DISTRIBUTION OF DIATOMS IN A SMALL AREA IN THE INDIAN SECTOR OF THE ANTARCTIC

Akito KAWAMURA and Tokuro ICHIKAWA*

Faculty of Fisheries, Hokkaido University, 1-1, Minato-cho 3-chome, Hakodate 041

Abstract: During the Pre-FIBEX cruise of the R.V. KAIYO MARU to the Indian sector of the Antarctic in 1979/80, a small area surrounded by 61° and 65°S parallels and 100° and 120°E meridians was investigated. The hydrographic stations were 37 where the surface samples were collected at each station and the subsurface samples at 9 stations. The diatom species were 38 species of Centrales and 16 species of Pennales in occurrence. Of 54 species identified, however, total percentages of 7 species accounted for more than 72% of the total cells of diatoms, and these 7 species were considered to be significant species in the study area. They were *Fragilariopsis 'nana'*, *F. rhombica*, *F. kerguelensis*, *F. curta*, *Nitzschia 'closterioides'*, *N. pungens*, and *Dactyliosolen* spp. The abundance of diatoms and the distribution of diatom species showed significant horizontal variations within a small spatial scale. The 'length-scale' of the patchiness was estimated to be an order of several tens to hundred kilometers, and the estimated range agreed with that in the North Pacific. It is also suggested that the local concentrations of *Euphausia superba* have a close relationship to the peculiar species of diatoms rather than to the diatom communities.

1. Introduction

Uneven distribution or patchiness of planktonic diatoms as well as zooplankton is a well-known phenomenon (HARDY, 1936; CUSHING, 1955; BAINBRIDGE, 1957), although the spatial scale or 'length-scale' (PLATT and DENMAN, 1980) of uneveness or patchiness is variable in many cases. In the North Pacific, VENRICK (1972) described that the spatial expansion of the diatom patchiness occurs in such an order as 1.8–1850 km whereas GOWER *et al.* (1980) pointed out its possible spatial scale as to be 10–100 km. In the Antarctic waters, however, very few studies has been made on the horizontal scale of diatom patches. The subject must be especially interesting when the local concentrations and food habits of *Euphausia superba* are considered, since *E. superba* is considered to feed intensively on a definite diatom species (BARKLEY, 1940; KAWAMURA, 1981). This paper aims to provide one of such data as the diatom patchiness observed in a small area in the Antarctic waters.

2. Materials and Methods

During the Pre-FIBEX cruise of the R.V. KAIYO MARU of the Fisheries Agency in 1979/80, 500 m*l* of surface water samples were collected in a small area in the Indian

* Present address: Daiwa Seiki K.K., 14-16, Maesawa 3-chome, Higashikurume-shi, Tokyo 203.

sector of the Antarctic Ocean during January 13–29, 1980. A total of 37 stations were occupied to form a grid with the spaces of every 40′ latitude and 5° longitude in the area surrounded by 61° and 65°S parallels and by 100° and 120°E meridians (Fig. 1). All water samples were collected from the sea surface with a bucket and preserved in 500 m*l* bottles. At nine stations along both 115° and 120°E, additional 500 m*l* of water samples were collected with Nansen bottles from five subsurface depths (10, 20, 30, 50, and 100 m). The collected water samples were fixed with formalin solution so as to preserve the material in a concentration of 3% formalin. After making diatoms to settle for at least 24 hours in the laboratory, water was decanted using a glass siphon

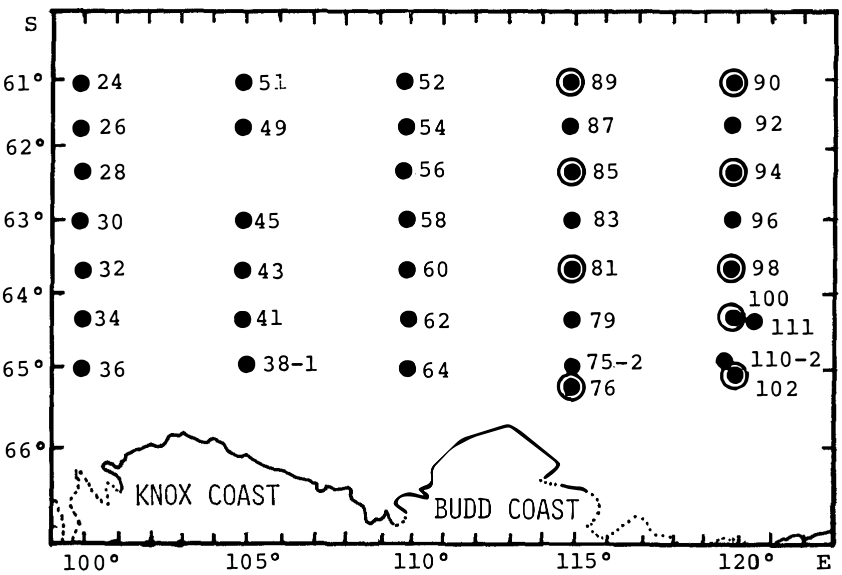

Fig. 1. Location of sampling station occupied during January 13–29, 1980. Solid spot shows the station of surface water sampling, and the encircled shows sampling from five subsurface depths with Nansen bottle.

in order to concentrate the samples into 10–15 m*l*. The number of diatom cells in 0.02 m*l* aliquot of the concentrated samples was counted by species under the light microscope. Microscopic observations were repeated 1–3 times to obtain an averaged result. The scanning electron microscope (JOEL and Akashi MiNi SEM) was used whenever it was necessary to identify the diatom species. The hydrographic data were quoted from the cruise reports (FISHERIES AGENCY, 1980).

3. Results

3.1. Hydrographic conditions in the study area

The horizontal distributions of the surface temperature and salinity are demonstrated in Fig. 2. There observed was −1.0°C isotherm along the coast of Antarctica where the northern edge of the pack-ice lies. Relatively higher temperatures of 0.6°–1.0°C were observed between 105° and 120°E longitudes along 63°S latitude. In the north of 64°S, the surface water temperature was higher at the eastern side than the western side in the study area.

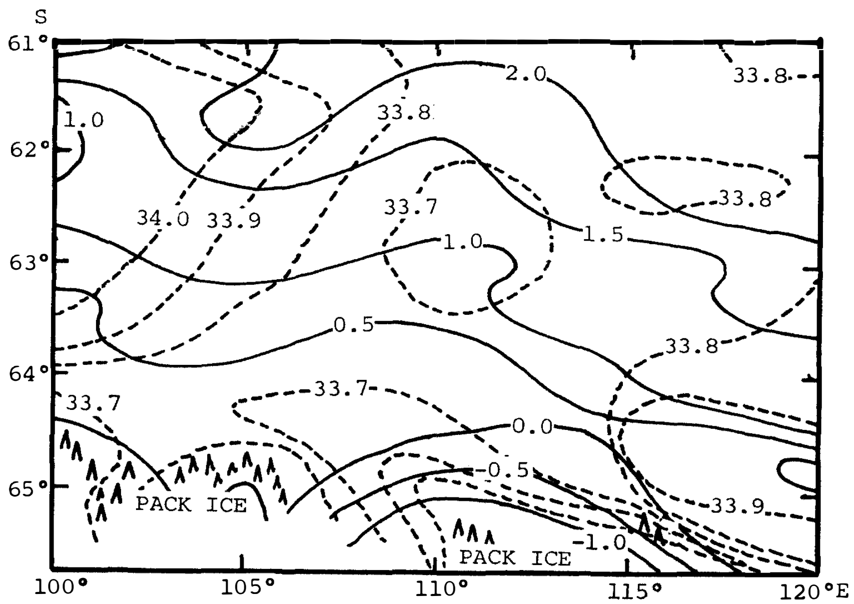

Fig. 2. Distributions of surface temperature (°C: solid line) and salinity (‰: broken line) in the study area (compiled from the data of FISHERIES AGENCY, *1980). Triangle shows the pack-ice.*

The low salinity was found in the area where the lowest temperature prevailed in association with the pack-ice, whereas the highest salinity usually coincided with the area of higher temperature. The water with a salinity of lower than 33.7‰ in the south of 64°S is formed by a dilution of ice melted water during the summer.

3.2. Diatom species observed

The diatom communities found in this study consisted of 13 genera, 38 species of Centrales and 6 genera, 16 species of Pennales. All species identified are listed in Table 1 in alphabetical order. However, the species which exceeded 10% of the total cell number at each of 37 stations were the following seven species in the order of dominance:

*Fragilariopsis 'nana'**
Fragilariopsis rhombica
Fragilariopsis kerguelensis
*Nitzschia 'closterioides'**
Nitzschia pungens
Fragilariopsis curta
Dactyliosolen spp.

The seven dominant species when they are combined altogether accounted for more than 72% of the total cell number, which may suggest a relatively monotonous composition of diatoms occurring in the Antarctic waters as stated by MARUMO (1953) whose studies were based on materials collected by the plankton net in the Pacific sector.

* Since *F. cylindrus* and *F. pseudonana*, and *N. prolongatoides* and *N. subcurvata* were difficult to identify under the light microscope, they were combined and expressed as shown by HASLE (1969).

Table 1. Diatom species identified.

Amphiprora sp.	*Fragilariopsis kerguelensis* (O'MEARA) HUSTEDT
Asteromphalus hyalinus KARSTEN	*F. rhombica* (O'MEARA) HUSTEDT
A. hookerii EHRENBERG	*F. ritscheri* HUSTEDT
A. parvulus KARSTEN	*F. pseudonana* (STEEMANN NIELSEN) HASLE
Biddulphia aurita var. *obtusa* (KUTZING) HUSTEDT	*F. sublinaris* (van HEUCK) HEIDEN
B. weissflogii GRUNOW	*Macrodiscus oliveranus* (O'MEARA) GRUNOW
Charcotia actinochilus (EHRENBERG) HUSTEDT	*Navicula directum* GRUNOW
Chaetoceros atlanticus CLEVE	*N.* spp.
Ch. borealis BAILEY	*Nitzschia closterium* (EHRENBERG) W. SMITH
Ch. bulbosus (EHRENBERG) HEIDEN	*N. heimii* MANGUIN
Ch. castracanei KARSTEN	*N. prolongatoides* (MANGUIN) HASLE
Ch. concavicornis MANGIN	*N. pungens* GRUNOW
Ch. criophilum CASTRACANE	*N. subcurvata* HASLE
Ch. curvisetus CLEVE	*N. turgidula* HUSTEDT
Ch. dichaeta EHRENBERG	*N.* sp.
Ch. natatum MANOUIN	*Pleurosigma directum* (GRUNOW)
Ch. pendulus KARSTEN	*Rhizosolenia alata* BRIGHTWELL
Ch. pervianus BRIGHTWELL	*Rh. carcar-avis* SCHULTZE
Ch. spp.	*Rh. cylindrus* CLEVE
Corethron criophilum CASTRACANE	*Rh. delicatula* CLEVE
Coscinodiscus bullatus JANISCH	*Rh. fragilissima* BERGEN
Cos. lineatus EHRENBERG	*Rh. hebetata* f. *semispina* (HENSEN) GRAN
Cos. radiatus EHRENBERG	*Rh. styliformis* BRIGHTWELL
Cos. tabularis EHRENBERG	*Streptotheca thamesis* SHRUFSOLE
Cos. spp.	*Thalassiosira antarctica* COMBER
Dactyliosolen antarcticus CASTRACANE	*T. ostrupii* (OSTENFELD) PROSCHKINA-LAVRENKO
Dact. mediterraneus H. PERAGALLE	*T.* spp.
Dact. sp.	*Thalssiothrix longissima* CLEVE et GRUNOW
Eucampia balaustium CASTRACANE	*Tropidoneis antarctica* (GRUNOW) CLEVE
Fragilariopsis curta (van HEUCK) HUSTEDT	
F. cylindrus (GRUNOW) KRIEGER	

3.3. *Abundance distribution*

The horizontal distribution of total cell number is demonstrated in Fig. 3. The abundance of diatoms changed greatly from station to station with a cell number between 2.3×10^4 and 3.2×10^6 cells per liter of sea water. Geographically, the diatom was abundant along both 105° and 110°E. In the south of 64°S along 120°E diatoms were very few in number being coincident with the water of slightly higher salinity but slightly lower temperature. In general, the diatom cells were richer towards the south with closer relationship to the water having a temperature between 0.5° and 1.0°C. It is also noteworthy that the Centrales diatoms, especially, *Dactyliosolen* sp. became a more important component at several stations in the northern region (see also Fig. 8). This distribution pattern coincides well with the results by HASLE (1969) who pointed out the importance of *Chaetoceros* species such as *Ch. dichaeta* and *Ch. neglectus* in the northern waters of the Antarctic Divergence.

Except Stn. 45 (63°S, 105°E), it is clear that the diatom communities in the study

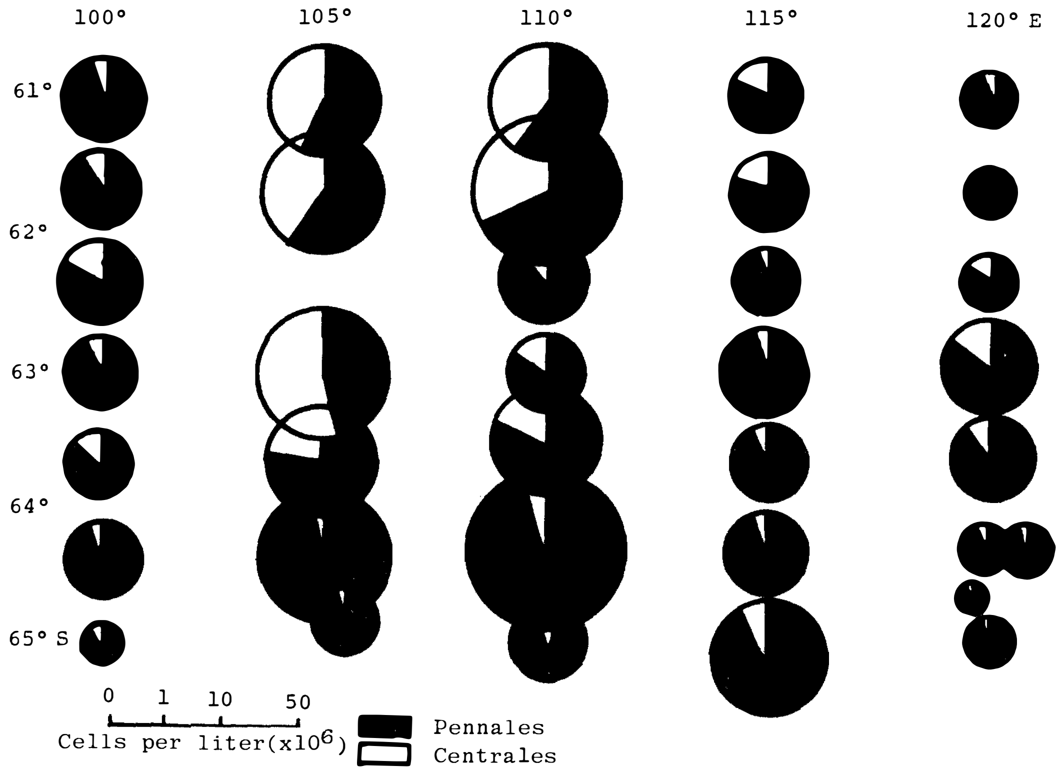

Fig. 3. Abundance distribution of diatoms.

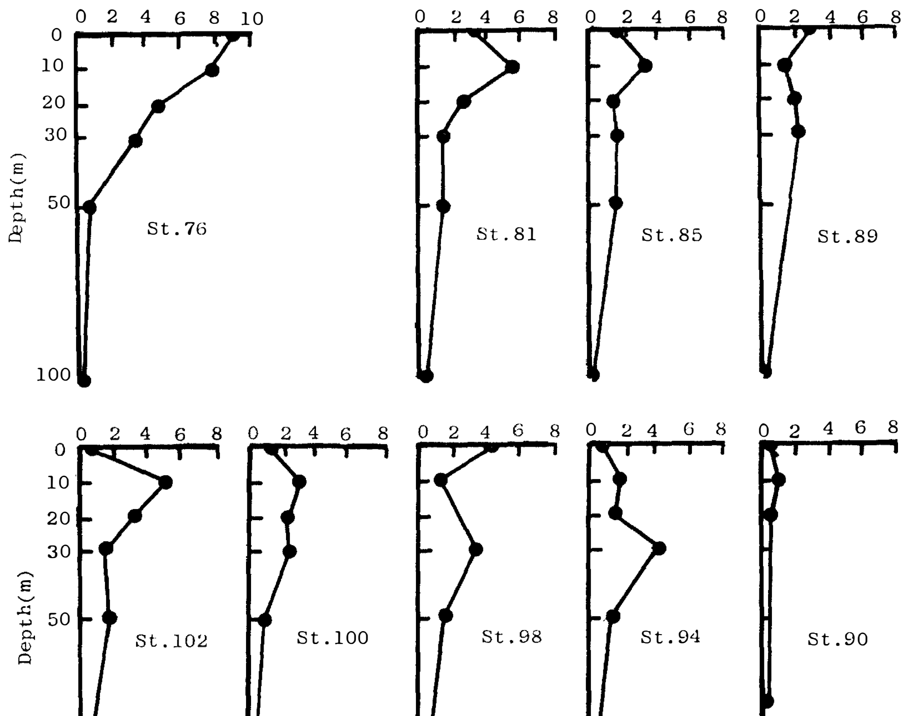

Fig. 4. Vertical distribution of total cell number of diatoms ($\times 10^5$ *celles per liter*).

area were represented by the Pennales species as described before, and the Centrales species reduced its relative importance towards the south. Averaged cell number throughout all stations was 6.1×10^5 cells/*l*. This figure agrees with that in the Antarctic zone of the Indian Ocean sector (KOZLOVA, 1966).

Since phytoplankton patchiness is not only the phenomenon at the surface but also related to the vertical structure of the diatom population (PLATT and DENMAN, 1980), it was also observed in the subsurface layer at the nine stations. Figure 4 demonstrates the vertical distributions of the total cell number. Usually, the subsurface maximum of diatoms was found at a 10 m depth, and the cell number decreased with increasing depth. At two stations, Stns. 94 and 98, however, the pronounced maxima were present at the depth of 30 m. The distinct surface maximum was demonstrated at Stn. 76, the southernmost station, where the water having a temperature of 0.5°C and a salinity of 33.5‰ prevailed, being influenced by the melting ice. From Fig. 4 it may be observed generally that the abundant diatoms were found mainly at the upper 10 m depth and the figure indicates that the vertical distribution of diatoms in this study had a similar pattern as reported previously.

3.4. Distribution of dominant species

Fragilariopsis curta: A large number of this species was found exclusively at the southern stations located near the pack-ice, and the species decreased in number clearly towards the north (Fig. 5). The relatively large population of the species along

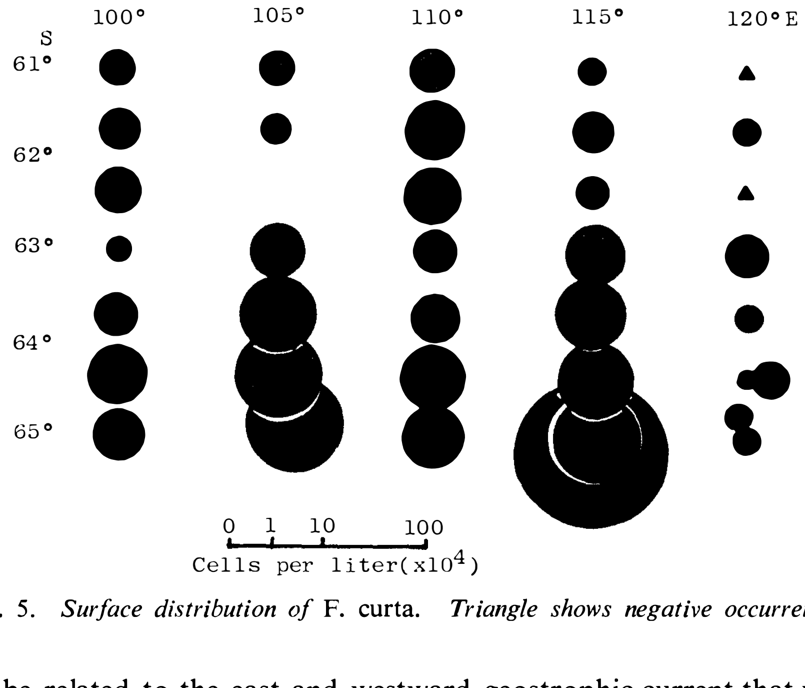

Fig. 5. Surface distribution of F. curta. *Triangle shows negative occurrence.*

110°E might be related to the east and westward geostrophic current that was observed during the present cruise (FISHERIES AGENCY, 1980). According to KOZLOVA (1966) and HASLE (1969), *F. curta* is endemic in the Antarctic waters of higher latitude, especially in the region closer to the pack-ice (*e.g.* HEUCK, 1909; HENDY, 1937; HASLE, 1969), and is eaten largely by *Euphausia superba* (BARKLEY, 1940; KAWAMURA, 1981).

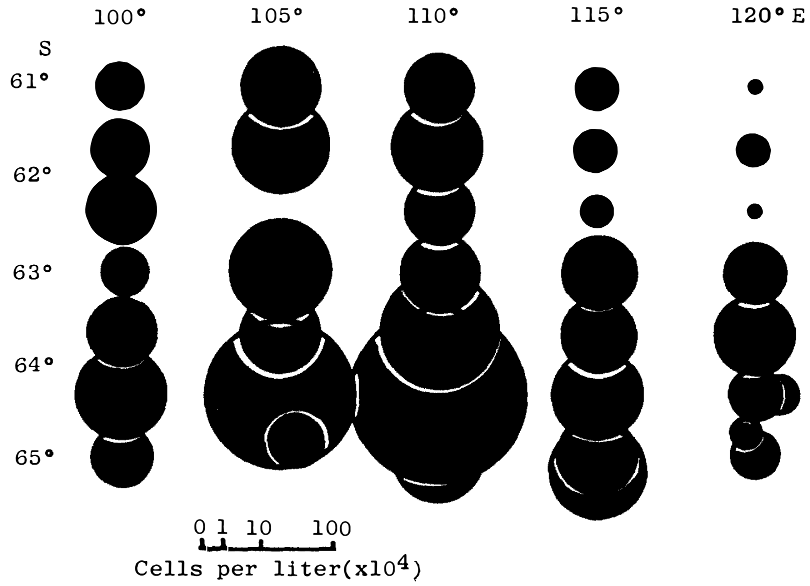

Fig. 6. Surface distribution of F. 'nana.'

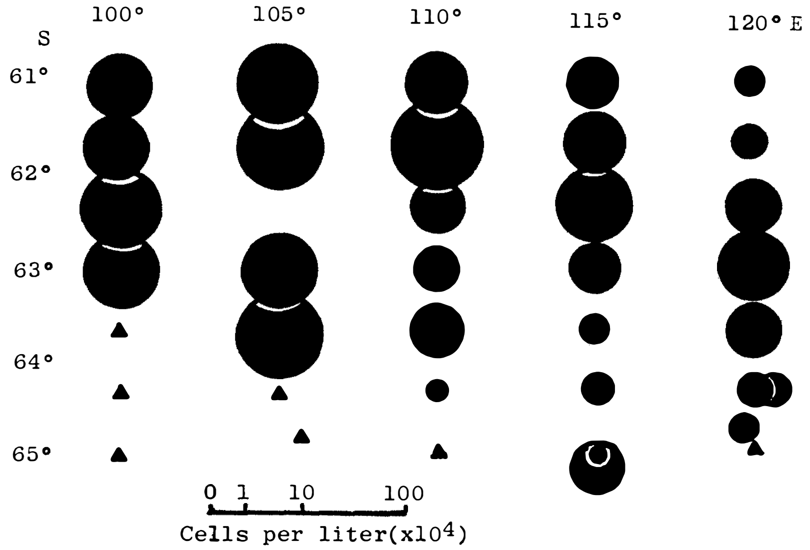

Fig. 7. Surface distribution of N. pungens. *Triangle shows negative occurrence.*

Fragilariopsis 'nana': General distribution pattern of the species was similar to that of *F. curta*. *F. cyclindrus*, one of the component species of '*nana*', is considered to be a cold and bipolar species (HASLE, 1964), and has been known to be distributed in the high latitude Antarctic region along with *F. curta* (HASLE, 1969). *F. pseudonana*, on the other hand, is distributed in more northern waters than the former. The maximum number of *F. 'nana'* was found at Stn. 62 where the cell number was 3.0×10^6 per liter of water (Fig. 6).

Nitzschia pungens: Different from the former two species, *N. pungens* was found in relatively northern waters, and was actually absent at seven stations in the southern Antarctic zone (Fig. 7).

Dactyliosolen spp.: In this genus both *D. antarcticus* and *D. mediterraneus* are included. Figure 8 shows the dense population of the species along 105° and 110°E. This fact suggests that *Dactyliosolen* spp. are likely to show the more pronounced uneven distribution pattern than the other species. The relatively small population of the species at Stns. 55 and 58 along 110°E agreed with the water of lower temperature and lower salinity.

Nitzschia 'closterioides': The species were widely distributed in the area investigated, and were small in number in the southern region. These facts will indicate that the main distributional area of the species would be in the northern Antarctic region (Fig. 9).

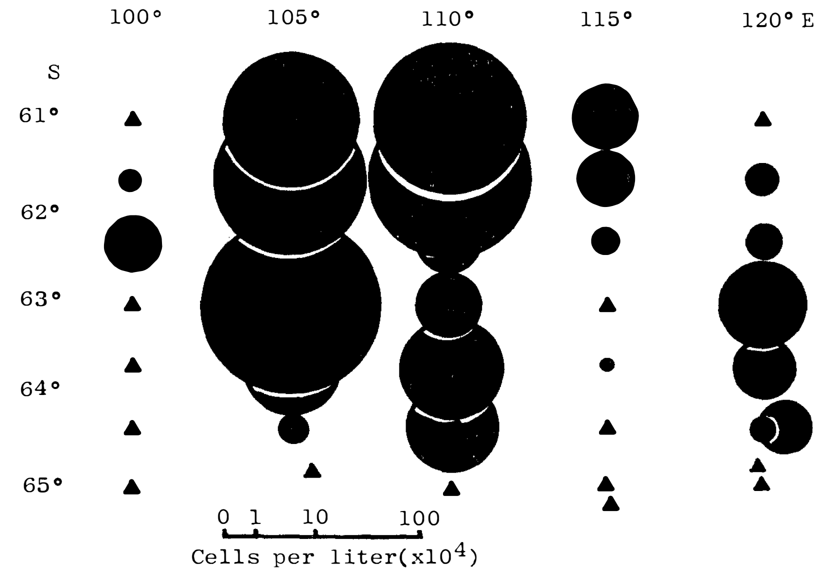

Fig. 8. Surface distribution of Dactyliosolen *spp. Triangle shows negative occurrence.*

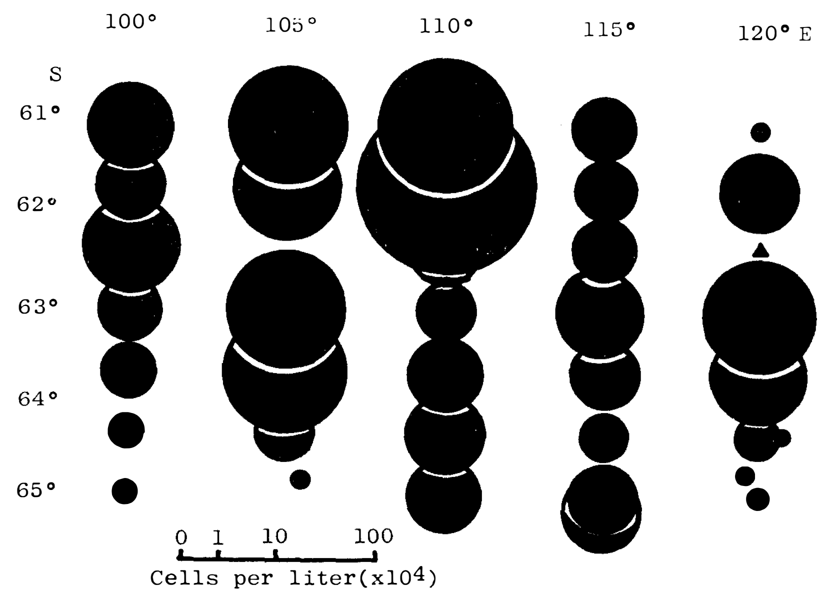

Fig. 9. Surface distribution of N. 'closterioides'. *Triangle shows negative occurrence.*

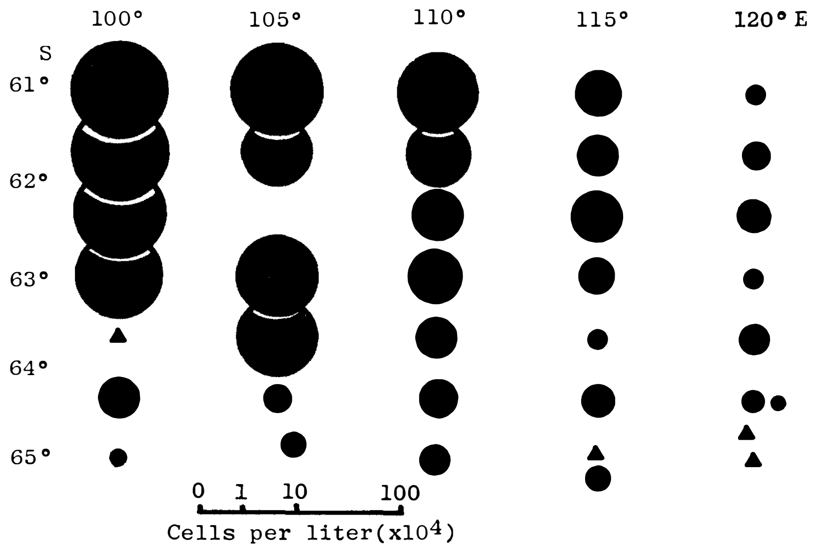

Fig. 10. Surface distribution of F. rhombica. *Triangle shows negative occurrence.*

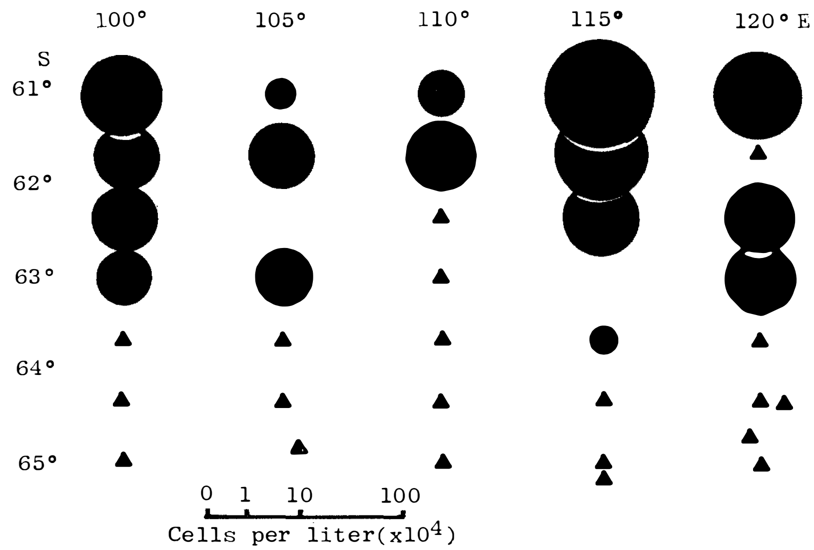

Fig. 11. Surface distribution of F. kerguelensis. *Triangle shows negative occurrence.*

Fragilariopsis rhombica: As shown in Fig. 10, a large number of this species was found in the northern waters north of 63°S where the water of higher salinity and higher temperature prevailed. KOZLOVA (1966) states that this species dominates in the waters north of the Antarctic Divergence.

Fragilariopsis kerguelensis: It was the most distinct northern species among the former six species. Although this species was found in 63°40′S, its main habitat was probably in the northern region north of 63°S (Fig. 11).

From the characteristic distribution of the dominant diatom species, it can be summarized that the diatoms in the area investigated seem to be closely related to the hydrographic conditions, especially to the geostrophic current including gyre along 105°–110°E.

3.5. Species composition

The composition of the diatom species in percentage at 35 stations is demonstrated in Fig. 12 where Stns. 110 and 111 are excluded because these two were closely located to Stns. 110 and 102 respectively. From the horizontal distributions of the seven dominant species or groups, *F. 'nana'* and *F. curta* were the most dominant species over a wider range of the southern region, whereas *F. rhombica*, *F. kerguelensis* and *N. 'closterioides'* prevailed in the north. *Dactyliosolen* spp. were dominant at several stations along 105° and 110°E. Generally speaking, the species composition of diatom communities became more monotonous in the southern region in relation to the paucity of the dominant species.

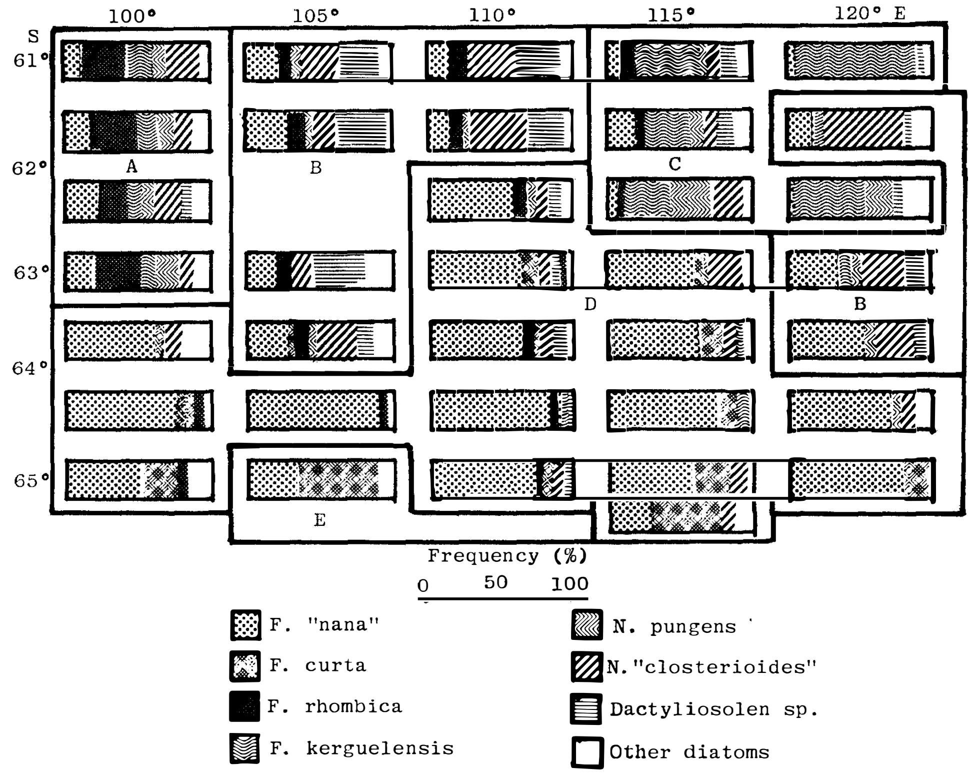

Fig. 12. Species composition of principal diatoms at the surface.

In contrast to the distinct changes in species composition of diatoms at the surface, a very stable species composition was observed in the water column from the surface to the 50 m depth (Fig. 13); that is, there does not seem to exist any shade or dim light species although *F. 'nana'* and *F. rhombica* tended to increase slightly in the subsurface waters. Therefore, it may be summarized that the species composition of diatoms in the subsurface water is very similar to that of the surface at the same station.

Using percentage similarity index the diatom communities at 37 surface stations were divided into five groups when they were classified with the similarity index at 0.75 level. That, is;

A: Very high percentage of *F. rhombica* and high species diversity under the environment of 0.6°–1.2°C, 33.9–34.1‰.

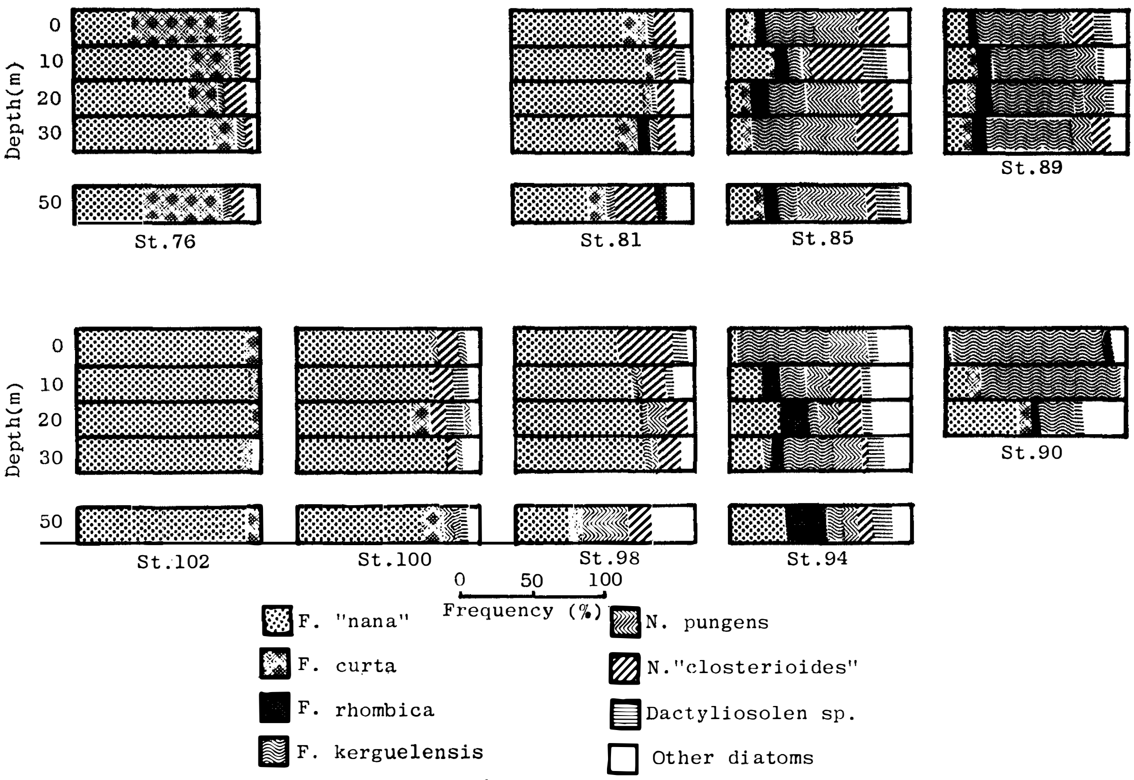

Fig. 13. Vertical distribution in species composition of principal diatoms.

B: Dominancy of the Centrales species such as *Dactyliosolen* spp., *Chaetoceros atlanticus*, *Ch. nanatum* and *Chaetoceros* sp. 0.8°–2.4°C, 33.7–34.0‰.

C: Dominancy of *F. kerguelensis* and *N. pungens* under the environment of the maximum temperature and high salinity. 2.0°–2.6°C, 33.8‰.

D: Dense population of *F. 'nana'*, and very low in species diversity. Waters of distinct change in temperature and salinity influenced by the summer waters. −1.0°–1.5°C, 33.4–34.0‰.

E: Predominant occurrence of *F. curta* in percentage composition, and very low in species diversity. It occurred in the southernmost region close to the pack-ice.

4. Discussion

Within a small area of about 932–1110×44 km, the abundance and the species composition of diatoms changed considerably from station to station. As shown in Fig. 3, the total cell number of diatoms was distinctly large only at the stations along 105° and 110°E where more than 10^5–10^6 cells per liter of water was found. Such distribution pattern demonstrated that the great horizontal changes of diatom population along the longitudes occurred within a distance of about 100–200 km in 'length-scale'. These distances between the possible patches were remarkably large when compared with the general distribution of the phytoplankton patchiness which appears in a spatial scale of several hundred meters (PLATT and DENMAN, 1980, Fig. 11.2). However, the great distance in the spatial scale of phytoplankton patches is also known in

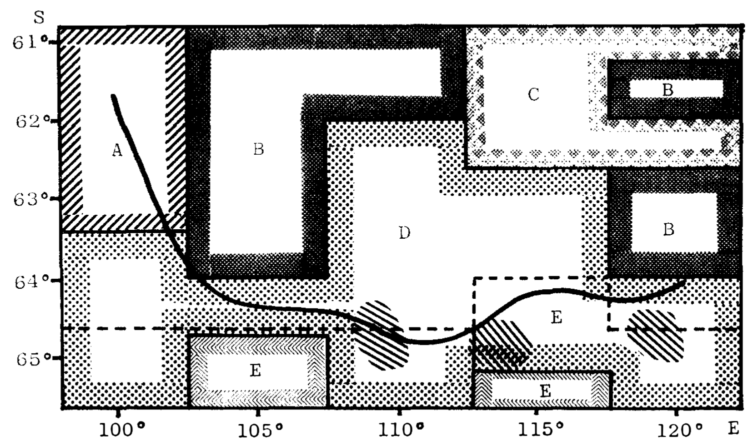

Fig. 14. Horizontal distribution of five diatom communities of different species composition (A–E). Broken line denotes the 'D' community of closer similarity to the 'E' community (E'). Solid line denotes the northern limit of the occurrence of Euphausia superba *in the catches of ORI-100 and KYMT net tows. Shade indicates the area where* E. superba *was caught abundantly.*

Rhizosolenia in the northern North Atlantic (CUSHING, 1955), and is nearly of the same order as that observed in the North Pacific by VENRICK (1972) and GOWER *et al.* (1980).

The horizontal distributions of the five diatom communities and *Euphausia superba* are shown in Fig. 14, where the occurrence of *E. superba* coincides well with the diatom communities of 'D' and 'E' in which *F. curta* predominated, and this is an evidence to support that *F. curta* is one of the important food of *E. superba* (BARKLEY, 1940). This evidence also supports a geographically biased occurrence of *E. superba* patches, which is related to the predominant occurrence of small sized diatom species (KAWAMURA, 1981).

The present study suggests that the patchiness of diatoms differs in its spatial scale by species, and the 'length-scale' of the patchiness can be considered of an order of several tens to hundred kilometers. Since *E. superba* seems to be related to a definite diatom species and/or communities in its geographical distributions, the total cell number of diatoms or chlorophyll-*a* content of the water does not seem to be a promising environmental factor for the location of abundant distributions of *E. superba*.

Acknowledgments

We are greatly indebted to Dr. K. NASU of the Fisheries Agency for his well-timed advice in collecting the materials. Thanks are also due to Captain T. TAKAHASHI and his crew of the R.V. KAIYO MARU who helped T. KIKUNO of the Faculty of Fisheries, Hokkaido University in collecting the water samples in the field.

References

BAINBRIDGE, R. (1957): The size, shape and density of marine phytoplankton concentrations. Biol. Rev., **32**, 91–115.

BARKLEY, E. (1940): Nahrung und Filterapparat des Walkrebschens *Euphausia superba* DANA. Z. Fisch. Deren Hilfswiss., **1**, 65–156.

CUSHING, D. H. (1955): Production and a pelagic fishery. Pt. III. Plankton patches and their identity. Fish. Invest., Ser. II, **18** (7), 19–35.

FISHERIES AGENCY (1980): Shôwa 54-nendo KAIYO MARU Chôsa Kôkai Hôkokusho (Report on the investigation cruise of the R. V. KAIYO MARU in 1979). Tokyo, 362 p.

GOWER, J. F. R., DENMAN, K. L. and HOLYER, R. J. (1980): Phytoplankton patchiness indicates the fluctuation spectrum of mesoscale oceanic structure. Nature, **288**, 157–159.

HARDY, A. C. (1936): Observations on the uneven distribution of oceanic plankton. Discovery Rep., **11**, 511–538.

HASLE, G. R. (1964): *Nitzschia* and *Fragilariopsis* species studied in the light and electron microscopes. I. Some marine species of the groups Nitzschiella and Lanceolate. Skr. Nor. Vidensk. Akad. Oslo, 1: Mat.-Naturv. Kl., **16**, 1–48.

HASLE, G. R. (1969): An analysis of the phytoplankton of the Pacific Southern Ocean; Abundance, composition, and distribution during the Brategg Expedition 1947–1948. Hvalradets Skr., **52**, 1–168.

HENDEY, N. I. (1937): The plankton diatoms of the southern seas. Discovery Rep., **16**, 151–364.

HEUCK, H. van (1909): Diatomées. Résultats de Voyage du S. Y. 'Belgica' en 1897–9. Expéd. Antarct. Belge, VI (Botany), 127 p.

KAWAMURA, A. (1981): Food habits of *Euphausia superba* and the diatom community. Biological Invesitgations of Marine Antarctic Systems and Stocks (BIOMASS), Vol. II. Cambridge, SCAR and SCOR, 65–69.

KOZLOVA, O. G. (1966): Diatoms of the Indian and Pacific sectors of the Antarctic. Jerusalem, IPST, 191 p.

MARUMO, R. (1953): On the diatom plankton in the Antarctic in summer, 1952. J. Oceanogr. Soc. Jpn., **9**, 33–38.

PLATT, T. and DENMAN, K. (1980): Patchiness in phytoplankton distribution. The Physiological Ecology of Phytoplankton, ed. by I. MORRIS. Oxford, Blackwell, 413–431 (Studies in Ecology, Vol. 7).

VENRICK, E. L. (1972): Small-scale distributions of oceanic diatoms. Fish. Bull., **70**, 363–372.

(Received December 12, 1983; Revised manuscript received April 6, 1984)