水産海洋研究　第62巻　第4号　334-342, 1998

Distribution of Minke Whales in the Weddell Sea in Relation to the Sea-Ice and Sea Surface Temperature

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Abstract

The relationship between the distribution of minke whales (*Balaenoptera acutorostrata*) and sea ice/surface temperature was analyzed using the data from systematic sighting surveys conducted in the Weddell Sea in 1986/87. Relatively high densities of minke whales were observed at Bransfield Strait, north of the South Shetland Islands; around the tips of the cold-water intrusions and the sea-ice extensions (at 61–64°S and 20–30°W, 69°S and 23°W) which might be derived from the Weddell Gyre, at the sea-ice edge around 71°S and 10°W, and in the offshore waters at the front between the cold waters and a warm-water intrusion at 63–67°S and 4–11°W. Large numbers of surface swarms of krill (Euphausiacea) and sea birds – Antarctic prions (*Pachyptila desolata*) and blue petrels (*Halobaena caerulea*)– were also observed at this front. The analysis suggested that although sea surface temperature and sea-ice alone do not appear to have a substantial impact on the distribution of minke whales, the oceanographic condition associated with the Weddell Gyre might influence their distribution in the Weddell Sea.

Introduction

The International Whaling Commission/International Decade of Cetacean Research (IWC/IDCR) Southern Hemisphere Minke Whale Assessment Cruises (IDCR cruises) has provided us with a vast amount of systematically collected data on the distribution of cetaceans in Antarctic waters and on concurrent environmental conditions. While the primary purpose of the research program was to estimate the abundance of minke whale (*Balaenoptera acutorostrata*) and other whales, the data have also been used to examine the large-scale distribution of many of the cetacean species in the Antarctic (KASAMATSU *et al.*, 1988, 1994, 1996, 1998, KASAMATSU and JOYCE, 1995). However, little information has been presented from this research concerning the relationship between the distribution of whales and the physical or biological environments. This paper examines the relationship between sea surface temperature and the distribution of minke whales in the Weddell Sea, where oceanographic and biological features were well identified (DEACON, 1937, MARR, 1962, MACKINTOSH, 1964, KNOX, 1994).

Materials and methods

Sighting Surveys and Area

The data were collected from the IDCR cruise conducted in 1986/87 in Area II (IWC management area, between longitude 0° and 60° W) in the Weddell Sea. The survey was conducted aboard four research vessels (converted whale catchers of 750–900 gross tonnes) from 26 December 1986 to 12 February 1987. Three of the four vessels were dedicated solely to this research and conducted standardized sighting surveys over tracklines that were pre-planned so as to obtain unbiased sampling coverage. The fourth vessel was used in the program for specialized experiments and ice-edge mapping used in trackline development. The three vessels conducting the sighting surveys traveled

1998年3月30日受付，1998年6月4日受理

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in one of two search-effort modes; the closing mode and the passing mode (ANON, 1987). In the closing mode, the vessel diverted course to approach the sighted animals to identify species and to count all the animals in the school. In the passing mode, the vessel navigated along the trackline without diverting, and all species identification and number estimates were made from the trackline. Sightings from the IDCR cruises were divided into two categories: sightings made when full searching effort was being applied (primary sightings), and all other sightings (secondary sightings). Only primary sightings were used to estimate density of schools. Search effort was recorded whenever there was any change that affected the effort. Environmental conditions (weather, visibility, sea surface temperature SST, ice conditions, etc.) were recorded hourly. Complete details of the cruise methodologies are found in KASAMATSU *et al.* (1988, 1996, 1998) and KASAMATSU and JOYCE (1995). The study area for this paper includes the Weddell Sea, the southern part of the Scotia Sea, and the Bransfield Strait. Cruise tracks of the three survey vessels are shown in Fig. 1. Details of this survey are described in ANON (1987).

Sea Surface Temperatures

Each of the three Japanese research vessels was equipped with a thermister-type temperature sensor coupled to an analog display (Murata M-22 model). The sensor was located on the hull of the ship, 4-5m below the sea surface. The measurement error of this equipment is about ±0.2° C. SST and sea-ice conditions (ice concentration) were recorded hourly from 0600 to 2000 hours by the Officer on watch.

In the analysis, SST data were averaged for blocks of 30 minutes of latitude by one degree of longitude to produce the sea surface isotherm plots. The sea surface isotherm plots were drawn by the SPYGLASS Transform (Spyglass Inc., 1995).

Density Estimates

Density of minke whale schools was estimated on a daily basis. The estimation of the density of schools from the sighting data was based on a line transect method (BUCKLAND *et al.* 1993). Because the number of animals in a school sighted could not be precisely estimated during the passing mode (IWC 1987), the estimate of density was based on number of schools seen rather than number of

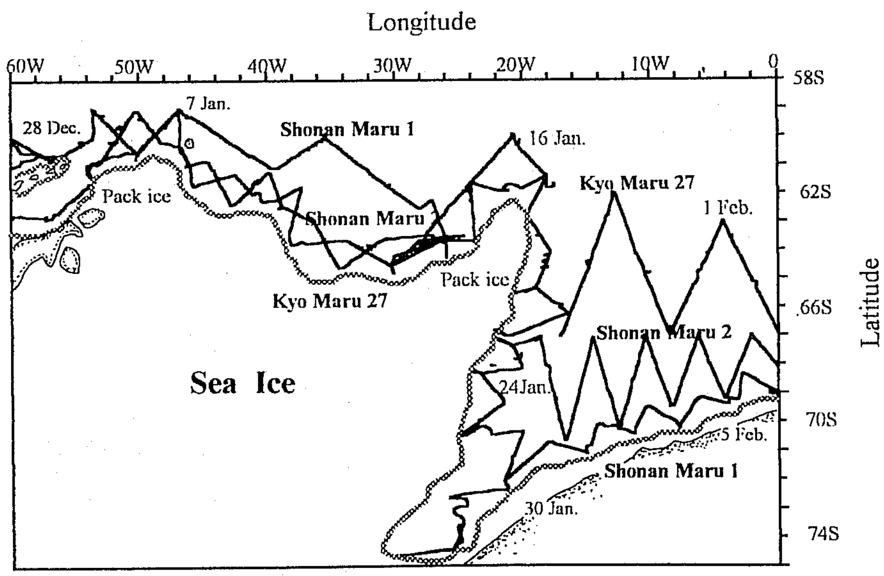

Fig. 1. Cruise tracks of the sighting research vessels.

whales seen. It should be noted, however, that there was little variation in the mean school size of minke whales within the research area (BORCHERS 1989). The following equation was used: $\hat{D}_i = n/2L_i\hat{w}$, where $\hat{D}_i$ is the number of schools estimated per one nautical mile (n.mile) square in i th day, n_i is the number of schools seen in i th day (primary sighting only), L_i is distance searched in i th day, $\hat{w}$ is effective search half width $(=1/(\hat{f}0)$, $\hat{f}(0)$ is the estimated probability density of perpendicular distance, evaluated at zero, as calculated from the Hazard rate model (BUCKLAND, 1985)). The values of w by vessel and by stratum were cited from BORCHERS(1989).

Satellite Image of the Sea-Ice Conditions

Satellite images were used to examine the overall sea-ice conditions in the Weddell Sea at the time of the survey. Data from the Scanning Multichannel Microwave Radiometer (SMMR) of the Nimbus-7 satellite were provided from the National Snow and Ice Data Center (NSIDC). The SMMR grid format was based on the original SSM/I grid design produced by the NASA Ocean Data System at the Jet Propulsion Laboratory, California Institute of Technology, incorporating the specifications designated by the Sea Ice Algorithm Working Group. All SMMR brightness temperature gird data were stored as 2-byte integers. Brightness temperatures are in 0.1 Kelvin intervals. Brightness temperature grids were presented as raster images mapped to a polar stereographic projection that cuts the earth along the 70-degree latitude plane. The NASA Nimbus-7 SMMR Team Algorithm (CAVALIUERI *et al.* 1984; GLOERSEN *et al.* 1984; GLOERSEN and CAVALIERI 1986) with the revised points was used to calculate ice concentrations from the SMMR brightness temperatures. The complete ice-concentration imagery was then created using a land mark (NSIDC 1994).

Environment Gradient

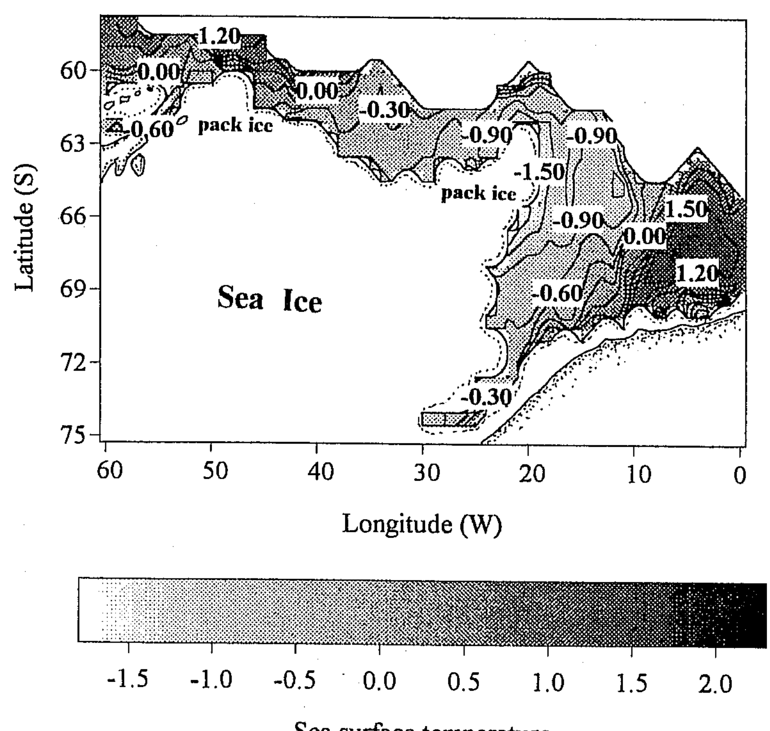

Fig. 2. Sea surface isotherms derived from observed sea surface temperatures.

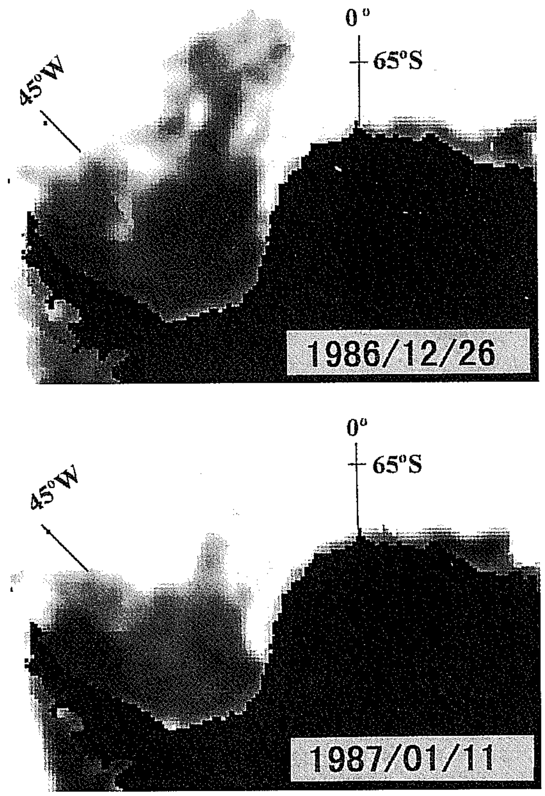

Fig. 3. Sea-ice concentration derived from the satellite in late December 1986 (above) and middle January 1987 (below). White areas are open waters. Ice concentrations are indicated through the colors of gray (lower concentrations) to black (high concentrations).

The relationship between the environment gradients and the distribution of minke whales can also be examined to analyze the influence of these factors on the distribution of minke whales in the Weddell Sea area. In this study, the effects of SST and the distance from the ice edge on the minke whale school density were analyzed. The density of minke whale schools is defined by the encounter rate, which is the number of schools seen per one n.mile search.

Results and Discussions

Distribution of Sea Surface Temperatures and Sea Ice

Fig. 2 shows the sea-surface isotherms based on

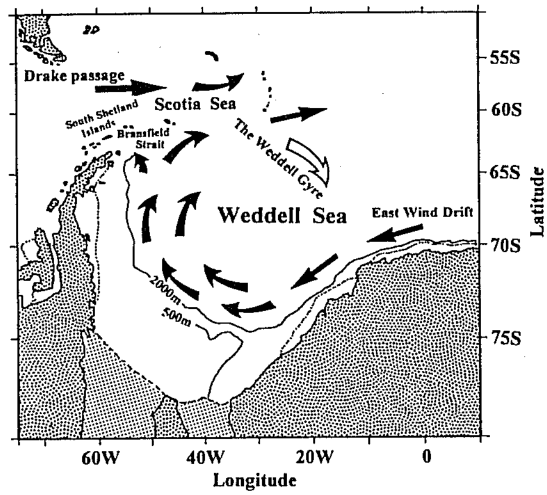

Fig. 4. Oceanographic features in Weddell Sea derived from MARR (1962) and KNOX (1994).

the observed sea surface temperature. A cold water intrusion, with a sea temperature less than $-1.0°$C was observed extending to the eastern part of the Weddell Sea (longitude of 20° W). The sea ice extension corresponded to this intrusion of cold water. Satellite data collected from SMMR in late December 1986 and middle January 1987 are shown in Fig. 3. These satellite images clearly indicate the northeastward sea-ice extensions during late December to middle January in the Weddell Sea.

As described by DEACON (1937, 1979, 1984), MARR (1962) and KNOX (1994), the East Wind Drift (EWD) flows along the Antarctic coast, and, when this current encounters the northward projection of the continent at Graham Land, the Weddell Gyre transports cold water from this coastal stream eastward and northward, eventually reaching relatively low latitudes (Fig. 4). DEACON (1979) further noted that the low temperature of the surface water and the occurrence of sea-ice so far north in the Atlantic Ocean are largely the result of the transfer of water from the East Wind Drift to the West Wind Drift by the northward current component of the Weddell Gyre which is the largest and best defined among the three large permanent cyclonic flowing gyres. In this study, the observations of the extension of the cold waters

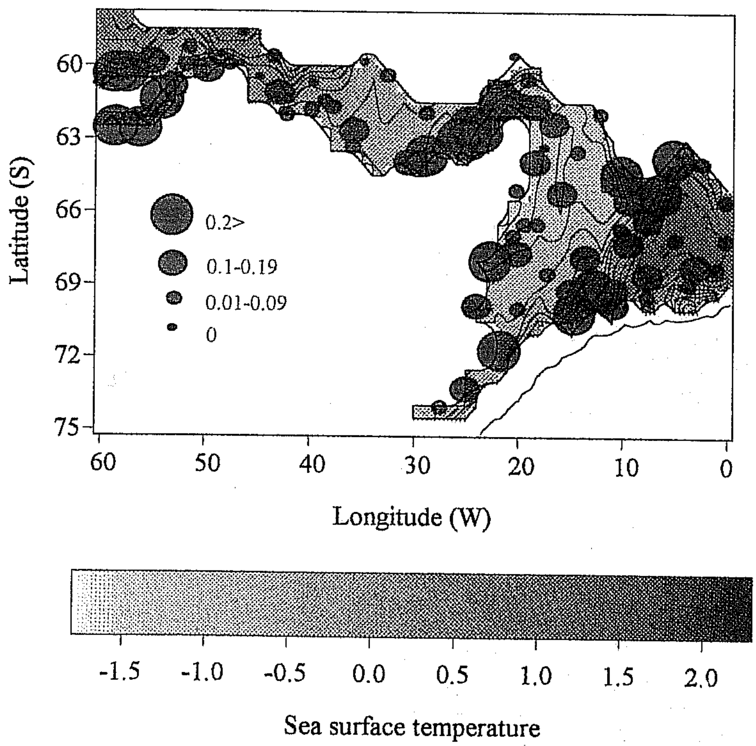

Fig. 5. Distribution of minke whale school densities and SST isotherms.

coincide with this component of the Weddell Gyre.

A warm-water intrusion with SST more than +1°C was observed extending from the northeast to the southwest at around 67°S and 0°E to 71°S and 10°W (Fig. 2). A similar intrusion of warmer water was reported in this region by MARR (1962) between the Weddell Sea current (the northern flowing component of the Weddell Gyre) and the well-defined westward movement of water near the continent. Regarding the region of the ocean fronts observed between the warm-water intrusion and the colder waters (at 63–67°S and 4–11°W), MARR (1962) reported a divergence region between 10°W and 10°E in the area between 61°S and 66°S, and a sharper divergence region in the area between 62°S and 70°S and 15°W to 20°W.

Distribution of Minke Whale Density Relative to Sea Surface Temperature

A plot of the observed surface isotherms and the observed minke whale school density is shown in Fig. 5. Relatively high densities of minke whales were observed in the following areas; the Bransfield Strait; north of the South Shetland Islands; around the tips of the cold-water intrusion (61–64°S and 20–30°W, 69°S and 23°W); in the region of the ocean fronts between the warm-water intrusion and the colder waters (at 63–67°S and 4–11°W); and near the sea-ice edge at around 71°S and 10°W. At the Bransfield Strait, CLOWS (1934) reported that a small current flows from the Weddell Sea to the west, around the northern extremity of the Antarctic Peninsula, and into the Bransfield Strait, carrying cold water from the Weddell Gyre. We observed cold water at the southeast corner of this strait, with SST below −0.8°C. In this area, highly aggregated groupings of minke whales were seen.

Relatively low minke whale densities were noted in areas between 54°W to 30°W, and within the warm-water intrusion (67–68°S and 0–8°W).

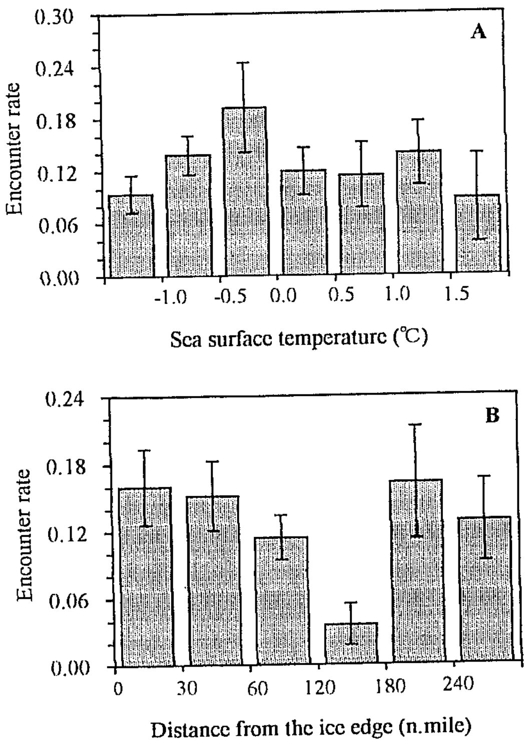

Fig. 6. Relationships between encounter rate (number of schools seen per one n.mile distance searched) of minke whale schools and SST (A), and distance from the ice edge (B). Vertical lines show the standard errors of the mean.

Other Wildlife

Observations of surface swarms of krill, sea birds, and other wildlife were not systematically recorded during the IDCR cruises, but areas of exceptional concentrations have sometimes been noted. In areas where relatively high densities of minke whales were observed (63-65° S and 4-8° W), substantial surface swarms of krill were also observed, together with a large number of Antarctic prions (*Pachyptila desolata*) and blue petrels (*Halobaena caerulea*). It has been suggested that the Antarctic prion plays a prominent role in the marine ecosystem of all open waters in the Weddell Sea (e.g., van FRANEKER *et al.*, 1997, KNOX, 1994).

Relationships Between Minke Whale Densities and Environments

Fig. 6 shows the relationships between minke whale school densities and SST and the distance from the ice-edge. The assumption that minke whale densities are uniform against the SST could not be invalidated (chi-square $\chi^2=6.14$, df=6, $p>0.05$), and the slope of the regression line of minke whale density on the SST was not significantly different from zero ($p=0.64$). The relationship between minke whale densities and the distance from the ice edge indicated that the minke whale densities were not distributed uniformly against the distance, but the slope of the regression line was not significantly different from zero ($p=0.73$). These results indicate that there was no clear density gradient in the density of minke whales that was related to the SST or to the distance from the ice-edge. This suggests that the distribution of minke whales in these area might be influenced by factors other than SST and the distance from the ice-edge, such as the availability of prey whose concentrations might be affected by oceanographic conditions.

Concluding Remarks

There have been several descriptions about feeding grounds of baleen whales (mainly large-size species such as fin whales *Balaenoptera physalus* and sei whales *Balaenoptera borealis*) in high latitudes (UDA, 1954, NEMOTO, 1957, MARR, 1962, NASU, 1966, KAWAMURA, 1974, GASKIN, 1976, 1982). These authors identified that the feeding grounds of the baleen whales are observed; at oceanic fronts, in areas of oceanic eddies, and in areas of upwelling. Concerning the distribution of minke whales with relation to physical oceanographic feature, there have been few published description in the Weddell Sea, although some descriptions have appeared recently regarding other regions (e.g., ICHII, 1990, ICHII and KATO, 1991, TYNAN, 1997).

TYNAN (1997) found a clear linkages between oceanographic features and concentrations of cetaceans in the waters of Kerguelen Plateau (82° E -115° E). Our observations also demonstrated the probable relationships between oceanographic features (especially the Weddell Gyre with sea-ice extents) and the distribution of minke whales in the Weddell Sea. In addition, we suggested that the presence of sea-ice or sea surface temperature alone may be insufficient to predict habitat use, and that the complex dynamics of several process are responsible for the concentrations of minke whales in these area. A similar suggestion was also made by TYNAN (1997).

Although we have provided some conjecture as to the relationship between minke whale distributions and oceanographic conditions in the Weddell Sea, the data-especially on oceanographic features were limited. In addition, this paper has not attempted to include any substantial data and analysis on the relationship between prey species (especially krill distribution) and whale distribution. According to MARR (1956, 1962, in a review of the distribution of krill during the modern pelagic whaling season), ICHII (1990), and SIEGEL and KALINOWSKI (1994), there were principal concentrations of krill in the areas of the shelf slopes north of the South Shetland Islands, in the Bransfield Strait, in Weddell West (west of 30° W), on the South Georgia whaling grounds, and in the western half of Weddell Middle (30° W- 0°). The areas of the high concentrations of minke whales observed in this study appear to correspond in general to those areas of krill concentrations. Recently REILLY (1990) and BALANCEe *et al.* (1997) have provided some interesting suggestions about the close relationships between food or oceanographic conditions and distribution of marine animals. A similar ecosystem approach to the study of whales in the southern ocean is needed in future.

Acknowledgements

Our sincere thanks are offered to the many people and organizations who contributed to the success of the IWC/IDCR Southern Hemisphere Minke Whale Assessment Cruises. We would specifically like to thank Dr. R. GAMBELL, Secretary of the IWC, who provided access to the IWC/IDCR sighting data. The SMMR data were provided by CD-Rom from National Snow and Ice Data Center. This CD Rom series, Nimbus-7 SMMR Polar Radiance and Arctic and Antarctic Sea Ice Concentrations was produced by P. GLOERSEN of the Oceans and Ice Branch, NASA Goddard Space Flight Center with support from the National Aeronautics and Space Administration, Headquarters, Climate and Hydrologic System Division, Cryosphere Brand. The authors thank Dr. M. NAGANOBU of the National Institute of Far Seas Fisheries Laboratory, and Dr. Y. OKADA, Marine Science and Technology of Tokai University for their advise about the SMMR data, and to Marianne MOON for her usual superb editing. The authors also express thanks to Drs. S. B. REILLY of Southwest Fisheries Science Center, and T. ICHII of the National Research Institute of Far Seas Fisheries for their comments on this study. We thank to two anonymous reviewers and Professor A. KAWAMURA of Mie University for their comments on the manuscript.

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ウェッデル海におけるミンククジラの分布－海氷と表面水温との関係

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南極海ウェッデル海におけるミンククジラの分布と海氷及び表面水温分布との関係を，1986/87に実施された組織的目視調査データを使用して解析した．ミンククジラの高密度海域は，ブランスフィールド海峡，サウスシェトランド諸島北側，ウェッデル環流によって形成されたと思われる北東方向への冷水と海氷の張り出し部周辺(61～64°S，20～0°W; 69°S，23°W)，70°S，11-16°Wの氷縁域，そして南西部の氷縁部から北東方向に形成された冷水と暖水の境界付近（71°S，10°W; 63～67°S, 4～11°W）に見られた．この冷水と暖水のフロントにはオキアミ類と思われる浮パッチとクジラドリが多数観測された．ウェッデル海においては，表面水温と海氷の存在それ自体だけではミンククジラの密度に大きな影響を与えないが，ウェッデル環流に伴うフロントの形成及び海氷の張り出しが，ミンククジラの沖合い域における分布と密度に大きな影響を与えている可能性がある．

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