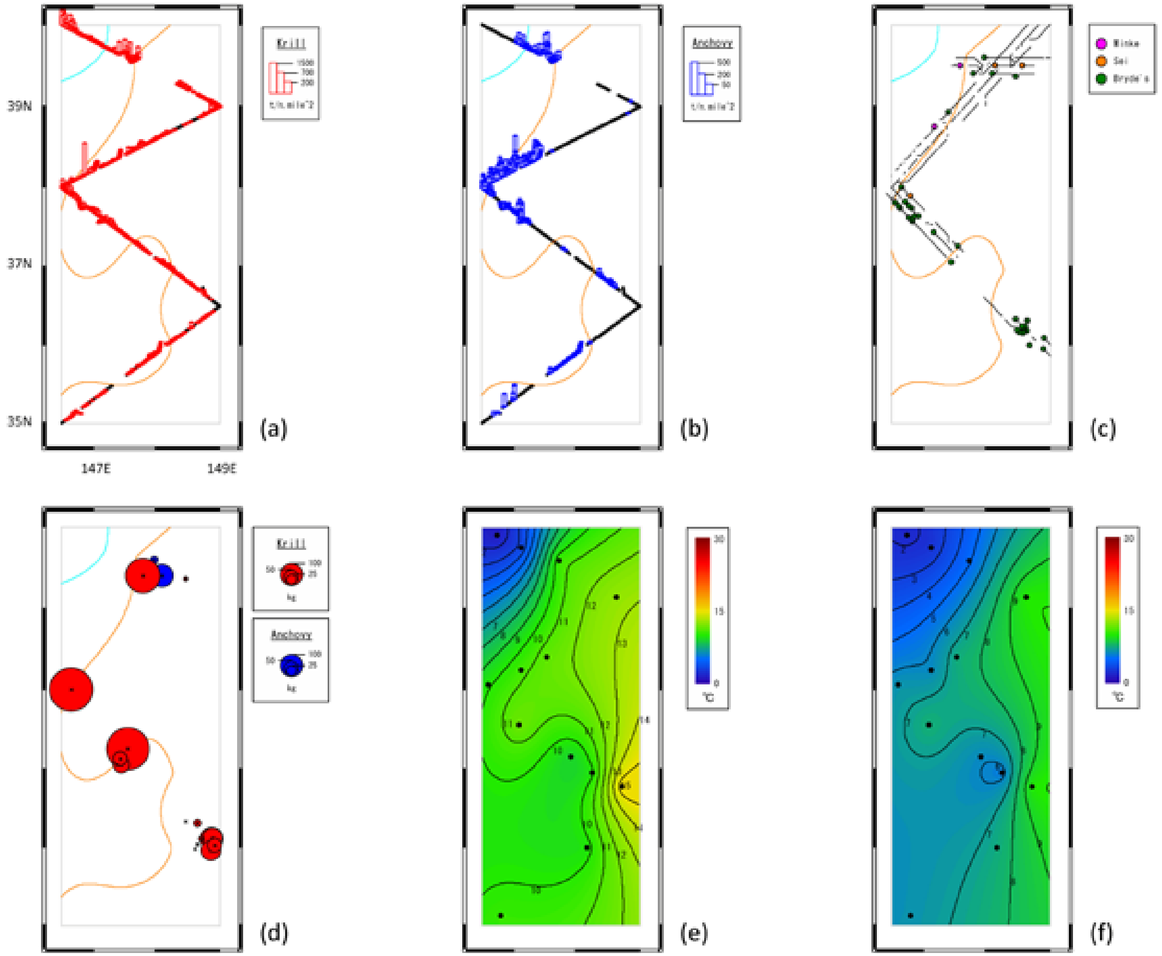

Fig.5. Maps in block B in 2003: Distribution patterns of krill (a) and Japanese anchovy (b), Sighting effort and sighting positions of Bryde's whales (c). Sampled positions and stomach contents of Bryde's whales (d). Water temperature at 100 m (e) and 200 m (f) water depth. Light blue and orange lines in maps (a)-(d) represent 4°C and 10°C isotherm at 100 m water depth, respectively.

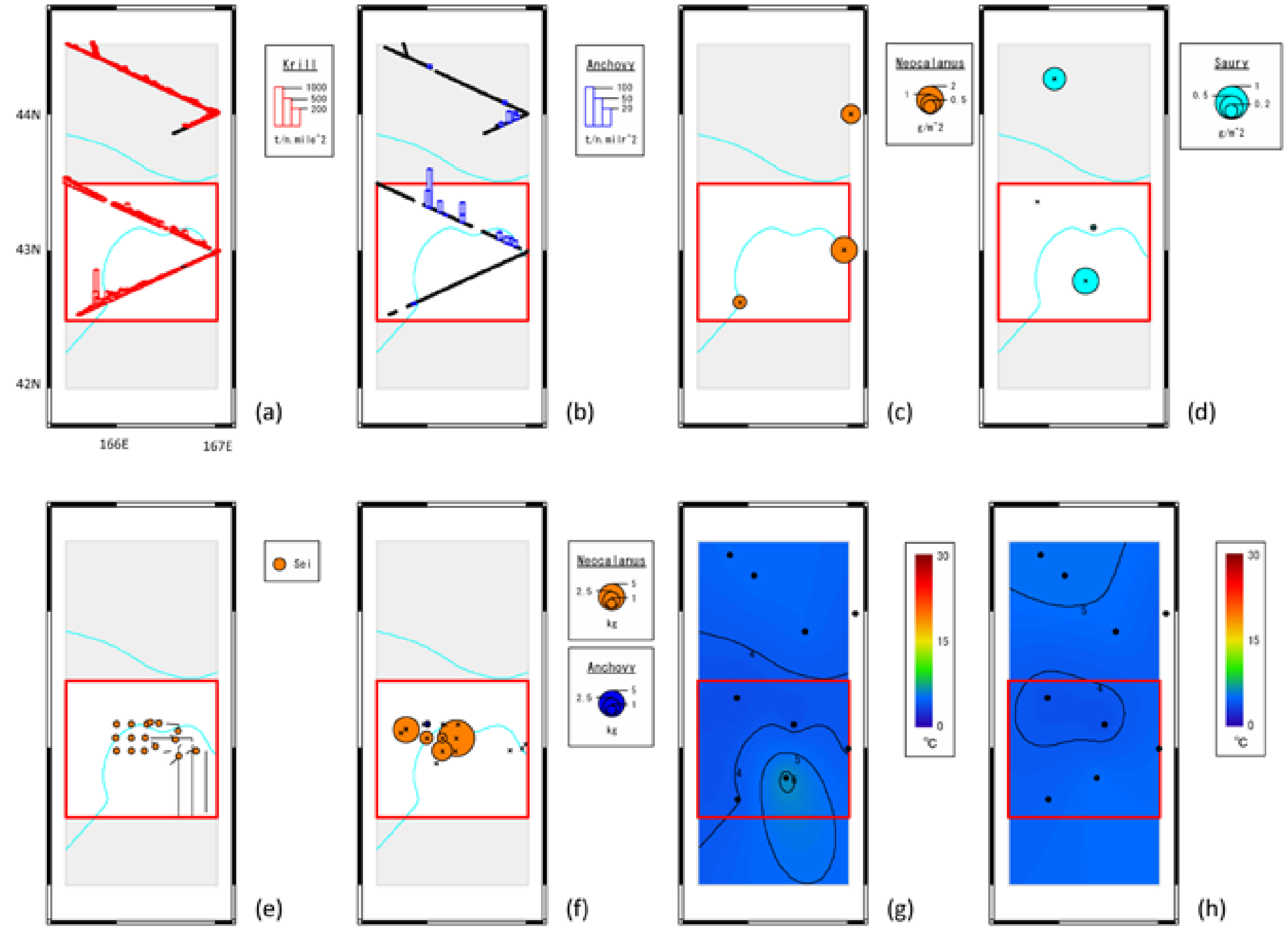

Fig.6. Maps in block O in 2004: Distribution patterns of krill (a), Japanese anchovy (b), copepods (*Neocalanus* spp. (C5)) (c) and Pacific suary (d). Sighting effort and sighting positions of sei whales (e). Sampled positions and stomach contents of sei whales (f). Water temperature at 100 m (g) and 200 m (h) water depth. Encircled area by red line is the poststratified area, O-C. Light blue and line in maps (a)-(f) represents 4°C isotherm at 100 m water depth.

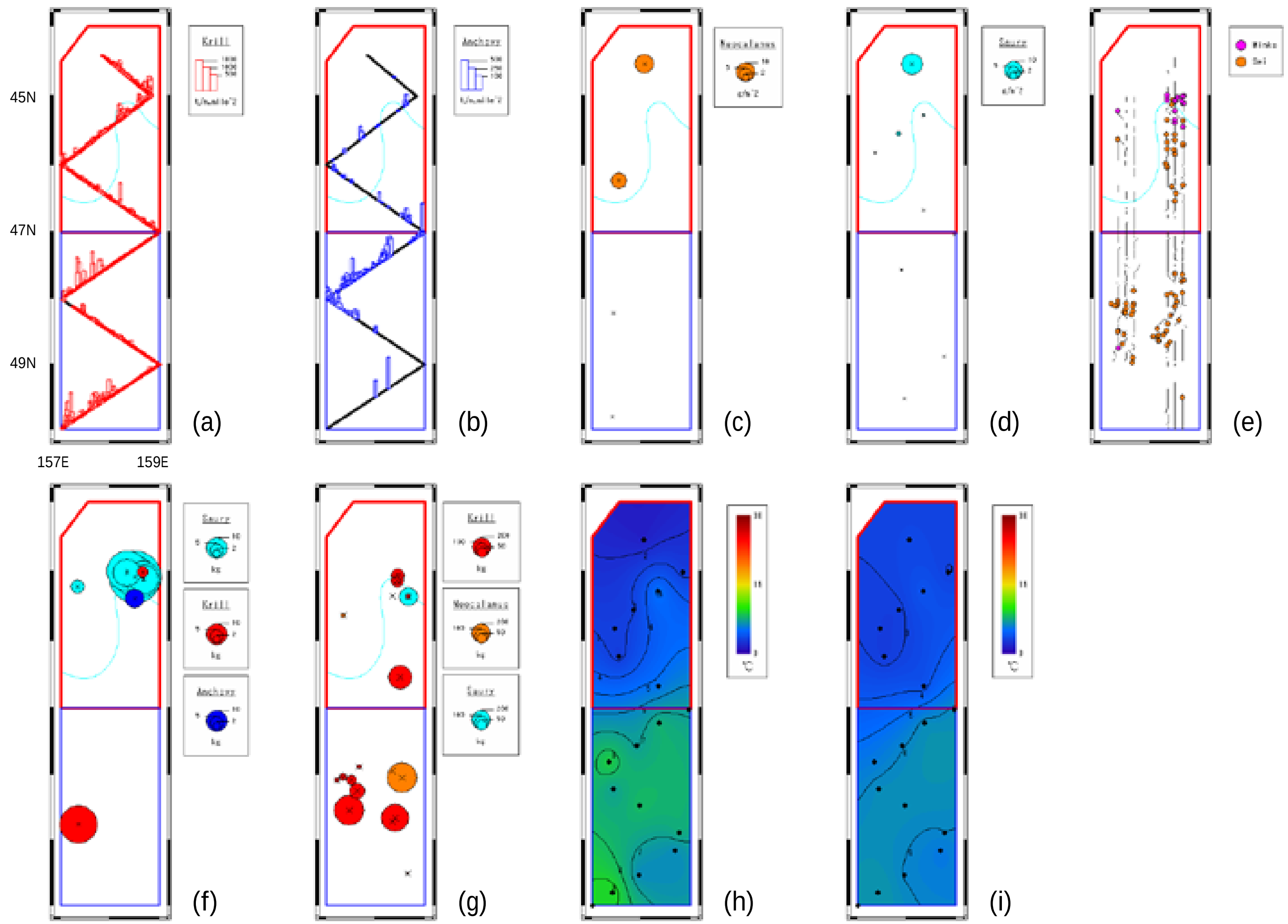

Fig.7. Maps in block E in 2005: Distribution patterns of krill (a), Japanese anchovy (b), copepods (*Neocalanus* spp. (C5)) (c) and Pacific suary (d). Sighting effort and sighting positions of common minke and sei whales (e). Sampled positions and stomach contents of minke (f) and sei (g) whales. Water temperature at 100 m (h) and 200 m (i) water depth. Encircled areas by red and blue lines are the poststratified area, E-N and E-S, respectively. Light blue line in maps (a)-(g) represents 4°C isotherm at 100 m water depth.

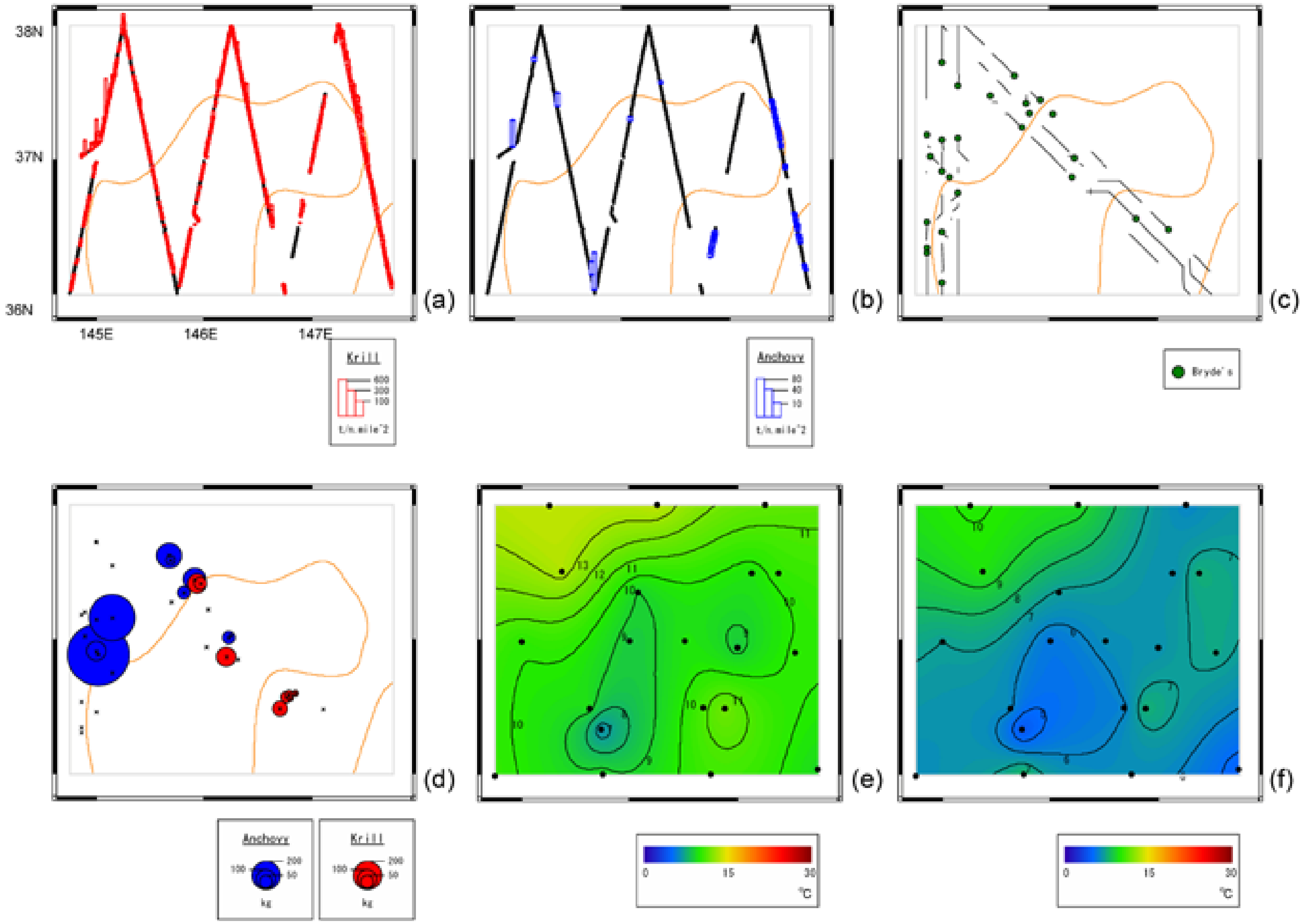

Fig.8. Maps in block W in 2005: Distribution patterns of krill (a) and Japanese anchovy (b). Sighting effort and sighting positions of Bryde's whales (c). Sampled positions and stomach contents of Bryde's whales (d). Water temperature at 100 m (e) and 200 m (f) water depth. Orange lines in maps (a)-(d) represents 10°C isotherm at 100 m water depth.

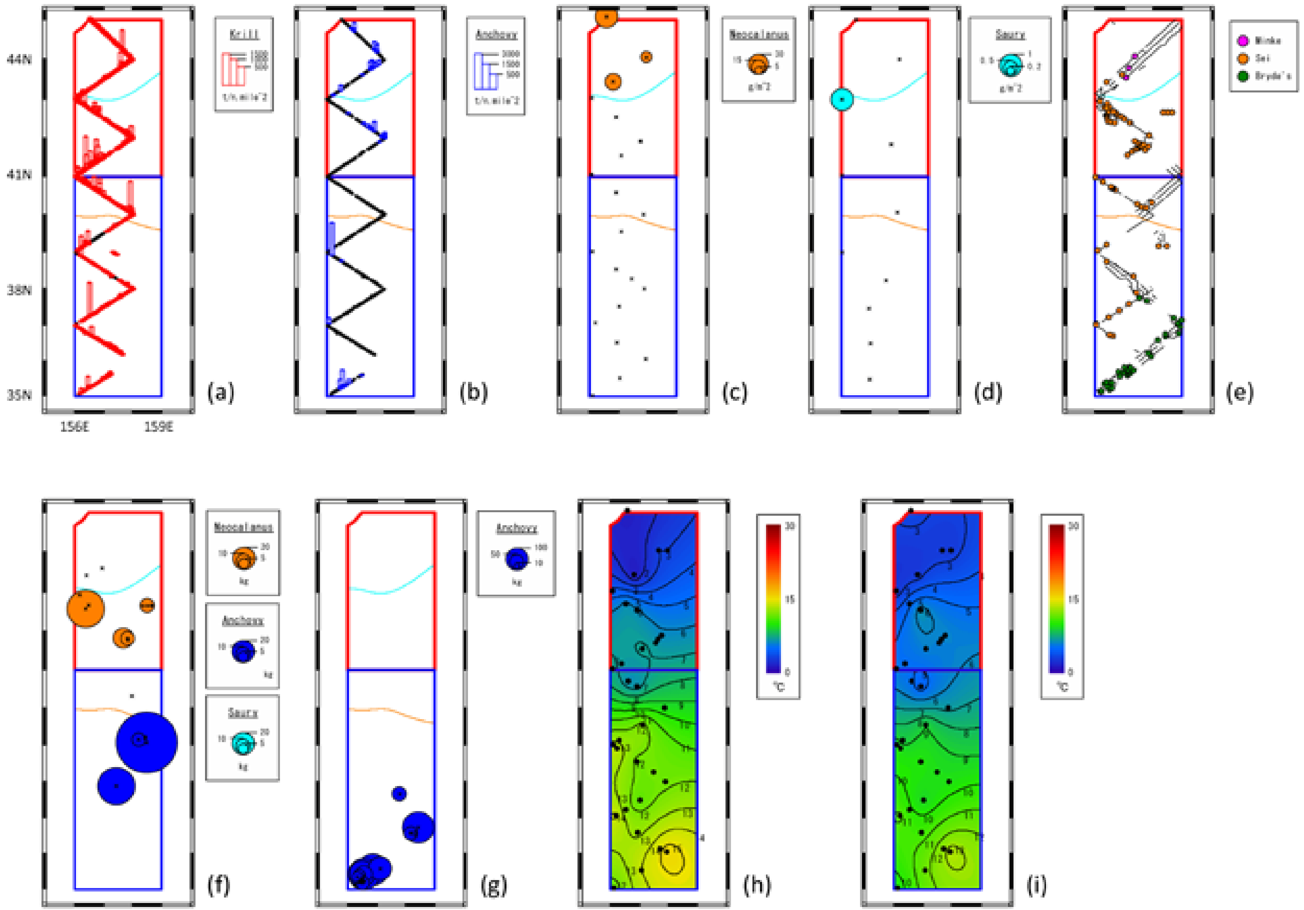

Fig.9. Maps in block 1 in 2007: Distribution patterns of krill (a), Japanese anchovy (b), copepods (*Neocalanus* spp. (C5)) (c) and Pacific suary (d). Sighting effort and sighting positions of common minke Bryde's and sei whales (e). Sampled positions and stomach contents of minke (f) and sei (g) whales. Water temperature at 100 m (h) and 200 m (i) water depth. Encircled areas by red blue lines are the poststartifed area, E-N and E-S, respectively. light blue and orange lines in maps (a)-(g) represent 4°C and 10°C isotherm at 100 m water depth, respectively.

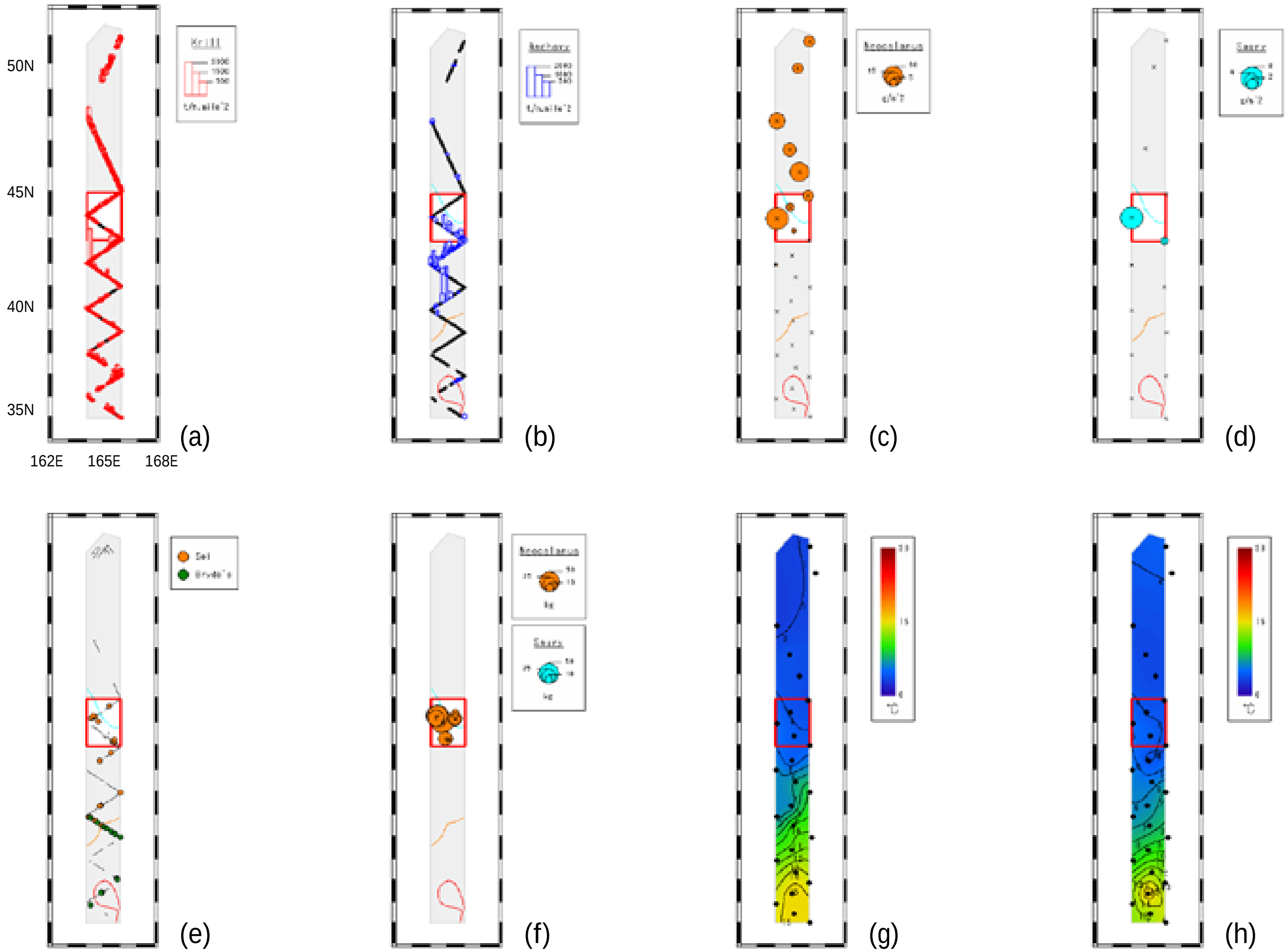

Fig.10. Maps in block 2 in 2007: Distribution patterns of krill (a), Japanese anchovy (b), copepods (*Neocalanus* spp. (C5)) (c) and Pacific suary (d). Sighting effort and sighting positions of Bryde's and sei whales (e). Sampled positions and stomach contents of sei whales (f). Water temperature at 100 m (g) and 200 m (h) water depth. Encircled area by red line is the poststratified area, 2-C. Light blue, orange and red lines in maps (a)-(f) represent 4°C and 10°C isotherm at 100 m water depth, and 14 °C isotherm at 200 m water depth, respectively.

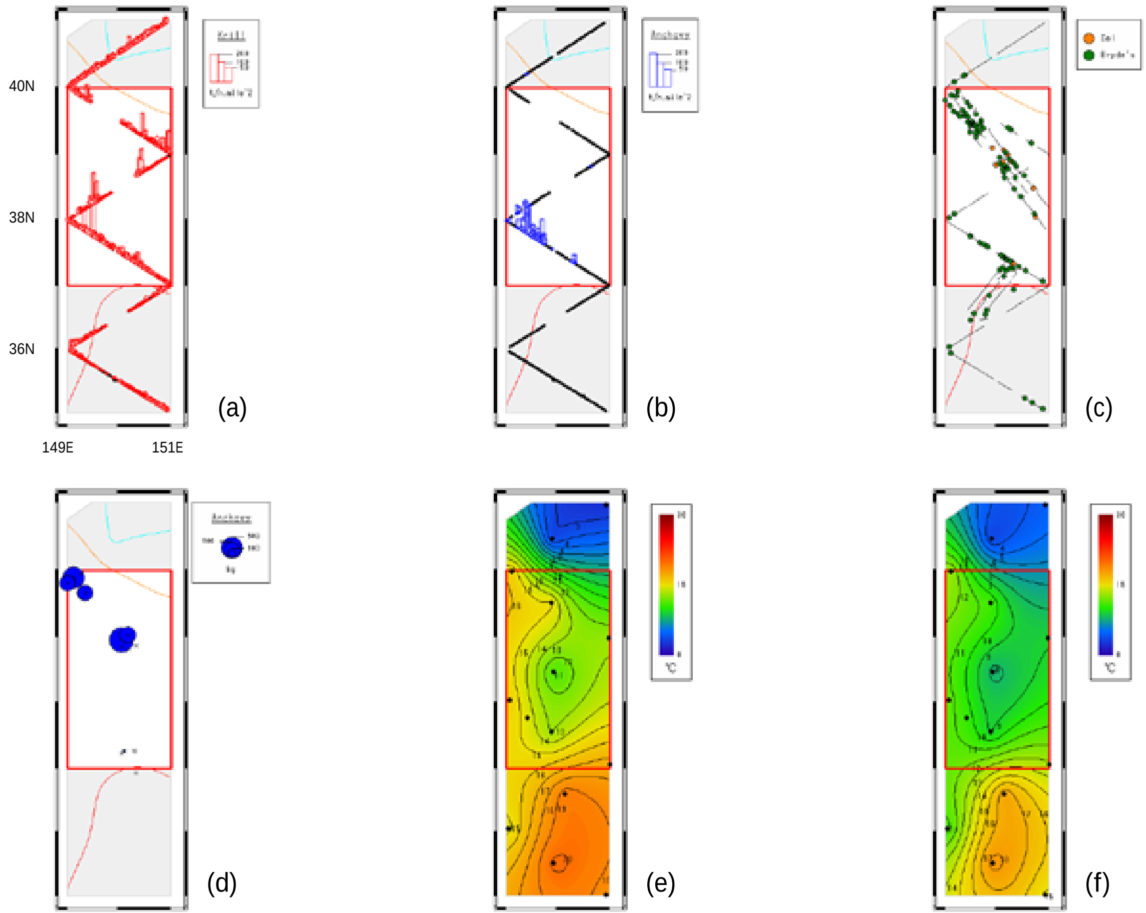

Fig.11. Maps in block 3 in 2007: Distribution patterns of krill (a) and Japanese anchovy (b). Sighting effort and sighting positions of Bryde's whales (c). Sampled positions and stomach contents of Bryde's whales (d). Water temperature at 100 m (e) and 200 m (f) water depth. .Light blue, orange and red lines in maps (a)-(d) repsentet 4°C and 10°C isotherm at 100 m water depth, and 14 °C isotherm at 200 m water depth, respectively.