Distribution and abundance of prey species and prey preference of common minke whale *Balaenoptera acutorostrata* in the coastal component of JARPN II off Kushiro from 2002 to 2007

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ABSTRACT: We studied prey preference of common minke whale *Balaenoptera acutorostrata* based on the data from midwater trawl, IKMT, and acoustic surveys in their habitat as well as the stomach content data of the whales off Kushiro, northern Japan. All surveys were conducted in the autumn of 2002-2007 as a part of the coastal component of the Research Program under Special Permit in the Western North Pacific (JARPN II). Among the potential prey species, Pacific saury *Cololabis saira* and euphausiids were mainly distributed in or close to the Oyashio region where sea surface temperature (SST) was 11-16˚C. Japanese anchovy *Engraulis japonicus* and Japanese common squid *Todarodes pacificus* were mainly found in the northern transition region of 14-18˚C SST, although distributions of the squid were almost restricted to the slope water region. Walleye pollock *Theragra chalcogramma* were widely distributed at 100-250 m depth in the continental shelf region where SST was 12-22˚C. The total abundance of these species was generally higher in the continental shelf region than in the offshore region due to high SST field (> 19˚C) in the latter region. These results suggest that slope water region of less than 18˚C SST is a rich prey environment in the both epi- and mesopelagic zones. The result of whale sighting surveys indicated that the common minke whale was generally distributed in the slope water region of less than 16˚C SST and that its distributions expanded to the offshore region in 2002 when SST of both inshore and offshore region was less than 15˚C due to the strong influence of the Oyashio. Therefore the common minke whale might prefer rich prey environment affected by the Oyashio not only in the continental shelf region where walleye pollock, Pacific saury, and euphausiids could be distributed but also in the offshore region where Pacific saury and euphausiids could be distributed. Based on the data of our surveys and whale sampling surveys, it was suggested that immature common minke whales prefer walleye pollock while mature animals prefer Pacific saury, although both frequently fed on Japanese anchovy in some years in the area within 50 nautical miles from Kushiro. These differences in prey preference might be explained by the trade-offs of cost of foraging activity for prey and/or energy demands between immature and mature whales.

KEY WORDS: common minke whale, distribution, abundance, prey species, prey preference, autumn, Kushiro, Oyashio, JARPN II

BACKGROUND ON PREY SPECIES SURVEY FOR CETACEANS

Generally, fisheries resources especially small epipelagic fish species such as sardine and anchovy largely fluctuate in decadal scales as seen in the remarkable rebound and collapse of the Japanese sardine (*Sardinops melanostictus*) stock from the 1970s to 1990s (Kuroda 1991, Nakata et al. 1994). The fluctuation of Japanese sardine stock greatly affected the total catch of Japanese fisheries, which decreased drastically from 13 to 7 million tons during 1988 and 1998. Historically, fishery management was conducted based on the ecological and biological information of a single target species and physical oceanographic conditions in their habitat. This approach was, however, inadequate to understand the primary factors of fluctuations and future status of the resource. Since the single species management focuses on maximizing the catch of the target species, this often ignores predators and prey of the target species, although such information is essential to understand the dynamics of these species. Therefore, the Fisheries Agency of Japan adopted the principle which first priority is given to ecosystem-based management within Japanese EEZ for the fundamental policy on fisheries in the future.

Ecosystem-based fisheries management based on ecosystem model is a new direction for fishery management. Building the ecosystem model is the worldwide recognition of the important approach to future fisheries (WSSD 2002, Pikitch et al. 2004). This is one of the major goals of the second phase of Japanese Whale Research Program under Special Permit in the western North Pacific (JARPN II, Government of Japan, 2002). The JARPN II ecosystem model is expected to establish the new system of sustainable utilization and management of whole marine ecosystem including marine mammals in the western North Pacific. In 2000, JARPN II started to construct Ecopath with Ecosim (EwE) model, which is one of the major ecosystem models (Okamura et al. 2001, Mori et al. 2008). In relation to the development of this model, the factor of prey preference of each cetacean species is essential to determine their ecological role. To obtain the information of prey preference, comparison between prey species composition in the cetacean stomachs and that in the cetacean habitat is necessary. Furthermore, International Whaling Commission (IWC) recommended a more quantitative estimation of the temporal and geographical variation in diet of cetaceans (IWC 2000). Therefore, JARPN II has conducted cooperative surveys of prey species and whale sampling.

The common minke whale *Balaenoptera acutorostrata* is one of the major baleen whale off Kushiro, eastern Hokkaido, where is one of the major fishing grounds of Japan, during summer and autumn. Results from previous program, JARPN (conducted from 1994 to 1999), indicated that this species feed mainly on commercially important fish and squids like Japanese anchovy *Engraulis japonicus* and Pacific saury *Cololabis saira*, suggesting the competition between the whale and fisheries (Tamura and Fujise 2000). In the JARPN II coastal component off Kushiro, prey species survey started in the autumn of 2002 during the sampling survey period of common minke whales to estimate abundance of potential prey in the habitat of the whale and prey preference of the whale. In this area, abundance and fishing area of these prey species is known to largely fluctuate by year due to annual changes of interaction between subarctic Oyashio waters and subtropical waters detached from the Kuroshio (Kawai 1972). These changes are thought to greatly affect the prey environment of common minke whale. Therefore, Kushiro area is thought to be suitable for both prey preference analysis and studies on feeding strategy of the whale.

OBJECTIVE

Based on the backgrounds above mentioned, we report the results of prey species survey in the JARPN II coastal component off Kushiro from 2002 to 2007 by focusing on the following four goals.

1. To clarify the geographical distribution patterns of prey species of common minke whale in relation to oceanographic features.
2. To estimate annual changes in biomass of the major prey species of common minke whale.
3. To clarify the geographical distribution pattern of common minke whale in relation to prey environment and oceanographic features.
4. To estimate the prey preference and feeding strategy of common minke whale. (In this paper, prey preference is defined as the animal choosing one particular resource over others irrespective of amount of resources.)

MATERIALS AND METHODS

Prey species survey

Prey species survey was conducted off the eastern Hokkaido, from 142º30’E to 147º00’E, and north of 41ºN except for Russian EEZ in autumn from 2002 to 2007 (Fig. 1). During the survey, the sampling survey of common minke whale was also conducted in the area of within 50 nautical miles from Kushiro (Kishiro et al. 2009a). For the quantitative analyses of prey environment, the survey area was divided into coastal and offshore blocks, and the coastal part was further divided into eastern, central, western and off-Hidaka blocks (Fig. 1). Zigzag track lines were set to cover each small block of the study area. On these lines, the distribution and abundance of prey species were investigated with the quantitative echosounder (38 and 120 kHz), midwater trawl, and Isaacs-Kidd midwater trawl (IKMT) during the daytime. We conducted two kinds of net samplings. One is target trawling to identify fish species and size compositions of acoustic backscatters. The other is so-called ‘predetermined trawling’ that was towed generally every 20 to 30 nautical miles on the track lines to examine the distribution and abundance of squids and neustonic organisms like Pacific saury that are difficult to detect by the echosounder. A Conductivity-Temperature-Depth (CTD) profiler cast was made down to 500 m depth or near the bottom of shallower than 500 m depth at each sampling station to depict the oceanographic conditions (see Okazaki et al. (2009).

All samples were identified to the lowest taxonomic level possible and wet body weight of each species was measured. For the major species, body length of each individual was measured from randomly selected 100 individuals. However, we did not measured body length of salmons in 2005. We also obtained the total wet weight of these samples to estimate the total catch number for each sampling.

Geographical distribution of major prey species

We estimated the geographical distribution patterns of each potential prey species of the common minke whale generally based on our acoustic and/or trawling data. Since our midwater trawl surveys near the bottom of the continental shelf were greatly restricted, we also used the data of bottom trawl samplings conducted by Hokkaido National Fisheries Research Institute in August and/or September from 2002 to 2006 to determine the distribution of walleye pollock *Theragra chalcogramma* and Japanese common squid *Todarodes pacificus* (Honda unpubl. data 2002, 2004, 2005, and 2006).

Estimation of biomass for potential prey species

We estimated biomass of Japanese anchovy, walleye pollock, and euphausiids based on the acoustic data. Biomass estimation of these species was conducted according to the method of Jolly and Hampson (1990) as follows:
Mean backscattering area per square nautical mile of sea surface (S_A) by species for every 1 nautical mile of survey transect over defined depth interval is calculated by following formula;

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

where r is depth from the sea surface, r_0 = 1m representing the reference range for backscattering strength. A length-target-strength (TS) relationship for Japanese anchovy (Anonymous 1990) is used;

$$TS = 20 Log TL - 72.5$$

where TL is total length in cm. A length-weight relationship for Japanese anchovy (Anonymous 1990) is used;

$$W = 0.004 TL^{3.09}$$

where W is weight in gram.
A length-target-strength (TS) relationship for walleye pollock (Foote and Traynor 1988) is used;

$$TS = 20 Log FL - 66$$

where FL is folk length in cm.
A length-weight relationship for walleye pollock (Pereyra et al. 1981) is used;

$$W = 0.0077 FL^{2.906}$$

where W is weight in gram.
Because no length-TS relationship for euphausiid was available in this area, we assumed that all euphausiids observed during two surveys was *Euphphausia pacifica* and length and TS were 16.4mm and –83.3 dB (Miyashita et al. 1996), respectively. The average weight was 30.6 mg calculated using formula described by Odate (1987).

Average area biomass density ($\bar{\rho}$) for each species is calculated as follows;

$$\bar{\rho} = \sum \frac{S_A}{\sigma} f_i W_i$$

where f_i is frequency distribution of ith length class. The acoustic cross section is converted from TS as follows;

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

Frequency distribution of each class (f_i) that is the acoustical contribution to the area backscattering for each length class (Ona 1993);

$$f_i = \sum_{j=1}^{\infty} n_j L_j^2$$

where n_j is the number of individuals in size class j and the length is L.

Following procedures are adopted from Jolly and Hampton (1990). Weighted mean of S_A of each block is;

$$\overline{S_{Ak}} = \frac{\sum_{i=1}^{N_k} \overline{S_{Aki}}(n_{k_i})}{\sum_{i=1}^{N_k} n_{k_i}}$$

where $\overline{S_{Ak}}$ = mean S_A in kth block, N_k = number of transects in *k*th block, $\overline{S_{Aki}}$ = mean S_A on the *i*th transect in *k*th block and n_{k_i} = number of 1 n.mile averaging intervals on the *i*th transect in *k*th block. In this formula, each transect is regarded as a single biomass density sample. Then variance of $\overline{S_{Ak}}$ is calculated with the formula (Jolly and Hampton 1990);

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

$\overline{S_A}$ is converted to $\overline{\rho}$ using above motioned formula.

Abundances of Pacific saury, less abundant small pelagic fishes, Japanese sardine and mackerel *Scomber* spp., and larger epipelagic nektons, Pacific pomfret *Brama japonica* and chum salmon *Onchorhyncus keta*, were estimated from the midwater trawl sampling data. We assumed that the area of mouth opening for the trawl net is 600 m^2, average towing speed of the net is 4 knots, and the catchability of the trawl is 14.4% for Pacific saury (Ueno et al. 2003), 18% for Japanese anchovy and mackerel, based on the similar sized Japanese anchovy (Japan Marine Fishery Resource Research Center 1991), and 10% for Pacific pomfret and chum salmons. The main distribution depth was assumed at 0-30 m for Pacific saury, Japanese sardine, and mackerel and at 0-100 m for Pacific pomfret and chum salmons. Using the data of midwater trawl, we also estimated the biomass of Japanese common squid above 100 m assuming that the catching efficiency of the trawl is 14.4%. We also used the data of the bottom trawl samplings conducted in the 100-250 m layer during the daytime to estimate the biomass of this squid assuming that mouth opening of the trawl is 10 m^2, average towing speed is 3.5 knots, and catchability of the trawls is 100% (Honda unpubl. data 2002, 2004, 2005, and 2006).

Analysis of geographical distribution of common minke whale

The data of cetacean sighting survey of JARPN II by the line transect method, and our trawl and CTD data were used for this analysis (Fujise et al. 2003, Kishiro et al. 2003, Tamura et al. 2005, Kishiro et al. 2005, Kishiro et al. 2006, Yoshida et al. 2007, Kiwada et al. 2008). Cetacean sighting survey was conducted concurrently with prey species and whale sampling surveys in 2002 and 2004-2007, and also conducted as a part of offshore component of JARPN II in 2003 when prey species and whaling surveys were not conducted in the coastal area off Kushiro (Tamura et al. 2004). All sighting surveys were conducted basically in passing mode, but abeam closing mode was also adopted for sighting within two nautical miles perpendicular to track line when the sighting was likely a baleen whale but species was not identified. During the survey, primary observers were allocated at the top barrel (three observers) and the upper bridge (two observers). Sea surface temperature (SST) was also monitored during the survey.

Analysis on prey preference

For prey preference analysis, we used prey species survey data conducted within 50 nautical miles from Kushiro and stomach content data of the common minke whale (Kishiro et al. 2009b). Temporal difference between prey species data and stomach content data was within 10 days before or after. We adopted Manly's α (Manly et al. 1972, also known as Chesson's index, Chesson 1978) to reveal prey preference of the whale. This index was successfully applied to the North Atlantic stock of minke whale to show prey preference (Lindstrøm and Haug 2001). Standardized Manly's α was written as;

$$\alpha_i = r_i / n_i \{1/\Sigma (r_j / n_j)\}$$

where r_i is percentage of *i*th prey species in wet weight in the whale stomachs, n_i is percentage of *i*th prey species in wet weight in the environment, r_j is percentage of *j*th prey species in wet weight in the whale stomachs, and n_j is percentage of *j*th prey species in wet weight in the environment. If α is equal to $1/m$ (*m* indicates total number of species in the environment), species *i* is randomly selected. If α is greater than $1/m$, species *i* is actively selected. If α is less than $1/m$, species *i* is avoided.

RESULTS

1. Geographical distribution and habitat temperature range of potential prey species

1.1. Oceanographic conditions

Our results of SST and oceanographic features reported by Okazaki et al. (2009) indicated that the subarctic Oyashio region, which is defined as a salinity of less than 33.6 PSU in the 50-200 m layer and a water temperature lower than 6˚C at 100 m (Kawai 1972), was approximately corresponded to the area of less than 14-15˚C SST in autumn off eastern Hokkaido. In the sampling survey area of common minke whale within 50 nautical miles from Kushiro, the area of less than 15˚C SST was accounted for more than 90% in 2002, 2004, and 2007 (Fig. 2). On the other hand, SST in that region was warmer in 2005 (48%) and 2006 (3%). These results show that Kushiro water shifted warmer from 2004 to 2006 then colder from 2006 to 2007 (Fig. 2). Among the small sampling blocks, this tendency was also shown in coast east and coast central blocks, which were located in the upstream region of the Oyashio (Fig. 3). In 2002, Oyashio influence was the greatest among all prey species survey years bringing cold water less than 15˚C SST to the offshore blocks and blocks of coast west and off Hidaka which were located in the downstream region of the Oyashio. However, among the six years from 2002 to 2007, Oyashio influence was the strongest in 2003 when SST area of less than 14-15˚C greatly expanded to the offshore region (Japanese Coast Guard: http://www1.kaiho.mlit.go.jp/KAN1/kaisyou/dwn/2003.html). Unfortunately, only sighting survey was conducted this year.

1.2 Prey species composition in the environment

The result of our predetermined trawl survey indicated that Japanese anchovy and Pacific saury were abundant component in the epipelagic smalll fish community (Table 1). According to our acoustic and IKMT data, and data from bottom trawl samplings (Honda, unpubl. data 2002, 2004, 2005, and 2006), other abundant potential prey species were walleye pollock, Japanese common squid, and euphausiids (most of which were *Euphausia pacifica*, see below).

1.3. Geographical distribution and habitat temperature range of potential prey species

1.3.1. Abundant five species

Pacific saury: The result of predetermined trawling survey indicated that this species was mainly distributed in the 11-15˚C SST areas with a strong influence of the Oyashio Current (Figs. 4 and 5). Although distribution area of this species in 2002 expanded to the offshore region due to relatively low SST, its main distribution was the coastal region in all years (Figs. 3 and 5). The southern limit distribution area of this species was corresponded to the 17 or 18˚C SST isotherms (Figs. 4 and 5).

Japanese anchovy: This species was mainly distributed in the Oyashio-Kuroshio transition region south of the Oyashio front where SST was 14-19˚C (Figs. 4 and 6). Its geographical distribution pattern was greatly changed in each year because distributions of 14˚C and 19˚C isotherms at 0 m depth were largely fluctuated by year. In 2002, this species was widely distributed from coastal to offshore region except for northern most area (< 14˚C SST) where was strongly affected by the Oyashio (Fig. 6). Its main distributions were restricted to the coastal region from 2004 to 2007 due to high temperature field in the offshore waters (> 18-19˚C SST).

Walleye pollock: This species was abundant around continental shelf area at 100-250 m depth in the daylight period (Watanabe and Kiwada unpubl. data, see Fig. 24) with the SST was 12-22˚C (Figs. 4, 7 and 8).

Japanese common squid: This squid was seemed to prefer slope water region where SST was 14-18˚C (Figs. 4, 8, and 9).

Euphausiids: The main habitat of euphausiids was in the slope water region affected by the Oyashio waters (Figs. 10a and 11a). In 2002 when Oyashio influence was remarkable in both inshore and offshore regions, its distribution expanded to the offshore region. Vertically, euphausiids were mainly distributed in the 100-200 m layer (Watanabe and Kiwada unpubl. data).

1.3.2. Less abundant four species

Japanese sardine: This species was captured in the area of 14-18˚C SST south of the Oyashio region in 2002, 2005, 2006, and 2007 (Figs. 4 and 12).

Mackerel: Mackerel were distributed mainly in the area of 14-18˚C SST, which was located in the Oyashio-Kuroshio transition region (Fig. 4). Its abundance was very small during 2002 and 2006 (Fig. 13). However, relatively high catches were recorded in the offshore region in 2007 where SST was 17-18˚C (Fig. 13).

Pacific pomfret: This large pelagic nekton was frequently captured in 2007 in the Oyashio and its adjacent regions where SST were 12-14˚C, including whale sampling area off Kushiro (Fig. 14).

Chum salmon: This species was collected in 2002, 2005, and 2007 in the Oyashio and its downstream regions where SST were 11-16˚C (Fig. 15).

These results indicated that geographical distribution patterns of each potential prey species could be categorized in relation to oceanographic conditions and/or continental shelf as follows; (1) Distributions were almost restricted to the Oyashio region: Pacific saury, euphausiids, Pacific pomfret, and chum salmon; (2) Distributions were mainly in the northern transition region: Japanese anchovy, Japanese sardine, and mackerel; (3) Distributions were mainly in the continental shelf region where was located in the northern transition region: Japanese common squid; (4) Distributions were in almost entire part of the continental shelf region: walleye pollock.

2. Annual changes in biomass of major potential prey species

Biomass of euphausiids largely fluctuated year-to-year within three orders and showed prominent peaks in 2002 and 2007 in the cold period (ANOVA, $p < 0.05$, Fig.10). Among the potential fish and squid prey, biomass of Pacific saury, Japanese anchovy, and Japanese common squid fluctuated annually within two or three orders in each block (ANOVA, $p < 0.05$, Fig. 10). This large fluctuation was also shown among blocks in the same year (ANOVA, $p < 0.05$). Contrasting with these species, biomass of walleye pollock in the coastal blocks was relatively stable in each year. It was remarkable that biomass of each species was extremely low in the offshore region except for 2002 (Fig. 10). In 2002, euphausiids and Japanese anchovy were relatively abundant in the offshore region although biomasses of these species were several times higher than those in the coastal blocks. These results indicate that coastal blocks were more favorable than offshore blocks in terms of prey environment of the whale during the five years studied.

In the sampling survey region of common minke whale, euphausids were abundant in the cold period in 2002 and 2007 and less abundant in the warm period from 2004 to 2006 (Fig.11). A total biomass of major fish and squid prey species showed prominent peak in 2002 due to densely distribution of Japanese anchovy and Japanese common squid. In other four years, biomass of fish and squids was relatively low but stable due to small annual fluctuation in abundance of walleye pollock. These results indicate that annual change in prey environment of common minke whale in the mesopelagic zone is relatively small comparing with epipelagic zone.

3. Geographical distribution of the common minke whale

The result of cetacean sighting survey indicated that common minke whale was mainly found in the area of < 16˚C SST (Fig. 16). This strongly suggests that this species was mainly distributed in or close to the Oyashio region in autumn off Kushiro. Geographically, hot spot of the whale seemed to be located in or close to the slope water region in each year. However, its distribution expanded to the offshore region in 2003, when SST of offshore region was extremely low (< 15˚C, Fig. 17). In 2006, this species was often found in the area of 16-20˚C SST, but its abundance was low (Fig. 17).

4. Prey preference of common minke whale

Size compositions of the potential fish and squid prey of the common minke whale were depicted in Figs. 18-22, indicating that these species could be categorized as small (10 to 20 cm in body length: Japanese anchovy, mackerel, and Japanese sardine), middle (20-35 cm: Pacific saury and Japanese common squid), and large (35-70 cm: walleye pollock, Pacific pomfret, and chum salmon) size classes.

Prey species compositions by wet weight in the stomachs of immature (approximately < 7 m in body length) and mature (> 7 m) common minke whale were shown in Table 2 (after Kishiro et al. 2009b). Immature whale fed mainly on walleye pollock in almost all years although euphausiids and Japanese anchovy were also popular preys in some years. The main prey of mature whale was Japanese anchovy in all years. Pacific saury (in 2002, 2003, and 2007) and Japanese common squid (in 2002, 2005, and 2006) were also one of the main preys of mature whale. In 2005, walleye pollock was the most popular prey of mature whale, but this prey was minor component in other four years (Table 2). These results indicated that there was a little overlap of main prey category or species between immature and mature whales except for Japanese anchovy.

According to Manly's α, both immature and mature whales avoid euphausiids which were the most abundant in all years in the whale sampling survey area (Table 3, Fig. 11). This indicates that the occurrences of the potential prey species in the environment were not reflected in stomach contents of the whale. Manly's α also indicated that immature whale selected walleye pollock regardless of the year (Table 3). In addition, immature whale's pick for other species was varied annually, i.e. Pacific saury in 2002 and Japanese anchovy in 2004, 2006, and 2007. Contrasting with immature whales, mature whales unlikely pick walleye pollock in almost all years except for 2005 and Pacific saury and Japanese anchovy were the most favoured by mature whales in the four of five years (Table 3).

DISCUSSION

1. Geographical distribution of potential prey species

The occurrence rates of each prey species in relation to SST at the sampling stations reflected the geographical distribution pattern of these species, as SST generally decreases from eastern or northern upstream region to the western or southern downstream region of the Oyashio. Among the potential prey species, occurrence rates of Pacific saury, Pacific pomfret, and chum salmon decreased with increasing SST, indicating that these species occurred off eastern Hokkaido with southward intrusion of Oyashio in autumn. Japanese anchovy, Japanese common squid, mackerel, and Japanese sardine were almost restricted to the mid SST areas. This reflects their summer northward migration and stay at the productive northern Oyashio-Kuroshio transition region north of the transition zone chlorophyll front, which is corresponded to the isotherm of 18-19˚C SST (Polovina et al. 2004). Furthermore, euphausiids were mainly distributed in the Oyashio region of less than 16˚C SST. These facts indicate that the SST is a good indicator to predict not only distributions of these prey species but also prey environment of common minke whale in autumn of the study area. SST, however, could not explain the habitat of walleye pollock. Considering that walleye pollock is distributed in the Oyashio Undercurrent below mixing zone all day, the distribution of this species should not be affected by the oceanographic conditions in the epipelagic zone. The distributions of these potential prey species greatly overlapped in the continental shelf area in or close to the Oyashio front where SST was 14-16˚C, suggesting that this area was rich prey environment for common minke whale in terms of prey species diversity and also prey biomass as we discuss below.

2. Annual change in prey environment

The decrease in abundance of euphausiids, most of which were *E. pacifica*, from 2002 to 2004 and increase in its abundance from 2006 to 2007 coincided with the shift of SST regime from cold to warm and from warm to cold, respectively. Biomass of Pacific saury was the highest in 2002 and the lowest in 2006. This fluctuation could be also explained by annual change in Oyashio influence, because SST field was the coldest in 2002 and warmest in 2006. In 2006, southward migration of Pacific saury was greatly delayed (Hokkaido Kushiro Fisheries Experiment Station, http://www.fishexp.pref.hokkaido.jp/exp/kushiro/). Hence this species was rarely collected in this study area.

Biomass of Japanese anchovy is known to have been at high level since mid 1990s (Takahashi et al. 2001). However, its biomass was extremely low in 2005 due to recruitment failure in 2004 (Takasuka et al. 2006). Therefore, prey environment for common minke whale in the epipelagic zone is thought to greatly change by year due to both fluctuation of Oyashio influence and recruitment status of each species.

Contrasting with epipelagic fishes, biomass of walleye pollock was relatively stable throughout the five years studied. This probably indicates that mesopelagic zone along continental shelf is favorable foraging area for common minke whale in terms of stability of prey density.

3. Distribution of common minke whale related to physical and prey environment

The present results indicated that the common minke whale was mainly distributed in the slope water region affected by Oyashio in each year and their main distributions expanded to the high sea area in 2003 when Oyashio influence was the greatest. In the slope water region, rich prey environment might be assured by the distribution of walleye pollock, which biomass showed small annual fluctuation. Furthermore, distribution center of other potential prey species were also located in this region although their biomass were largely fluctuated annually. These facts suggest that common minke whale prefer the productive slope water region in both warm and cold periods (Fig. 23).

In 2003 when common minke whale was abundant both in the slope water and offshore regions, Pacific saury might be also plenty in the coastal to offshore regions because most part of these regions were less than 14-15˚C in SST (see Figs. 2 and 4). Expansion of Oyashio followed by Pacific saury may have led common minke whales to swim around from coastal to the offshore regions in 2003 (Fig. 23). This might indicate that common minke whale has so-called area preference, which is related to the distribution of Pacific saury in autumn off eastern Hokkaido. Pacific saury migrates from subtropical to highly productive subarctic regions to feed in summer (Odate 1977, Taniguchi 1981). According to Tamura et al. (2009) and Konishi et al. (2009), common minke whale also carries out a northward migration and feed mainly on Pacific saury during summer in the subarctic region. Considering that Pacific saury is the most abundant small epipelagic fish in the subarctic region in summer (Odate 1977, Ueno et al. 2003, Murase et al. 2009), their distribution area might be a favorable feeding environment for common minke whale. Therefore, common minke whale possibly migrate following the southward migration of Pacific saury to maintain rich prey environment during summer and autumn. This view is probably adopted at least for mature common minke whale, because they showed a strong prey selection for Pacific saury (see below).

4. Prey preference

According to Kishiro et al. (2009b), two small epipelagic fish, Japanese sardine and mackerel, were not found in the stomachs of common minke whale, which probably due to extremely low abundance of these species in the whale sampling area. Although size ranges of walleye pollock and Pacific pomfret were similar, Pacific pomfret is more muscular than walleye pollock. Furthermore, chum salmon also has muscular body. Therefore, the present result that common minke whale rarely fed on these species probably due to their swimming ability (Kishiro et al. 2009b). Generally, common minke whale prefer small pelagic fishes like anchovy and herring and slope water demersal fish like pollock, which are distributed above 100-200 m depth (Harbitz and Lindstrøm 2001, Haug et al. 1996, Lindstrøm and Haug, 2001, Skaug et al. 1997, Murase et al. 2007). These prey species is known to form dense school and their swimming ability is relatively low among the pelagic nektons (Yamamura et al. 2002, Takahashi et al. 2001, Ueno et al. 2003). Hence common minke whale seems to have a feeding strategy to utilize abundant and dense schooling resources effectively with lower foraging energy cost. *Euphausia pacifica* are usually abundant and making dense school in the subarctic region especially in the slope water region (Taki et al. 1996), as was also shown in this study. However, both immature and mature whales did not prefer this prey, which is reasonable in terms of their lower caloric value comparing with other potential fish and squid preys (3500 kJ/kg, vs. 4200-11000 kJ/kg, Watanabe unpubl. data).

In the whale sampling survey region off Kushiro, immature and mature whales were generally distributed in the shallower slope water region (< 500 m depth) and from the deeper slope water to the offshore regions, respectively (Kishiro et al. 2009b). The present results indicate a preference of immature and mature whales for mesopelagic and epipelagic fishes, respectively, suggesting that habitat segregation of immature and mature whales reflect their different feeding strategies. Immature whales preferred walleye pollock in all years studied. Generally, small epipelagic fish and squids like Japanese anchovy are unevenly distributed with dense school, suggesting that predators require more energy to seek and capture them (Fig. 24). In contrast, walleye pollock was almost uniformly distributed in the slope water region of 100-250 m depth (Fig. 24). Furthermore, its biomass was relatively high and stable among the year. Therefore, walleye pollock may be a favorable prey for common minke whales that have low prey searching ability, although caloric value of this demersal fish is much lower than those of small epipelagic fish preys like Japanese anchovy and Pacific saury (4200 kJ/kg vs. 6300-11000 kJ/kg, Watanabe unpubl. data) and diving behavior entails a high energetic cost for cetaceans (Goldbogen et al. 2007). Immature whales may therefore trade off the energy cost of in and out associated with feeding behavior. The present result also showed that immature whales also preferred Pacific saury or Japanese anchovy in some years, suggesting that they could utilize these epipelagic fish prey when they abundantly and/or frequently migrate into slope water region.

Contrasting with immature whale, mature whales preferred Pacific saury in all years except for 2006 when abundance of this species was extremely low due to high SST field off Kushiro. Furthermore, mature whales also preferred Japanese anchovy for four of five years. Among the potential prey species found in this study, caloric value of Pacific saury is the highest (11000 kJ/kg), followed by Japanese anchovy (6300 kJ/kg, Watanabe unpubl. data). Because foraging ability and/or energy demands thought to increase as they grow, mature whales may prefer epipelagic fish prey with higher caloric value. However, mature whales frequently fed on walleye pollock in 2005. This might relate to the low abundance of Pacific saury and Japanese anchovy off Kushiro and suggests that the main prey of large whale switch to walleye pollock when small epipelagic fish prey is not sufficiently available. Similar prey switching from epipelagic to mesopelagic prey species is also reported for Dall’s porpoise *Phocoenoides dalli* in the Sea of Japan (Ohizumi et al. 2000). However, this tendency was not recognized in 2007, when abundance of epipelagic fishes was also extremely low. Hence further cooperative survey of prey species and whale sampling is needed to clarify this prey switch hypothesis.

5. Conclusion and future direction

In autumn in the Kushiro area, difference in feeding habits between immature and mature common minke whales could be explained by difference in their habitat and prey selection procedures (Fig. 25). These differences are probably reflected the differences in seeking or catching ability for prey species, or a trade-off between low and high-energy demands of their lifestyles. In the future, data on feeding behavior of the immature and mature whales might be accumulated by using depth and temperature data loggers to clarify their feeding strategies. Such surveys should be conducted concurrently with prey species and whale sampling surveys because prey environment is thought to greatly affect feeding behavior of the whale and lethal survey is also important to obtain actual stomach content data of the whale. Prey species survey is also needed to construct the ecosystem models off eastern Hokkaido in the future. This model would contribute to aid the recovery of the resource of walleye pollock around Hokkaido, which showed low levels of abundance in recent years (Hokkaido National Fisheries Research Institute, 2007: http://cse.fra.affrc.go.jp/anishimu/hnfweb/doko1000/Summary1000R.pdf).

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Table 1. Species composition (CPUE, kg /h) by predetermined trawling survey. A cross indicates a catch of less than 0.1 kg. A bar indicates no catch.

Species / Year	2002	2004	2005	2006	2007
Japanese anchovy	83.2	87.6	56.3	99.2	50.7
Pacific saury	16.6	8.1	22.2	+	1.9
Mackerels	0.1	1.8	0.5	0.7	23.6
Japanese sardine	-	-	-	+	0.2
Pacific pomfret	0.1	2.5	2.5	-	21.7
Chum salmon	-	-	18.3	-	1.9
Others	+	-	0.1	-	0.1

Table 2. Stomach contents of common minke whale during and within 10 days before and after prey species survey period in the whale sampling survey area off Kushiro (after Kishiro et al. 2009b).

(A) Immature whale

Year	No. whales sampled	Stomach content composition (%WW)									Total wt of stomach content (kg)
		Euphau-siids	Japanese anchovy	Pacific saury	Walleye pollock	Japanese sardine	Mackerel	Pacific pomfret	Chum salmon	Common squid	
2002	19	36.4	29.4	2.1	32.1	0	0	0	0	0	415.1
2004	18	0	85.0	3.8	11.1	0	0	0	0	0	305.2
2005	22	16.0	2.0	0	82.0	0	0	0	0	0	1696.2
2006	12	1.4	30.9	0	67.7	0	0	0	0	0	231.3
2007	18	0	9.5	2.0	88.6	0	0	0	0	0	331.2

(B) Mature whale

Year	No. whales sampled	Stomach content composition (%WW)									Total wt of stomach content (kg)
		Euphau-siids	Japanese anchovy	Pacific saury	Walleye pollock	Japanese sardine	Mackerel	Pacific pomfret	Chum salmon	Common squid	
2002	14	0	23.4	36.7	2.4	0	0	0	0	37.5	439.9
2004	23	0	72.0	27.3	0	0	0	0	0.4	0.3	597.9
2005	22	7.2	17.7	2.9	59.1	0	0	0	0	13.1	994.6
2006	10	0	79.9	0	0.7	0	0	0	0	19.4	188.1
2007	10	4.5	22.4	71.6	1.2	0	0	0.4	0	0	283.8

Table 3. Manly's α of common minke whale for each prey species in the whale sampling survey region off Kushiro in the autumn of 2002-2007. -: Species was not found in the environment. m: total number of species in the environment. If Manly's α is greater (smaller) than 1/m, prey species *i* is actively (negatively) selected. Shaded area indicates positive prey preference.

(A) Immature whales

Prey species / Year	2002	2004	2005	2006	2007
Euphausiids	0.002	0.000	0.002	0.000	0.000
Pacific saury	0.501	0.026	0.000	-	0.155
Japanese anchovy	0.156	0.746	0.103	0.663	0.670
Japanese sardine	-	-	-	0.000	0.000
Mackerel	-	0.000	0.000	0.000	-
Pacific pomfret	-	-	0.000	0.000	0.000
Chum salmon	-	-	0.000	0.000	0.000
Walleye pollock	0.340	0.228	0.896	0.347	0.175
Common squid	0.000	0.000	0.000	0.000	-
1/m	0.200	0.167	0.125	0.125	0.167

(B) Mature whales

Prey species / Year	2002	2004	2005	2006	2007
Euphausiids	0.000	0.000	0.000	0.000	0.000
Pacific saury	0.934	0.207	0.299	-	0.780
Japanese anchovy	0.013	0.703	0.308	0.680	0.220
Japanese sardine	-	-	-	0.000	0.000
Mackerel	-	0.000	0.000	0.000	-
Pacific pomfret	-	-	0.000	0.000	0.000
Chum salmon	-	-	0.000	0.000	0.000
Walleye pollock	0.003	0.000	0.221	0.002	0.000
Common squid	0.005	0.090	0.172	0.318	-
1/m	0.200	0.167	0.125	0.125	0.167

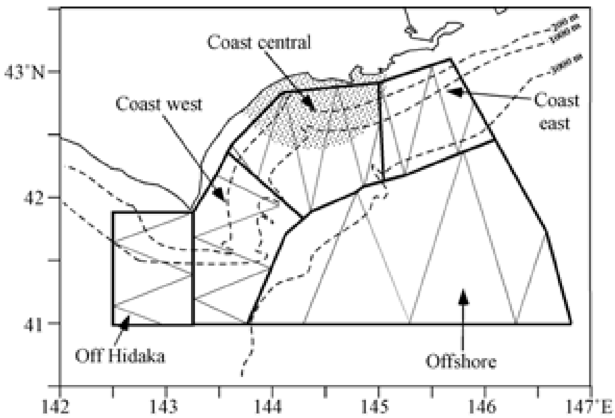

Fig. 1. Sampling area and distribution of each small block in the JARPN II coastal survey off Kushiro in 2007. Dotted area indicates the whaling survey area of common minke whale. Thin lines indicates the prey species survey line in 2007.

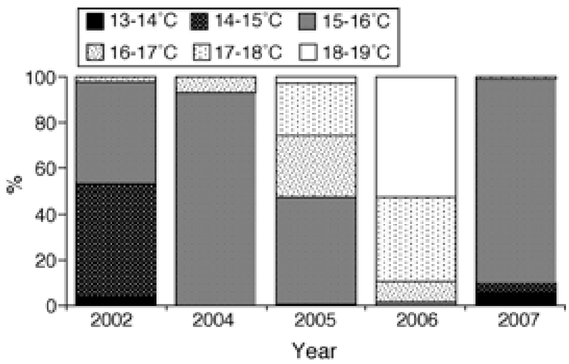

Fig. 2. Percent composition of each SST area in the sampling survey region of common minke whale.

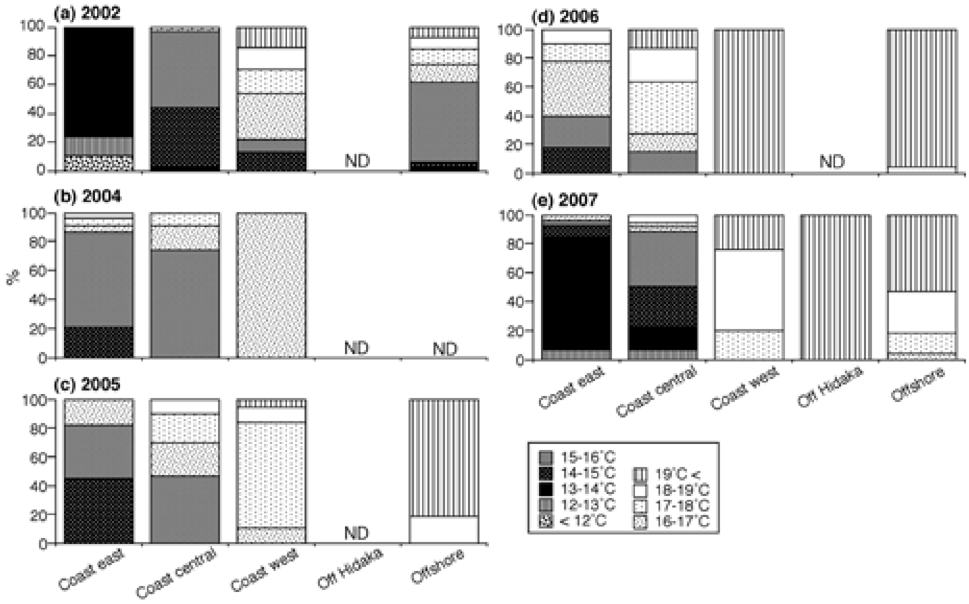

Fig. 3. Percent composition of each SST area in each small block.

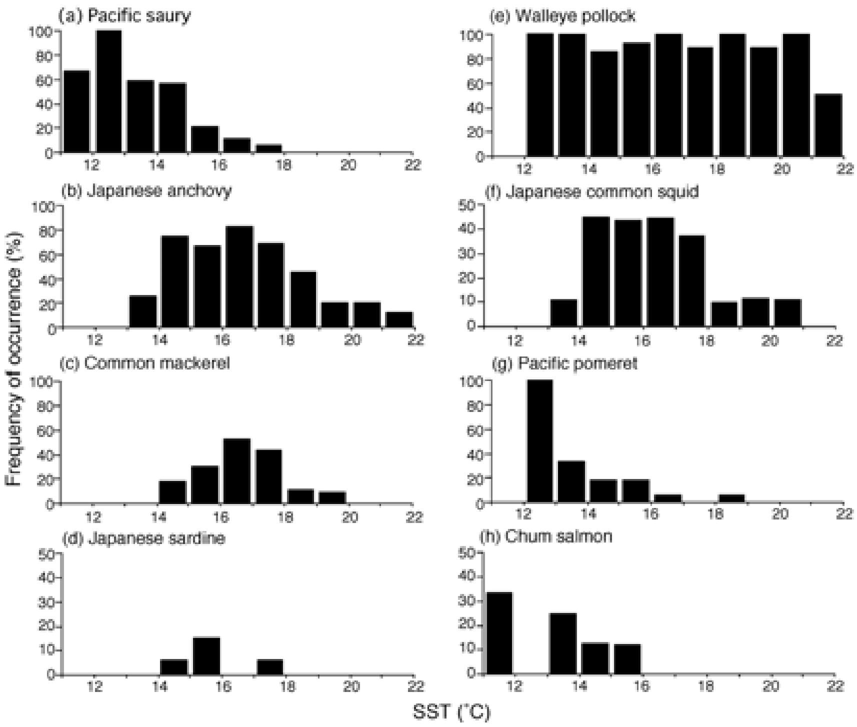

Fig. 4. Percent occurrence of total number of predetermined midwater trawl samplings in relation to SST for eight potential prey of minke whale during autumn off eastern Hokkaido. Five years of data were pooled.

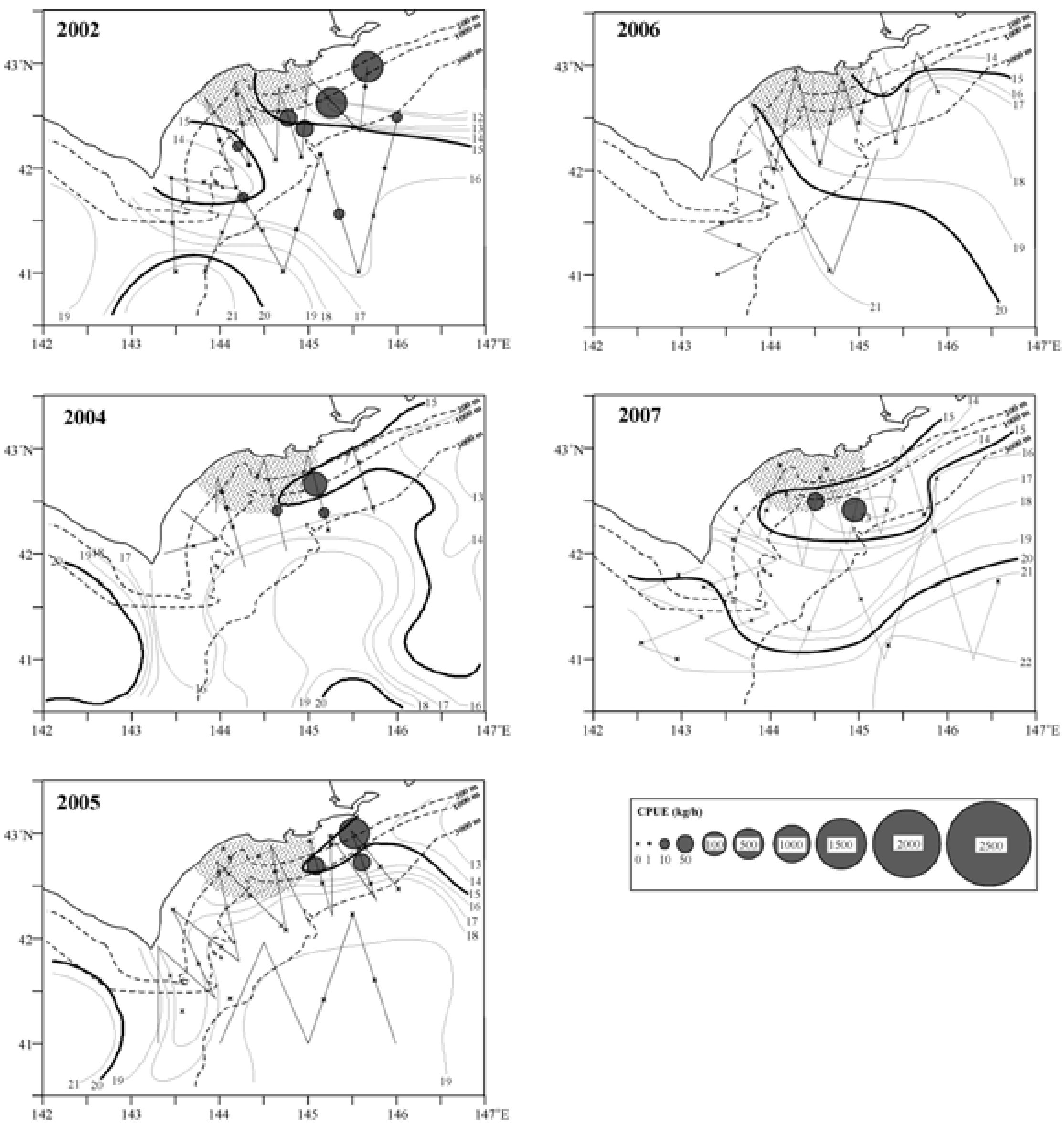

Fig. 5. Geographical distributions of Pacific saury based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007. Isotherms of 200, 1000, and 3000 m and SST during the survey period was also indicated. Dotted area indicates the whaling survey area of common minke whale. Thin lines indicate the track line of prey species survey.

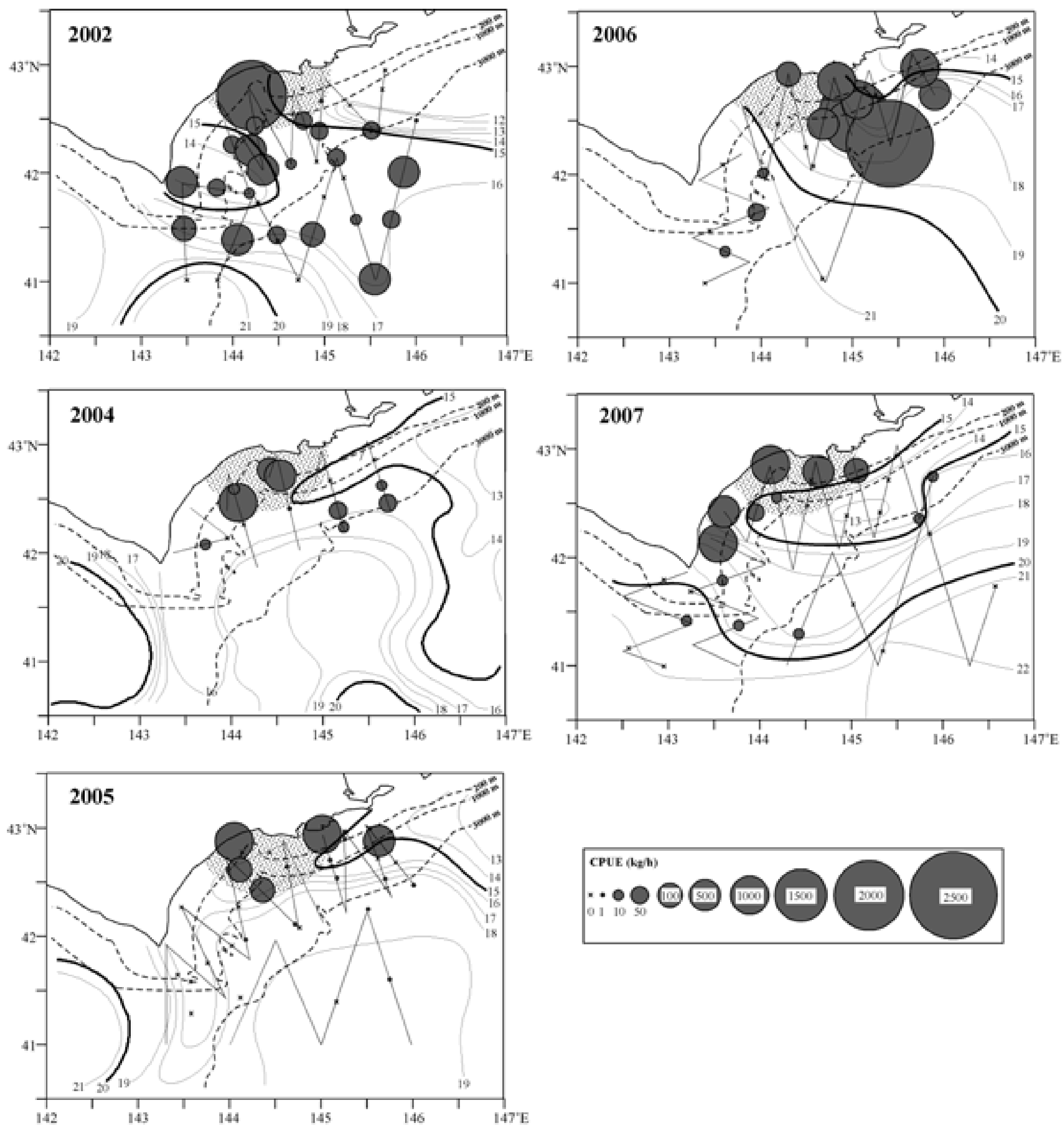

Fig. 6. Geographical distributions of Japanese anchovy based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007.

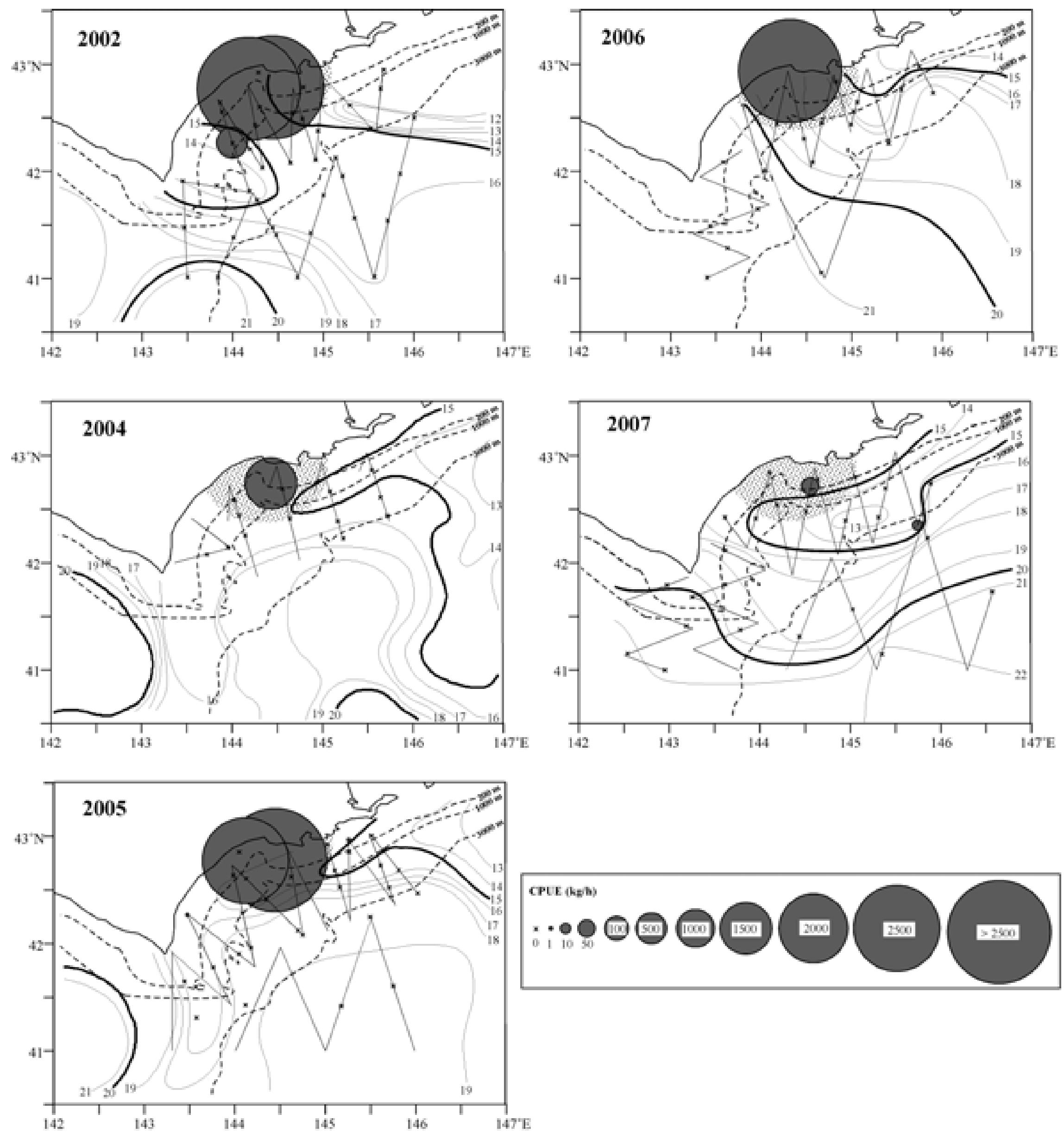

Fig. 7. Geographical distributions of walleye pollock based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007.

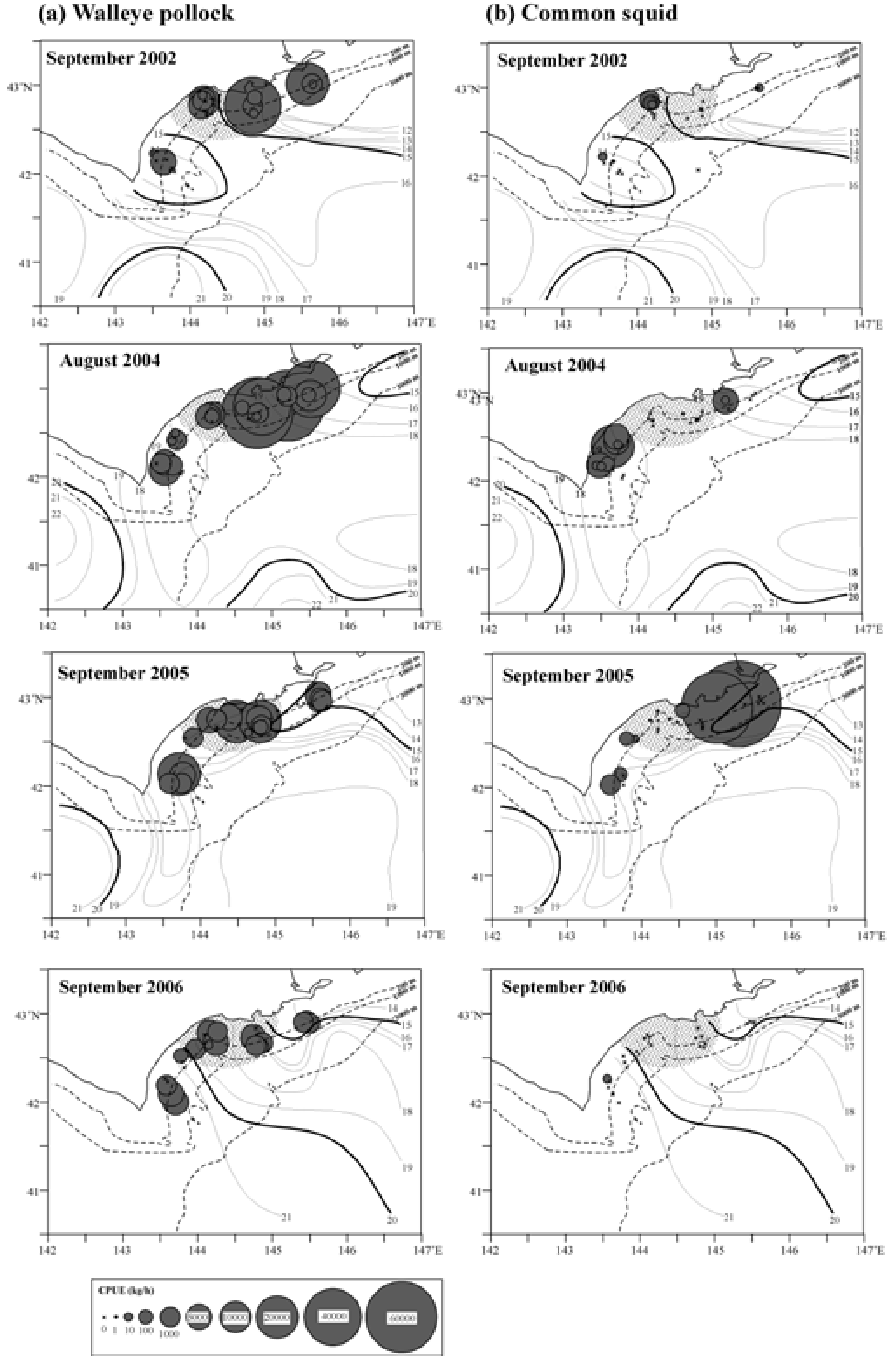

Fig. 8. Geographical distributions of (a) walleye pollock and (b) Japanese common squid based on the result of bottom trawl survey conducted by Hokkaido National Fisheries Research Institute off eastern Hokkaido during 2002-2006.

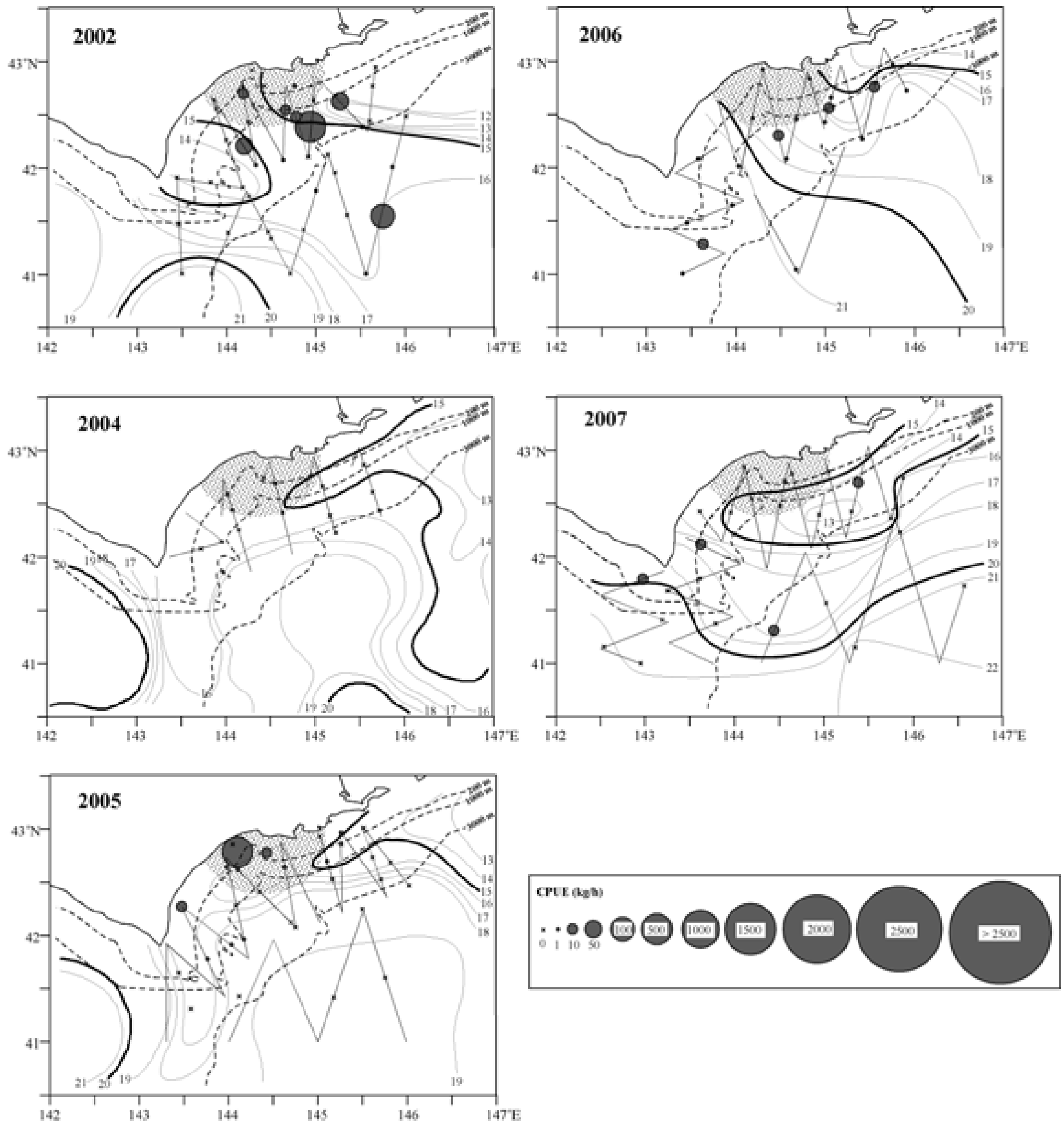

Fig. 9. Geographical distributions of Japanese common squid based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007.

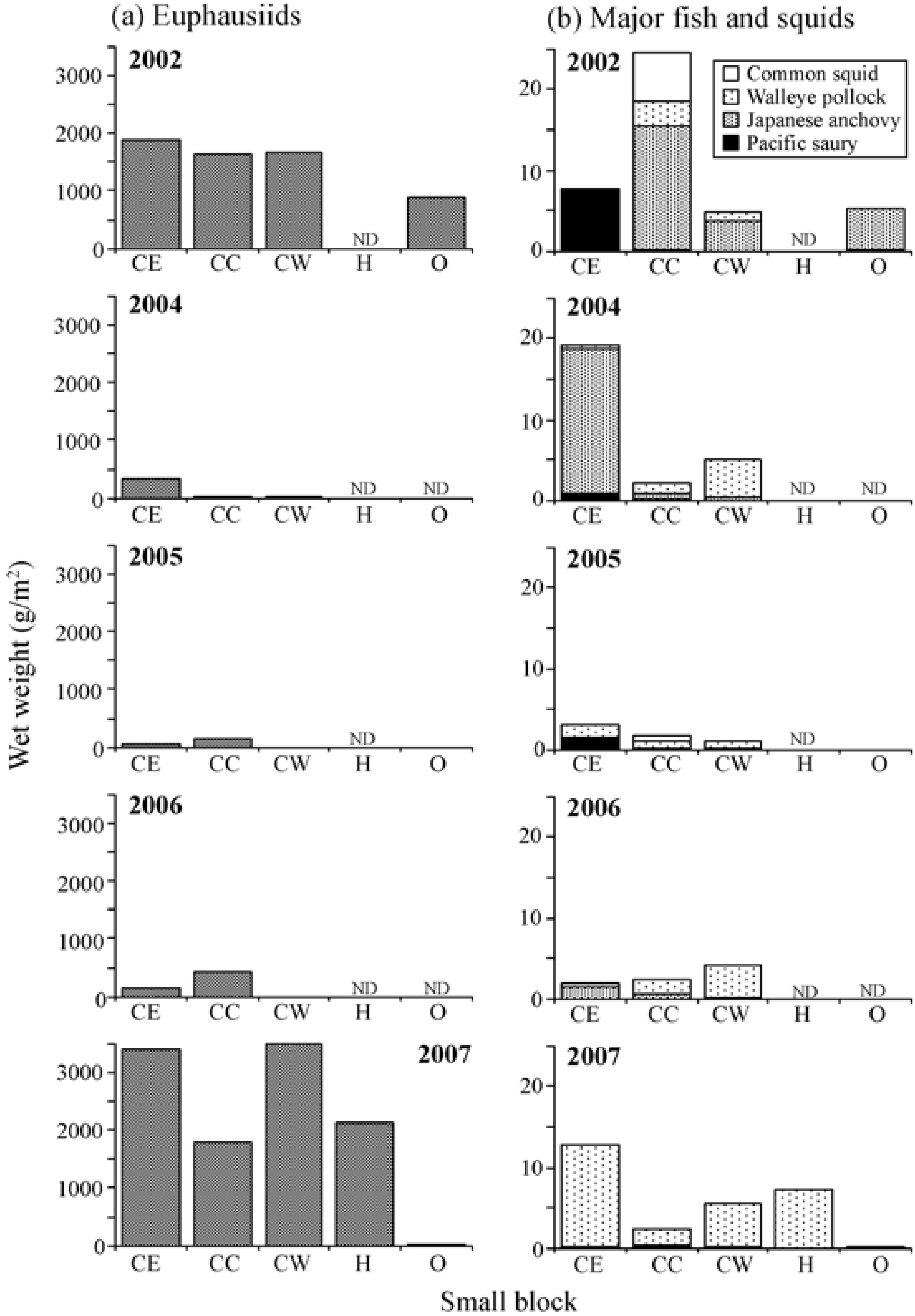

Fig. 10. Annual change in biomass (g/m^2) of the major potential prey species of common minke whale in each sampling block. ND: survey was not conducted; CE: coast east block; CC: coast central block; CW: coast west block; H: off Hidaka block; O: offshore block.

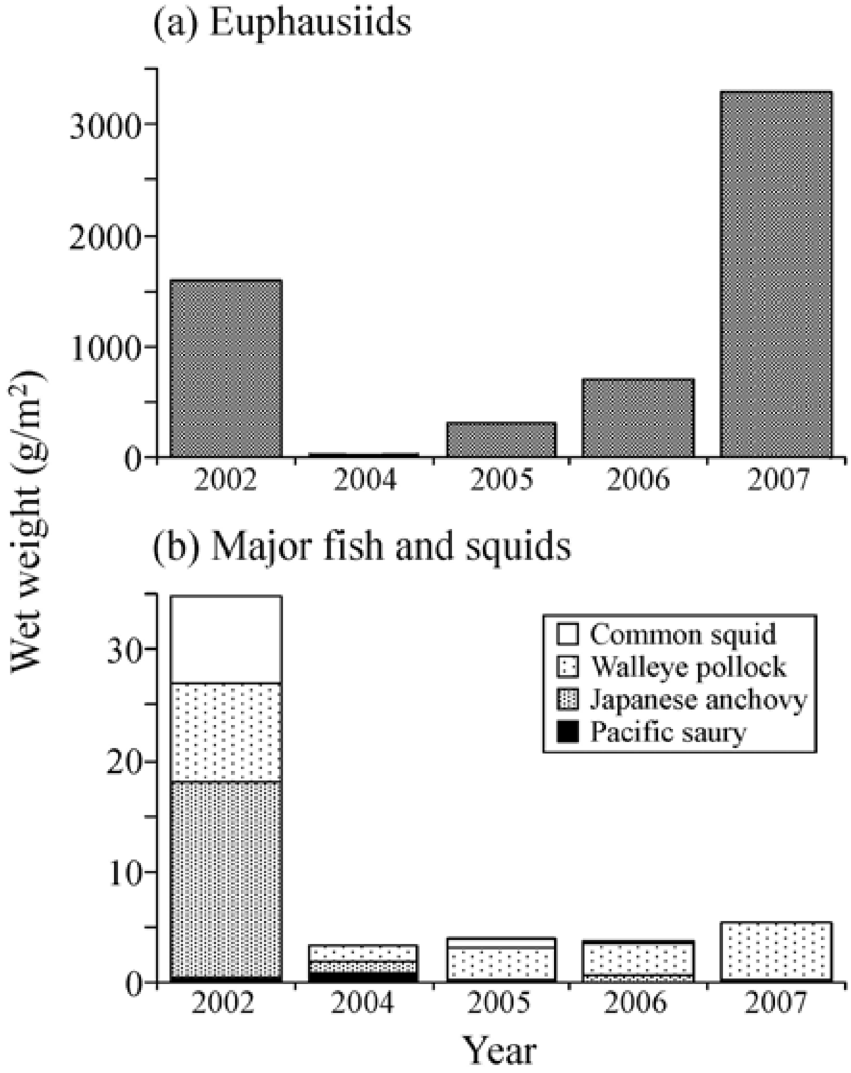

Fig. 11. Annual change in biomass (g/m^2) of the major potential prey species of common minke whale in the whale sampling survey region off Kushiro. ND: survey was not conducted.

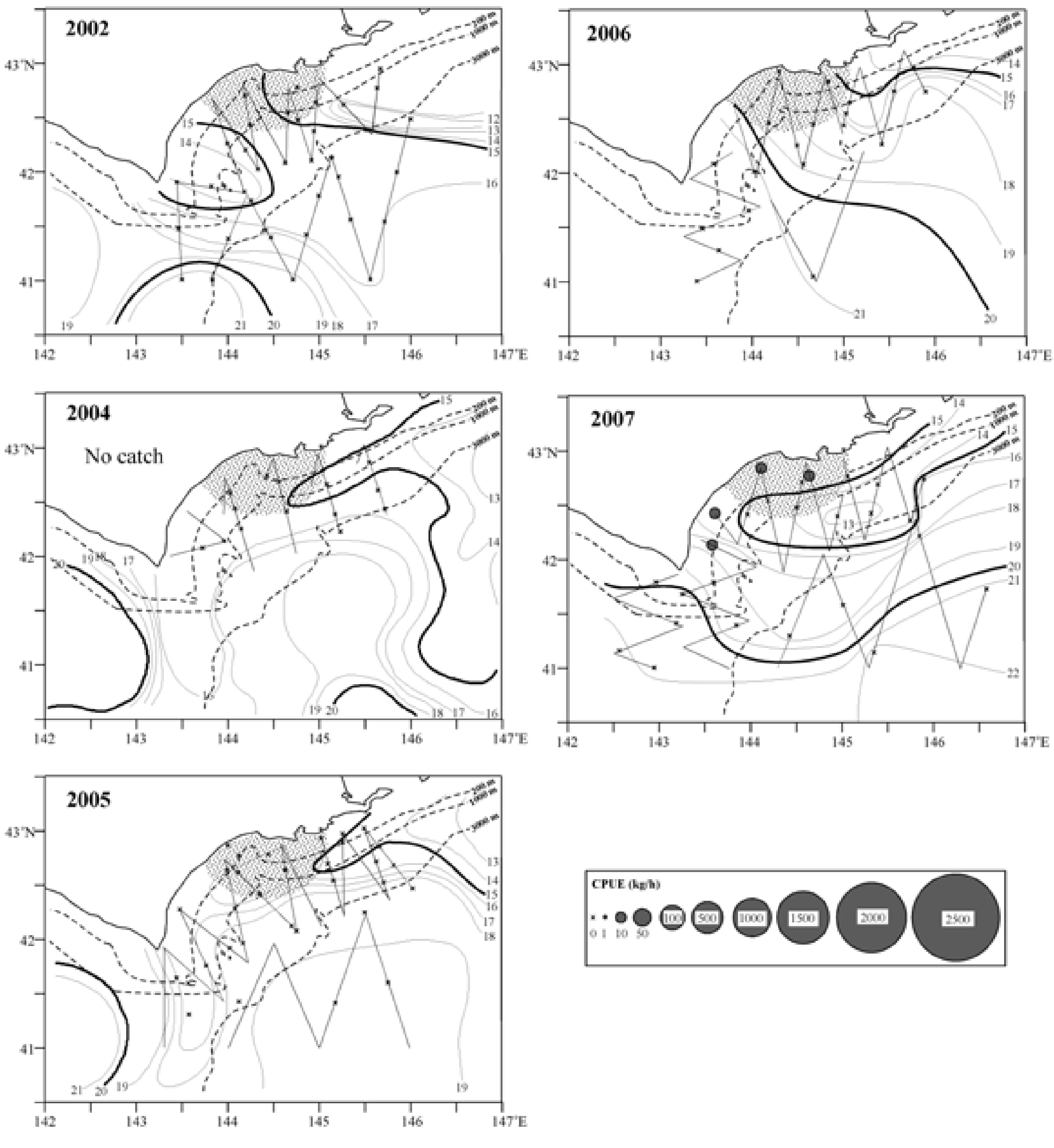

Fig. 12. Geographical distributions of Japanese sardine based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007.

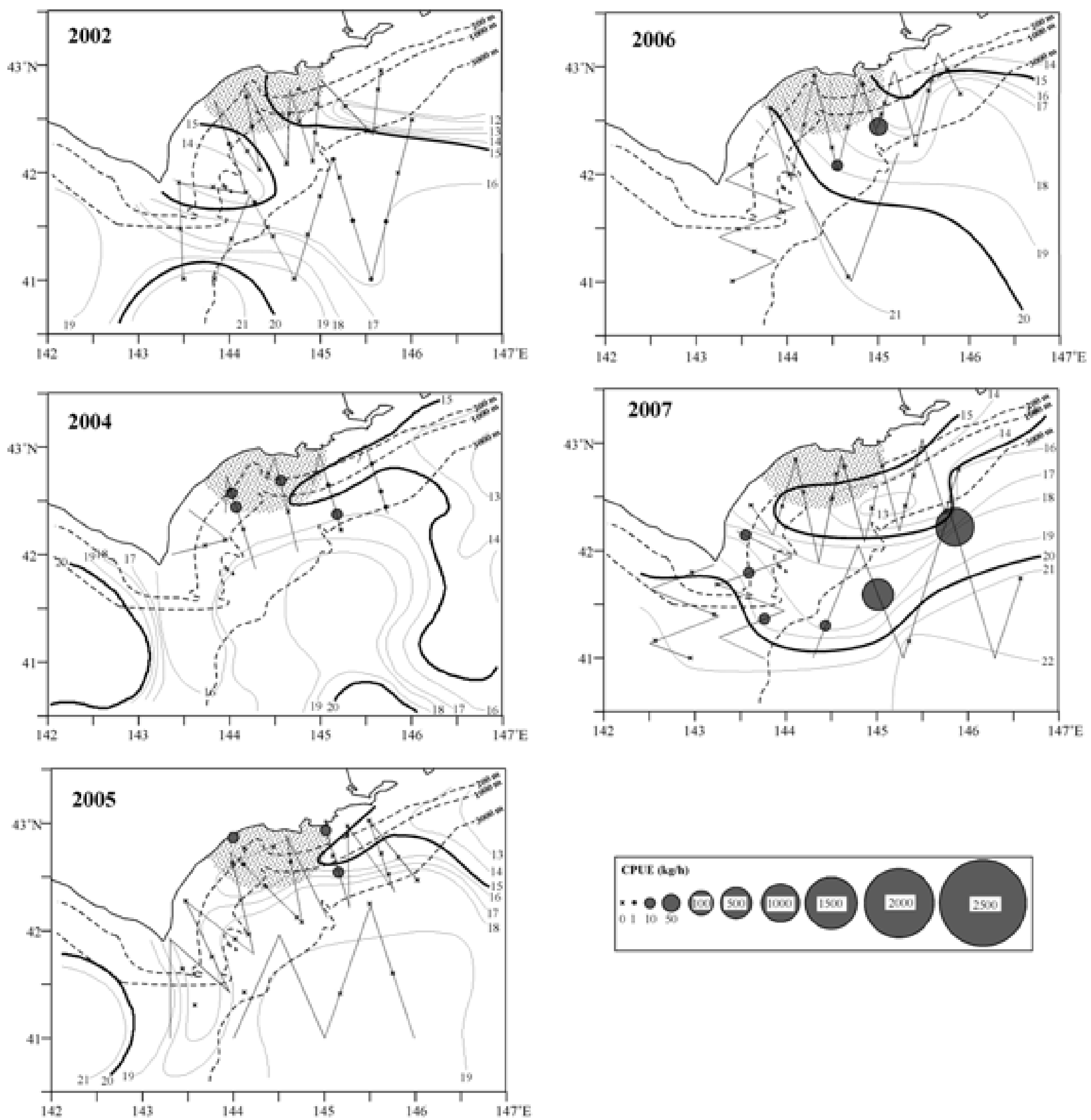

Fig. 13. Geographical distributions of mackerel based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007.

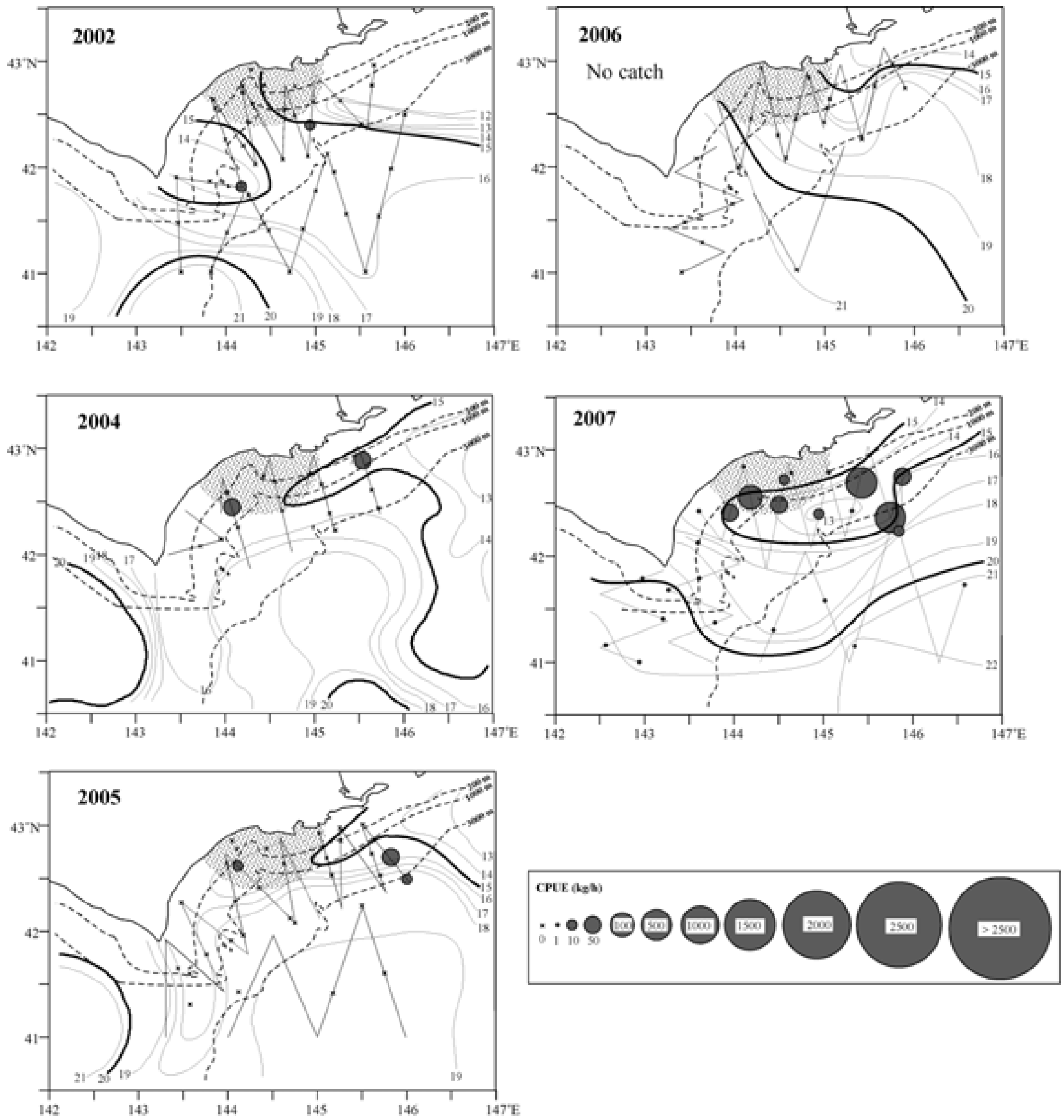

Fig. 14. Geographical distributions of Pacific pomfret based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007.

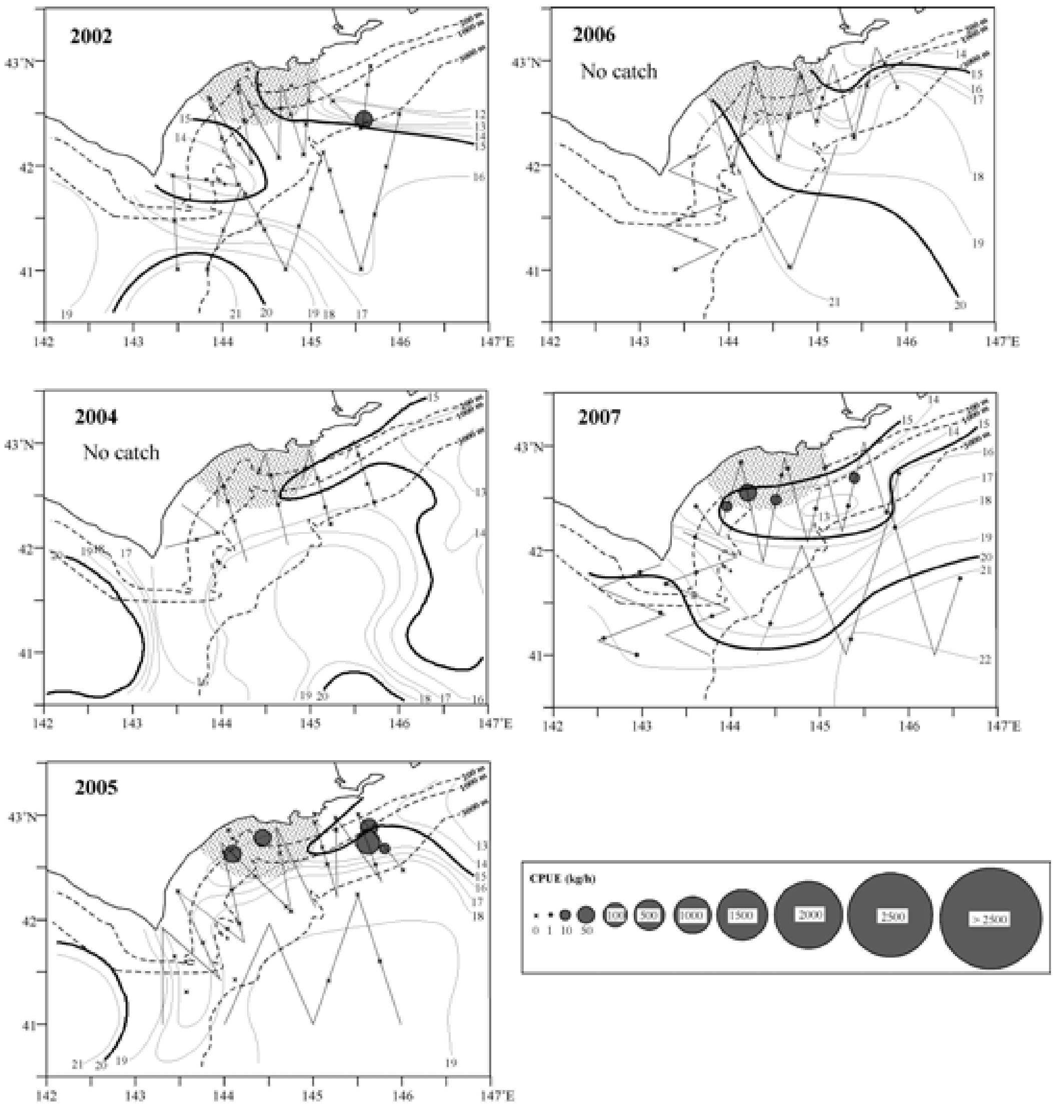

Fig. 15. Geographical distributions of chum salmon based on the result of midwater trawl survey off eastern Hokkaido during 2002-2007.

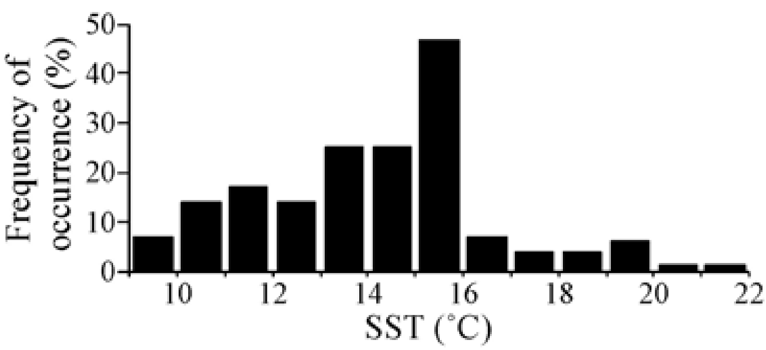

Fig. 16. Occurrence rate of common minke whales in each SST area. Six years from 2002 to 2007 of data were pooled.

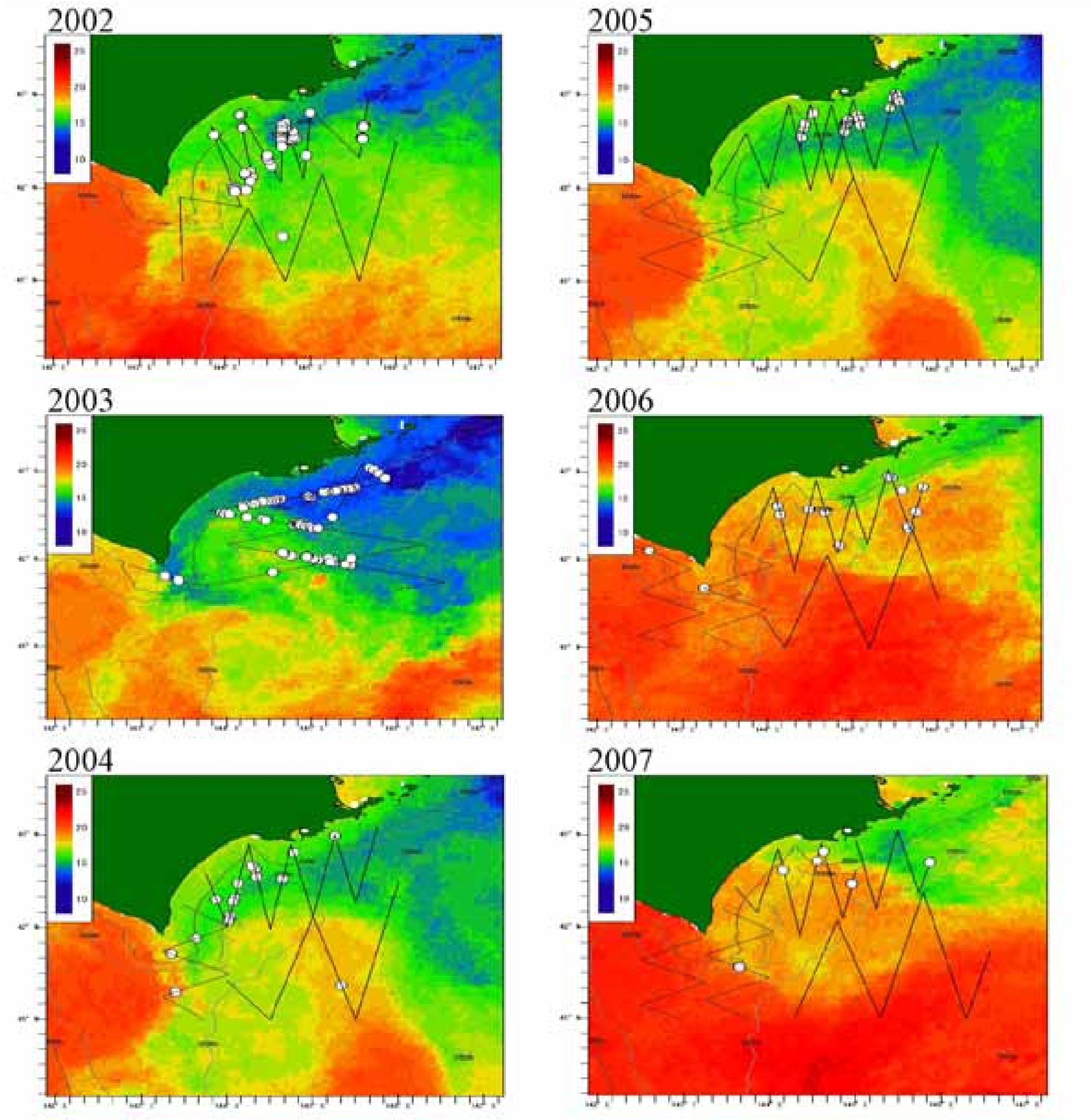

Fig. 17. Geographical distribution of common minke whales off eastern Hokkaido during 2002-2007. Isotherms of 200, 1000, and 3000 m and SST during the survey period was also indicated. Thin lines indicate sighting survey line for cetaceans.

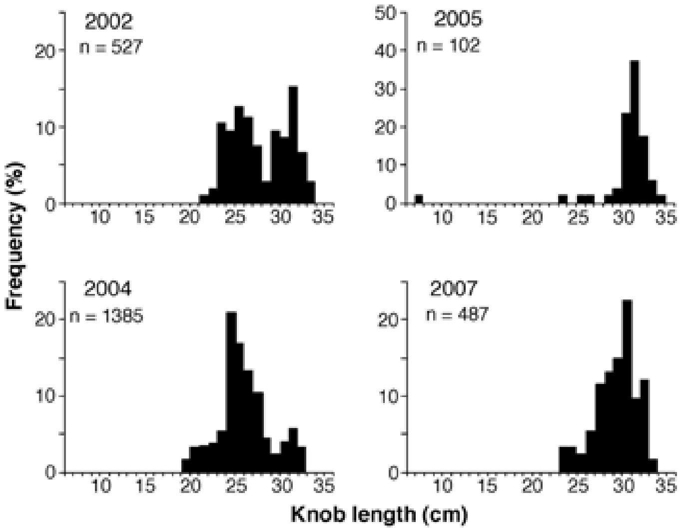

Fig. 18. Size frequency of Pacific saury in the environment of the area within 50 nautical miles from Kushiro.

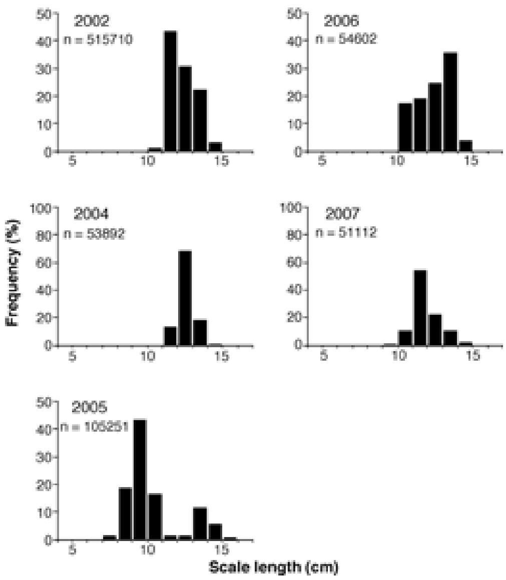

Fig. 19. Size frequency of Japanese anchovy in the environment of the area within 50 nautical miles from Kushiro.

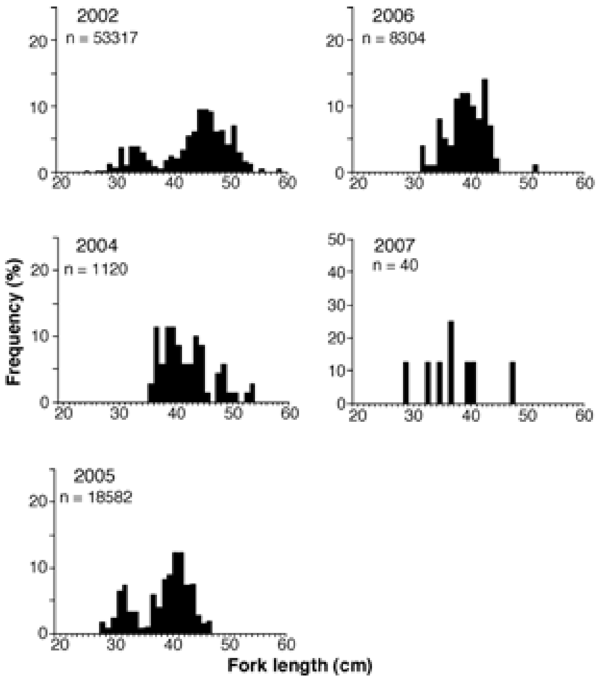

Fig. 20. Size frequency of walleye pollock in the environment of the area within 50 nautical miles from Kushiro.

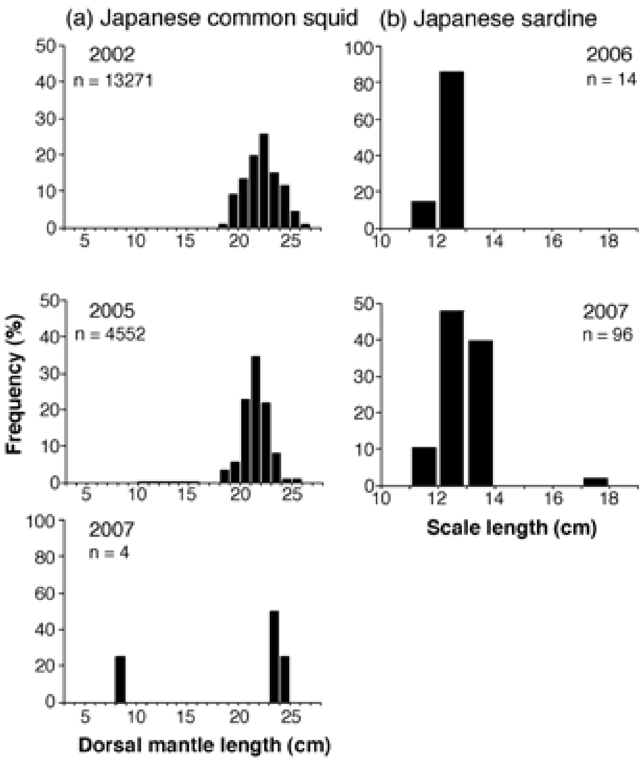

Fig. 21. Size frequency of (a) Japanese common squid and (b) Japanese sardine in the environment of the area within 50 nautical miles from Kushiro.

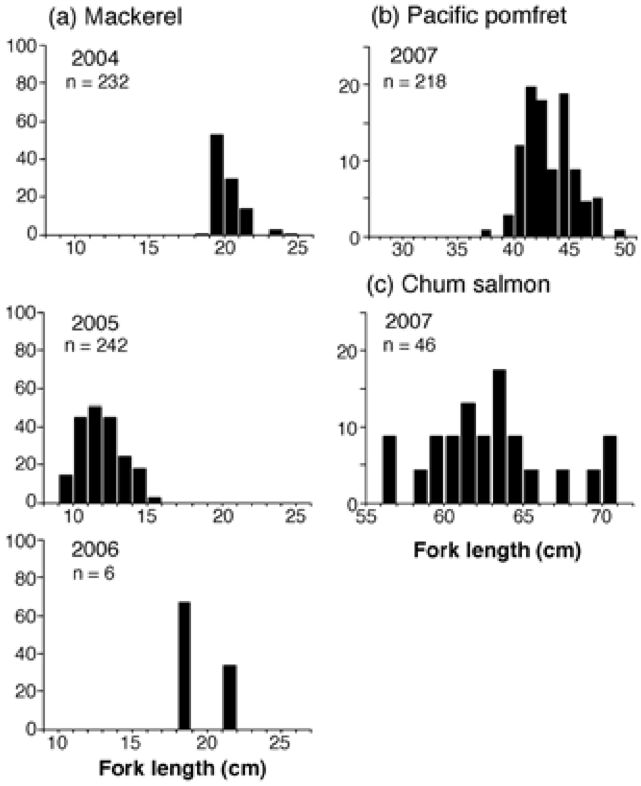

Fig. 22. Size frequency of (a) mackerel and (b) Pacific pomfret in the environment of the area within 50 nautical miles from Kushiro.

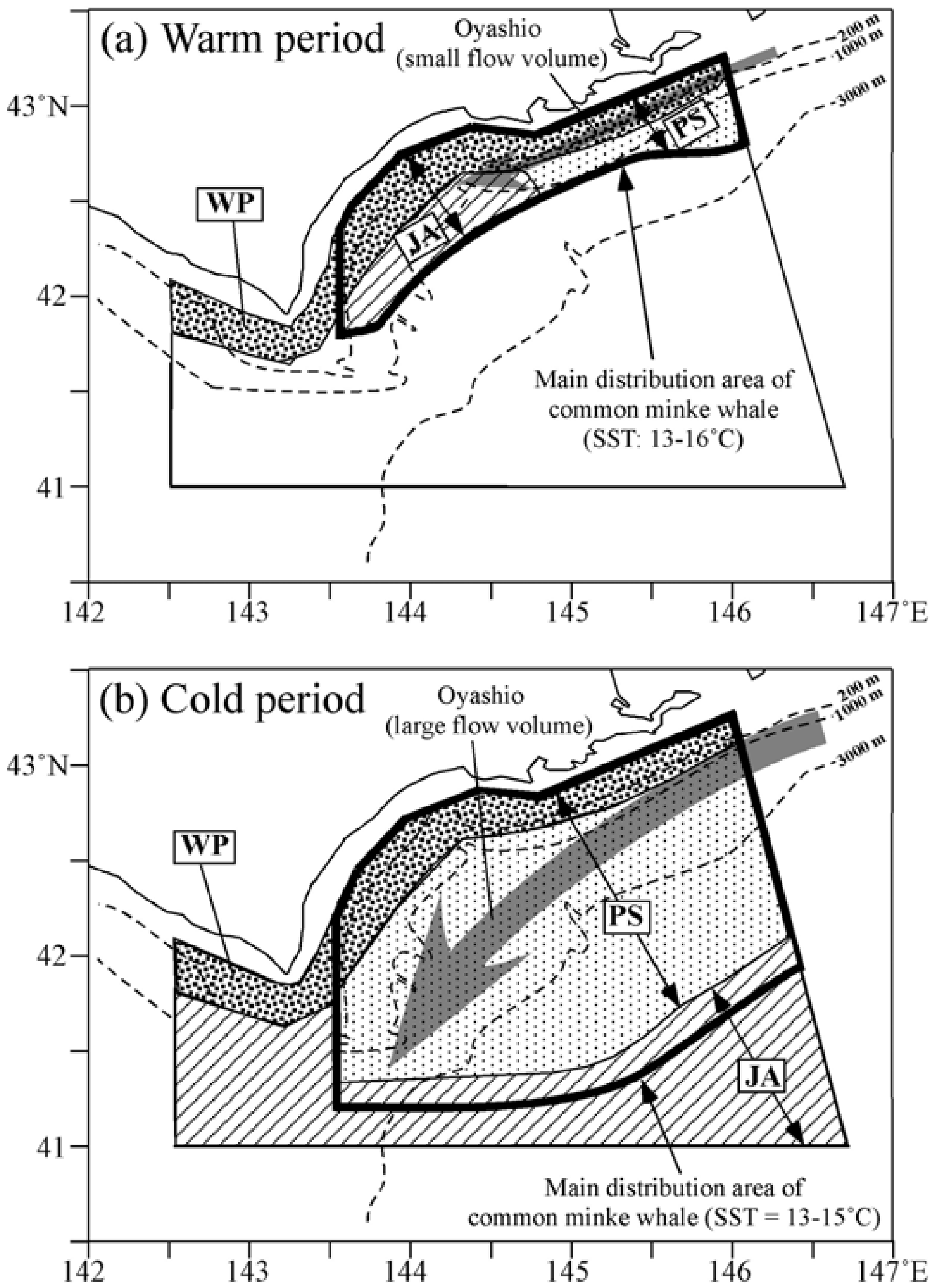

Fig. 23. Distribution patterns of common minke whale and its main prey species in the (a) warm and (b) cold periods off eastern Hokkaido in autumn. WP: walleye Pollock; PS: Pacific saury; JA: Japanese anchovy.

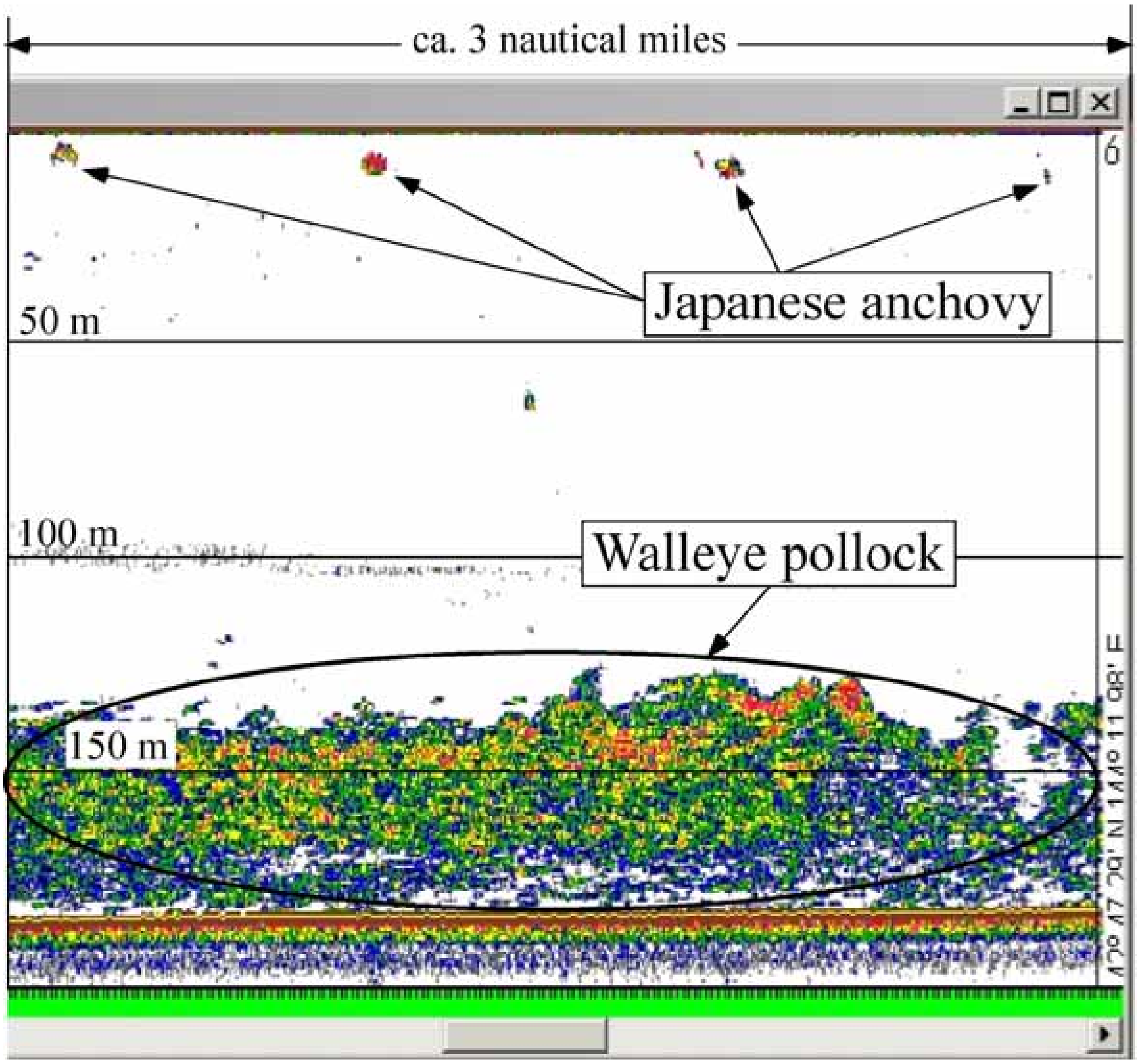

Fig. 24. Echogram (38 kHz) in the slope water region off Kushiro in September 15, 2002, showing that walleye pollock was distributed more uniformly than Japanese anchovy.

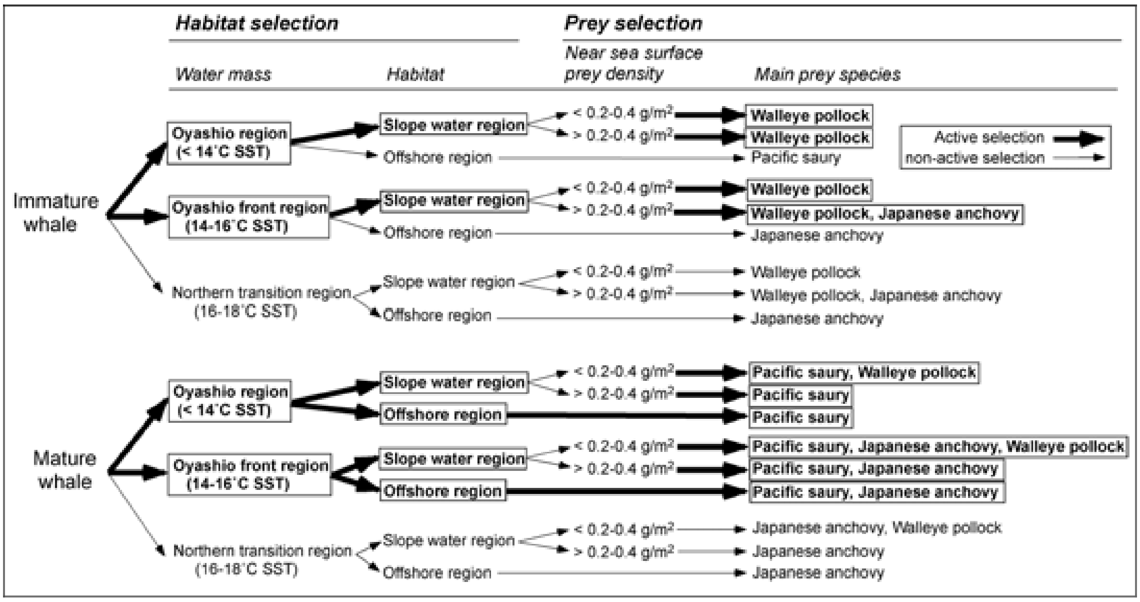

Fig. 25. Alternative interpretation in prey selection procedure for immature and mature common minke whales off Kushiro in autumn.