Comparison between stomach contents of Antarctic minke whale and krill sampled by RMT net in the Ross Sea and its adjacent waters

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ABSTRACT
The comparison between stomach contents of the minke whale and the net sampling using the multiple rectangular mid-water trawl (RMT (1+8)M) were conducted in the meso-scale area. In the Ross Sea and the adjacent waters from late of December 2004 to mid of February 2005, a cooperative survey between JARPA and R/V *Kaiyo Maru* was conducted. The Antarctic minke whales (*Balaenoptera bonaerensis*) fed mostly on Antarctic krill (*Euphausia superba*) in offshore area, and ice krill (*E. crystallorophias*) in coastal (shallow: depth under 1,000 m) area on continental shelf of Ross Sea. There was almost coincidence of frequency in body length of the krill between the stomach contents of the whales and the RMT net sampling. The size difference of the krill consumed by the minke whale in each meso-scale area seems to depend on the size of krill distributed. It seems that the minke whales have not prey size selectivity. In the western slope area, the stomach content weights of the minke whale were the highest, and empty stomachs were not found. The minke whale fed on the large size (BL: 40–50 mm) Antarctic krill in the western slope zone. This study indicates that the continental slope in the Ross Sea is an important feeding ground for the Antarctic minke whales. It is still a paradox that minke whales, especially pregnant females, are abundant in the Ross Sea, in spite of low density of their prey.

INTRODUCTION

The four main objectives of the JARPA (Japanese Whale Research Program under Special Permit in the Antarctic) are (1) elucidation of the stock structure of Antarctic minke whales to improve the stock management, (2) estimation of biological parameters of the Antarctic minke whales, (3) elucidation of the role of whales in the Antarctic marine ecosystem through the study of whale feeding ecology and (4) elucidation of the effect of environmental changes on cetaceans. Many previous studies reported that the Antarctic krill (*Euphausia superba*) is the most important prey species for the Antarctic minke whale (*Balaenoptera bonaerensis*) (Kawamura 1980, Bushuev 1986, Ichii and Kato, 1991). Some results of food habit of the minke whale in the Antarctic were reported in the JARPA review meeting in 1997 (e.g. Ichii *et al*., 1997; Tamura *et al*., 1997). These studies were evaluated to understand the role of whales in the Antarctic marine ecosystem through the study of whale feeding ecology. But it was recommended to examine the distribution and abundance of prey species in the meso- scale area in JARPA survey. In coastal (shallow) area, such as Ross Sea and Prydz Bay, they fed mainly on the ice krill *E. crystallorophias* and some fishes (Bushuev 1986, Tamura 1998).

In 2004/05 season, a cooperative prey species survey was conducted concurrently with JARPA from 25 December 2004 to 27 February 2005 (65 days) in the Ross Sea and adjacent waters by R/V *Kaiyo-Maru* (2,630 GT) of Fisheries Agency of Japan.

In this study, the body length of Antarctic krill and ice krill between the stomach contents of the minke whale and the net sampling were compared in the meso-scale area. Based on existing the prey species and the fresh stomach contents weight, the food habitat of the minke whale in the Ross Sea and adjacent waters was discussed.

MATERIALS AND METHODS

Survey area and periods

The main survey areas were the Ross Sea and its adjacent waters between 165E and 165W straddling the longitude 180 south of 60S, Antarctica. Transect lines along 165E, 175E, 180, 175W and 165W were investigated to cover the high concentrated area, which krill and whales were expected. The six sub areas of meso-scale survey area were divided from the latitude, longitude and the water depth as below (Fig. 1).

* Western Offshore area (WO)
  Between 170E and 175W, south of 60S, over 3,000 m of the water depth.

* Eastern Offshore area (EO)
  Between 175W and 160W, south of 60S, over 3,000 m of the water depth.

* Western continental slope (WSL)
  Between 170E and 175W, south of 68S, between 1,000 and 3,000m of the water depth.

* Eastern continental slope (ESL)
  Between 175W and 160W, south of 68S, between 1,000 and 3,000m of the water depth.

* Western continental shelf (ES)
  Between 170E and 175W, south of 68S, under 1,000 m of the water depth.

* Eastern continental shelf (ES)
  Between 175W and 160W, south of 68S, under 1,000 m of the water depth.

In the Ross Sea and the adjacent waters during 25 December 2004 to 27 February 2005, a cooperative survey between JARPA and R/V *Kaiyo Maru* was conducted. The comparison between the stomach contents of the Antarctic minke whales and the catch of net sampling using the multiple rectangular mid-water trawl (RMT(1+8)M) were conducted in the small scale area. The station point of RMT net by R/V *Kaiyo Maru* and the sighting position of the minke whales sampled in each prey species was shown in Fig. 1.

Analyses of stomach contents and net sample

A total of 231 minke whales were collected in random sampling method during the cooperative survey during 25 December 2004 to 27 February 2005 (Table 1). The detail of this cruise is described by Nishiwaki *et al*. (2005) and Naganobu *et al*. (2005). The sighting positions of the minke whales sampled were shown in Fig. 1.
The stomach contents were removed after capture on the ship's deck. The contents were first classified to major prey groups, such as euphausiids, copepods, fish and others on board. The freshness of stomach contents was categorized into four classes (1 = fresh, 2 = lightly digested, 3 = moderately digested, 4 = heavily digested). Then, the contents from each stomach were weighed to the nearest 0.1 kg. When undigested krill were occurred, a sub-sample (N=66) was removed and fixed in 10 % formalin water for later analyses.
The net samples using the multiple rectangular mid-water trawl (RMT (1+8)M) was described in Naganobu *et al.* (in this meeting).
In the laboratory, prey species in the sub-samples were identified to the lowest taxonomic level as possible. Between 50 and 100 individuals of krill from each sub samples, the body length was measured to the nearest 1 mm, from the anterior tip of the rostrum to the posterior end of the telson using Makarov and Denys (1981).

RESULTS

Prey species

The minke whales fed mainly on *E. superba* from the continental slope to offshore, but they changed the prey to *E. crystallorophias* above the continental shelf of the Ross Sea (shallow area). The stomach contents of some whales were other fishes, Amphipods and salps, but those were less abundant (Table 2).

Food habits of the minke whales in some meso-scale areas

The body length composition of Antarctic krill and ice krill consumed by the minke whales and sampled by RMT net were shown in Fig. 2 in meso-scale areas. The prey composition of the minke whales in each small area was shown in Fig. 3. The fresh stomach contents weight of the minke whales was shown in Fig. 4. The distribution of the stomach contents weight of the minke whales was shown in Fig. 5. The empty ratio of the stomach contents of the minke whale in each meso-scale area was shown in Fig. 6.

Western Offshore area (WO)

The minke whale fed only on the Antarctic krill. The Antarctic krill with a mode at body length of 20-30 mm were dominant in the stomach contents of the minke whale and the RMT net samples. The body length composition of Antarctic krill consumed by the minke whale coincided with that of the RMT net samples. The average undigested stomach content was 62.4 kg. The empty ratio of the stomach contents of the minke whale was 10.0 %.

Eastern Offshore area (EO)

The minke whale fed only on the Antarctic krill. The Antarctic krill with a mode at body length of 15-20 mm were dominant in the stomach contents of the minke whale. The krill samples caught by the RMT net were few. The average undigested stomach content was 54.9 kg. The empty ratio of the stomach contents of the minke whale was 8.3 %.

Western continental slope area (WSL)

The minke whale fed only on the Antarctic krill. The Antarctic krill with a mode at body length of 40-50 mm were dominant in the stomach contents of the minke whale and the RMT net samples. The average undigested stomach content was the largest in six meso-scale areas, 94.7 kg. The empty ratio of the stomach contents of the minke whale was the smallest in six meso-scale areas, 0.0 %.

Eastern continental slope area (ESL)

The minke whale fed only on the Antarctic krill. The Antarctic krill with a mode at body length of 40-50 mm were dominant in the stomach contents of the minke whale. The krill samples caught by the RMT net were few. The average undigested stomach content was the smallest in six meso-scale areas, 23.5 kg. The empty ratio of the stomach contents of the minke whale was 15.4 %.

Western continental area (WS)

The prey composition of Antarctic krill and ice krill in the stomach of the minke whales were 44 % and 56 %, respectively. The Antarctic krill with a mode at body length of 40-50 mm were dominant in the stomach contents of the minke whale. The Antarctic krill samples caught by the RMT net were few. The ice krill with a mode at body length of 15-35 mm were dominant in the stomach contents of the minke whale, whereas the ice krill with a mode at 10-15 mm in the RMT net samples. The average undigested stomach content was 43.6 kg. The empty ratio of the stomach contents of the minke whale was the largest in six meso-scale areas, 21.6 %.

Eastern continental area (ES)

The prey composition of Antarctic krill and ice krill in the stomach of the minke whales were 15 % and 85 %, respectively. The Antarctic krill with a mode at body length of 40-50 mm were dominant in the stomach contents of the minke whale. The Antarctic krill samples caught by the RMT net were few. The ice krill with bimodal at body length of 10-15 mm and 20-35 mm were dominant in the stomach contents of the minke whale and the RMT net samples. The average undigested stomach content was 49.2 kg. The empty ratio of the stomach contents of the minke whale was the largest in six meso-scale areas, 13.3 %.

DISCUSSION

Prey selectivity and size selectivity

It was confirmed that the Antarctic minke whales fed mostly on the Antarctic krill in the offshore area (WO and EO) and the continental slope area (WSL and ESL), and the ice krill in the continental shelf area (WS and ES). The stomach contents of some whales have also shown the occurrence of less abundant other prey such as fishes, Amphipods and salps, but those were less abundant. Generally the baleen whales are grouped into two types on the feeding behavior, swallowing and skimming (Nemoto, 1959). They feed on swarming zooplankton such as the Antarctic krill and the ice krill, indicating an ability of the minke whales to pursue single prey species aggregations. The other prey such as less abundant other krill species, fishes, Amphipods and salps were assumed to be eaten by chance.

According to the krill composition of RMT net sampling data in the offshore area, the Antarctic krill was most dominant species, whereas *Thysanoessa macrura* was dominated secondary and *E. triacantha* was thirdly dominated species (Naganobu *et al*, in this meeting). *T. macrura* has been reported to be an important prey species for other baleen whales such as fin and humpback whales in the area ranged from 100 W to 130 W. However, the minke whales did not feed on *T. macrura* in this study. As *E. triacantha* does not swarm in the adult stages (Baker, 1959), it is assumed that it does not comprise a suitable prey for the minke whales. The difference of krill composition between stomach contents of the minke whale and RMT net samples in the offshore area suggests that the minke whales seems to feed selectively on *E. superba*.

In the continental shelf area, the ice krill is dominant krill species, while the occurrence of Antarctic krill increases close to the continental shelf break and further off the shelf (Thomas and Green, 1988). According to RMT net sampling data in the continental slope area, the ice krill was most dominant species. The ice krill is important prey for the minke whales in the Ross Sea. RMT net sample have also shown the occurrence of less abundant euphausiids such as *E. superba*. In this concurrent prey and whale survey, it was confirmed that the prey species of the minke whales during austral summer fed mainly on two krill species depending on the distribution of each species. It is suggested that the minke whale in the Ross Sea and the adjacent waters has been feeding on most abundant prey species, the Antarctic krill and the ice krill.

Ruud (1932) reported that the large size of the Antarctic krill consumed by the fin whale, while small ones were consumed by blue whale. The body length composition of Antarctic krill and ice krill consumed by the minke whales and sampled by RMT net were almost coincided. The body length of krill ingested by the minke whales ranged from 9 to 56 mm. These results were coincided with the previous report (Mackintosh, 1974, Kawamura and Kikuno, 1980, Tamura, 1998). Ichii and Kato (1991) noted that the larger Antarctic krill (BL: 40-50 mm) were more important prey for the minke whale than smaller ones (BL: 15-30 mm). According to the theoretical growth curve for the Antarctic krill (Ikeda, 1985), body length between 40 and 50 mm are matured krill, 3 or 4 years old, while 15-30 mm krill are juvenile stage, one years old. Our results suggested that the smaller Antarctic krill was consumed by the minke whale in the offshore area, whereas the larger Antarctic krill consumed by the minke whale in the continental slope area and the continental shelf area. In this concurrent prey and whale survey, the size difference of the krill consumed by the minke whale in each meso-scale areas seems to be depended on the size of krill distributed. It seems that the minke whales have not size selectivity. However, the density of the minke whales expressed as number seen per 100 n miles in the continental slope area and the continental shelf area were higher than one in the offshore area (Naganobu *et al*, in this meeting). This result seems to lead that the minke whale were concentrated in the aggregation of the larger size Antarctic krill.

The suitable feeding ground for the Antarctic minke whales

In the western continental slope area, the stomach contents weight of the minke whale was the largest, the empty ratio was the smallest in six meso-scale areas. Generally, in the continental slope area, the large matured Antarctic krill distributed and spawned (Siegel, 1988). Our results suggested that it was important for the feeding ground of the Antarctic minke whales in this area. However, the other baleen whales such as fin whales and humpback whales mainly distributed in the western offshore area (Naganobu *et al*, in this meeting). In the western offshore area, it was topographically complex. The water depth is ranged from under 1,000 m to over 3,000 m. The biomass of the krill was higher than other meso-scall areas (Naganobu *et al*, in this meeting). In this 2004/2005 JARPA, the segregation was observed among the Antarctic minke whales and other baleen whales such as fin whales and humpback whales (Naganobu *et al*, in this meeting). It seems that fin and humpback whales fed mainly on the smaller Antarctic krill or other krill species such as *T. macrura* (Nemoto and Nasu, 1958).

The Ross Sea

The Ross Sea (the continental shelf area, WS and ES in this study) is a wide and deep embayment of the continental shelf, its average depth is 500 m (Hatherton, 1990). Ichii *et al.* (1998) noted that although a large number of minke whales, especially pregnant female were distributed in the Ross Sea, their stomach contents were low. The Ross Sea area was characterized by a low food supply throughout the austral summer season. Because the summer was short, it could not sustain a high biomass of zooplankton (Hempel, 1985). Our results lead the same situation. The empty ratio of the stomach contents of the minke whale in the western continental shelf (WS) was the highest in the six meso-scale areas, and the stomach contents weight was significantly low. However, the pregnant female with high energy requirements was mainly distributed in the Ross Sea in 2004/2005 season (Nishiwaki *et al.*, 2005). In this area, only blue whale and the minke whales were distributed (Naganobu *et al.*, in this meeting). The predator avoidance hypothesis can not be understand, because the killer whales, a potential predator on the minke whales, are also relatively abundant in the Ross Sea (Kasamatsu *et al*., 1990; Naganobu *et al.*, in this meeting). One of the reasons for this phenomenon, pregnant females can reduce the effects of unfavorable weather such as heavy wind and swell. However it is still a paradox that minke whales, especially pregnant female are abundant in the Ross Sea, in spite of low density of their prey.

In the future works

In recent years, abundance of large baleen whales in the Antarctic was increased (Matsuoka et al., 2005). Further study on the interaction among the baleen whales such as the Antarctic minke, blue, fin and humpback whales will be needed for modelling study and long-term monitoring research, which clarify the interaction of major predators and their prey in the Antarctic.

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Table 1. Sample size used in this study

	WO	WSL	WS	EO	ESL	ES	Total
Male	35	11	14	1	0	2	63
Female	19	17	77	13	13	29	168
Total	54	28	91	14	13	31	231

Table 2. Prey species found in the stomachs of Antarctic minke whales sampled by the JARPA

	species
Main prey	
Krill	*Euphausia superba*
	E. crystallorophias
Miner prey	
Amphipoda	*Parathemisto gaudichaudi*
Salps	Unidentified
Pisces	*Pleuragramma antarcticum*
	Notolepis coatsi
	Electona antarctica
	Chionodraco sp.
	Notothenis sp.

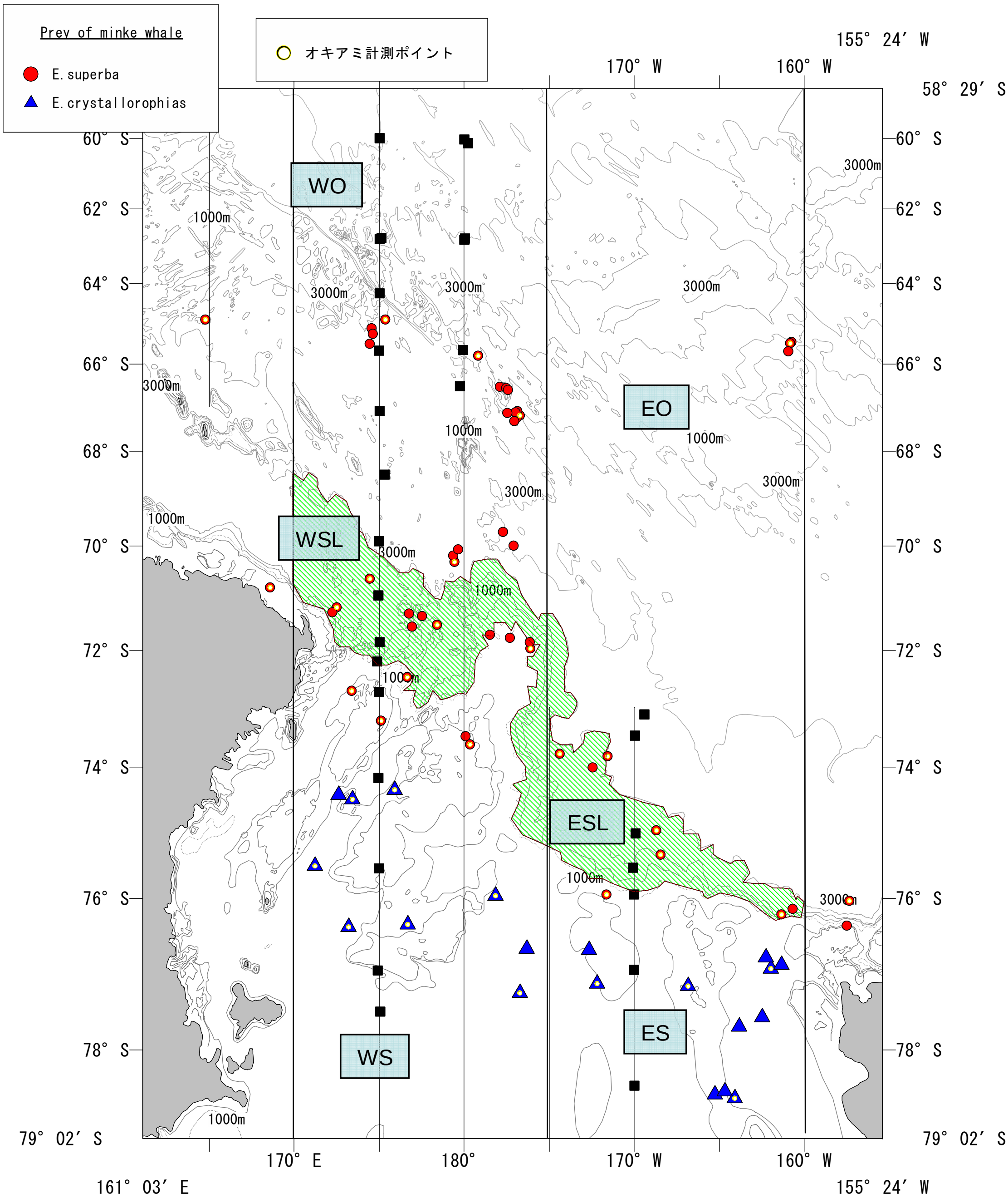
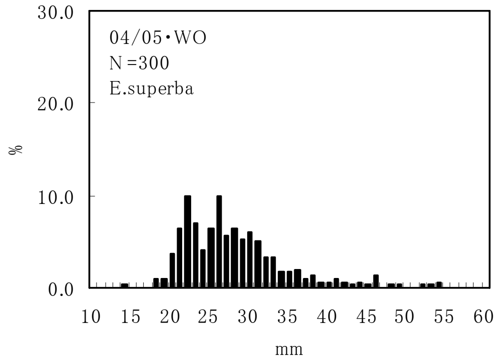


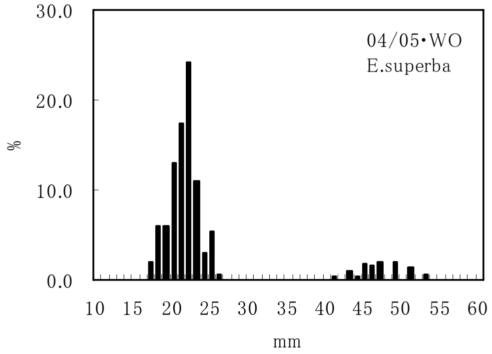
Fig. 1. The station point of RMT net by R/V Kaiyo Maru and the sighting position of the minke whales sampled in each prey species. Shade area is shown in the continental slope (■: the station point of RMT, ●: *Euphausia superba*, ▲: *Euphausia crystallorophias*).

- **Western offshore (WO) : 175E－175W**

Euphausia superba

Stomach contents（N=3） RMT net sample

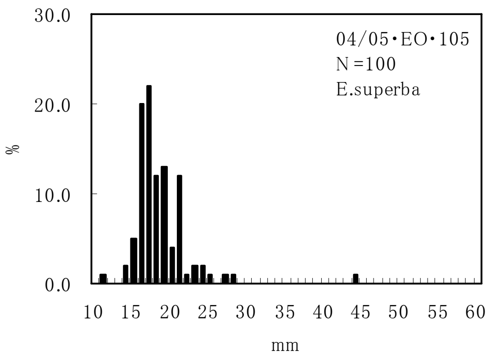


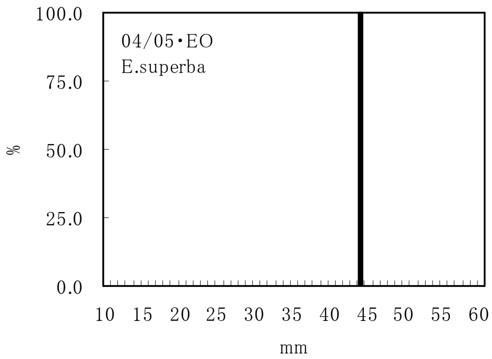


- **Eastern offshore (EO) : 175W－160W**

Euphausia superba

Stomach contents（N=1） RMT net sample

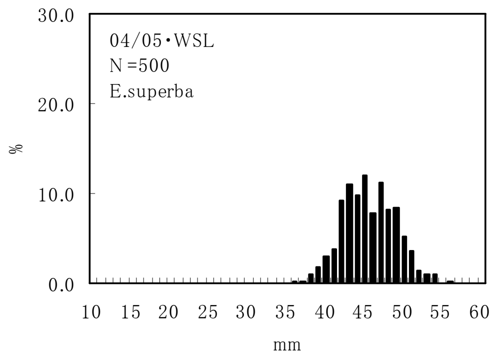




- **Western continental slope (WSL) : 175E－175W**

Euphausia superba

Stomach contents（N=5） RMT net sample



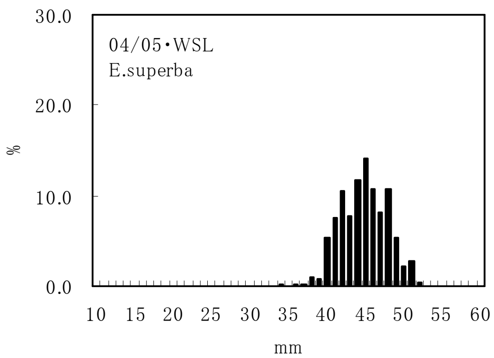
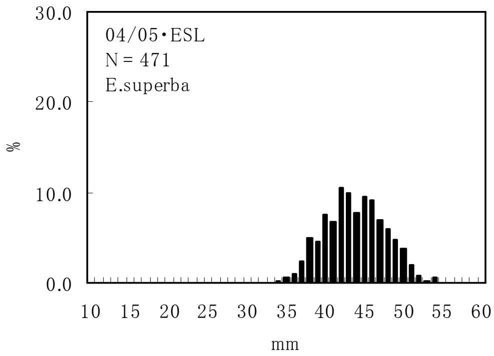


Fig. 2. The body length of Antarctic krill and ice krill consumed by the minke whales and sampled by RMT net.

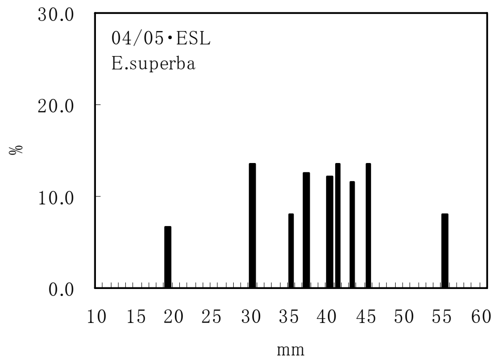
- **Eastern continental slope (ESL) : 175W－160W**

Euphausia superba

Stomach contents（N=5）



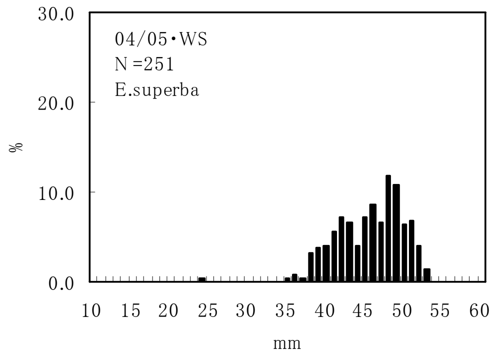
RMT net sample



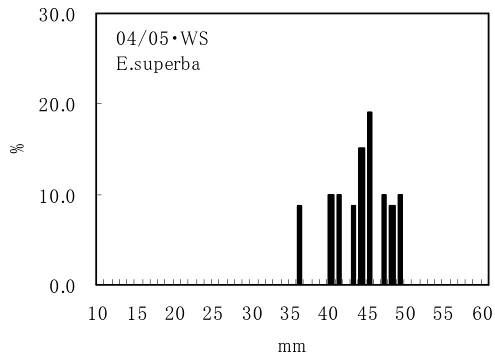
- **Western continental shelf (WS) : 175E－175W**

Euphausia superba

Stomach contents（N=3）

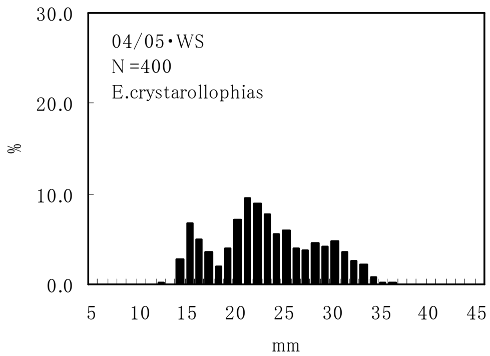


RMT net sample



Euphausia crystallorophias

Stomach contents（N=4）



RMT net sample

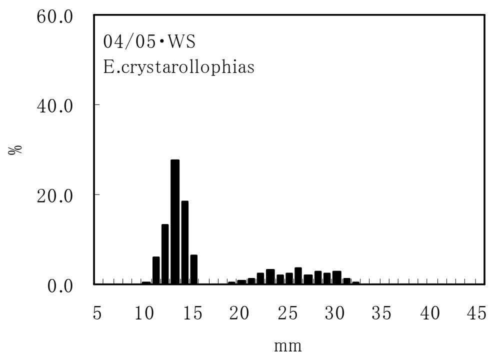
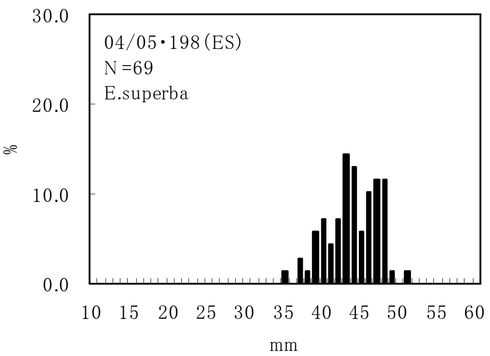


Fig. 2.　Continued.

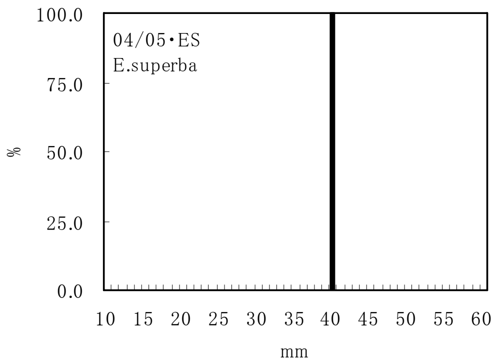
・ **Eastern continental shelf (ES) : 175W－160W**

Euphausia superba

Stomach contents（N=1）

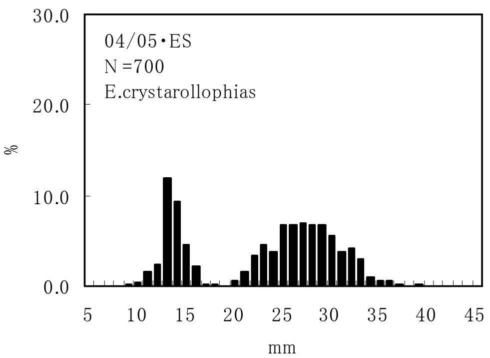


RMT net sample



Euphausia crystallorophias

Stomach contents（N=7）



RMT net sample

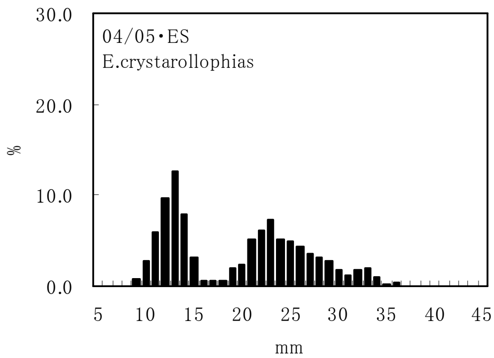


Fig. 2. Continued.

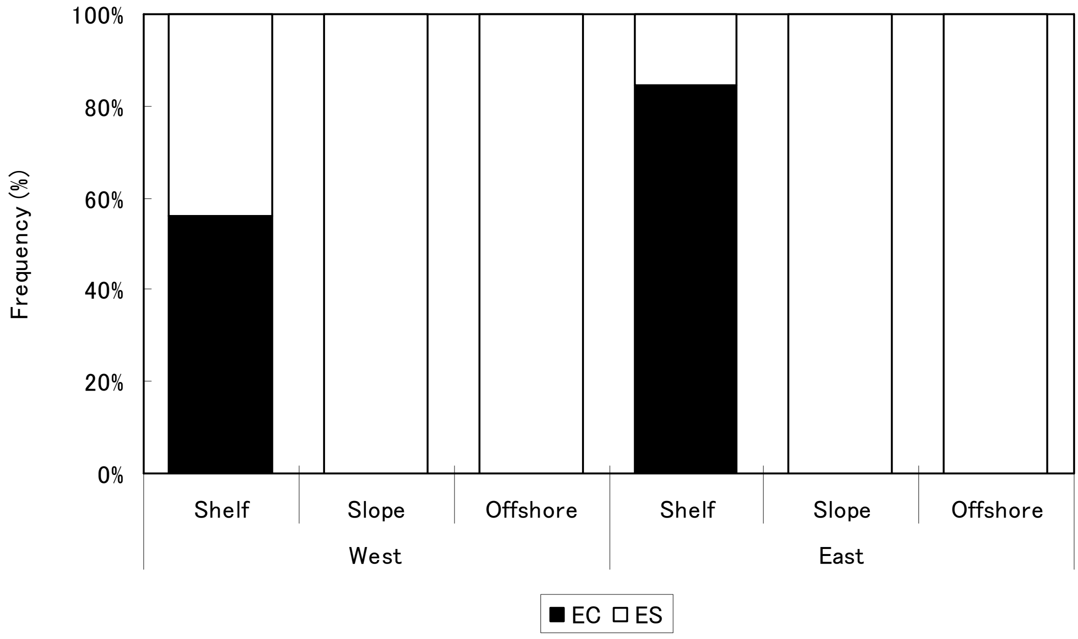


Fig. 3. The prey composition of the minke whales in each meso-scale area.
(EC: *Euphausia crystallorophias*, ES: *Euphausia superba*)

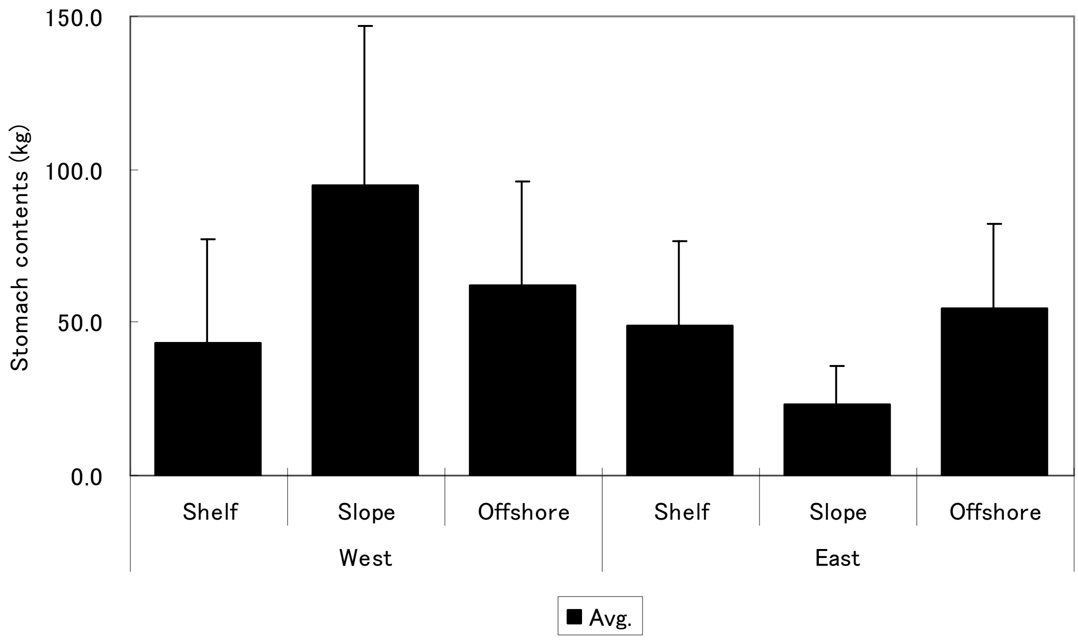


Fig. 4. The undigested stomach contents weight of the minke whales

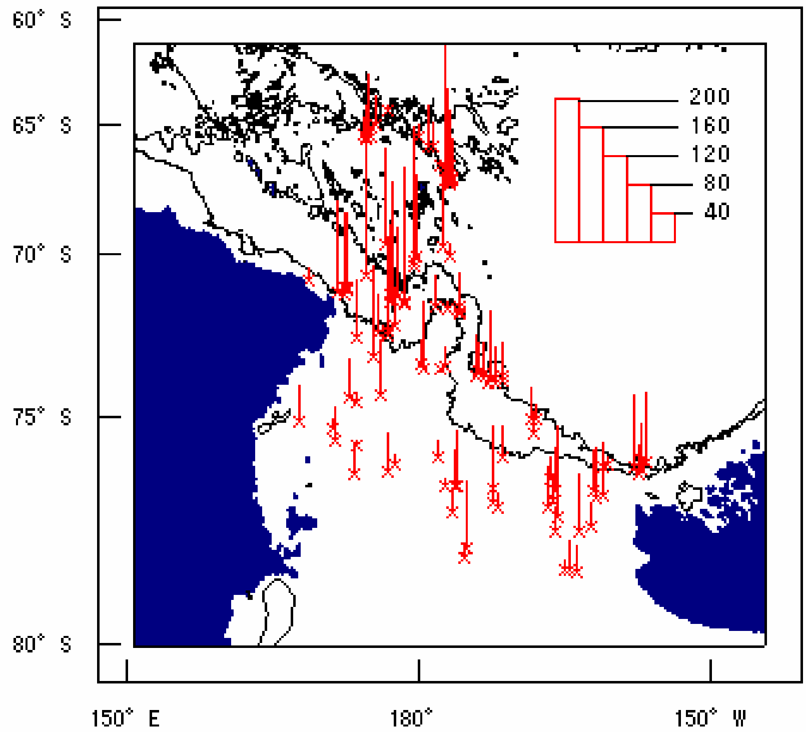


Fig. 5. **The distribution of the stomach contents weight of the minke whales**

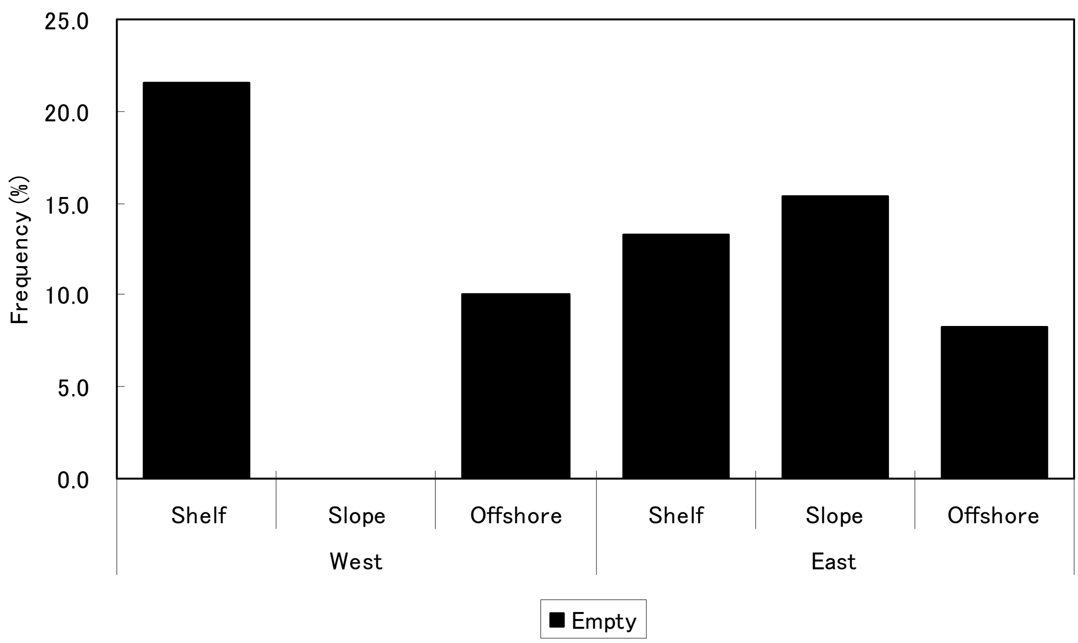


Fig. 6. **The empty ratio of the stomach contents of the minke whale in each meso-scale area.**