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Environmental conditions and phytoplankton standing crop near pack-ice in the Scotia Sea (December 1988 — January 1989)

ABSTRACT: Results of an oceanographic survey along the edge of drifting pack ice in the area between Elephant Island and the South Orkney Islands are reported. The influence of sea ice on hydrological factors was very weak. It was not possible to develop oceanographic features characteristic for marginal sea-ice zones in the areas with well marked surface currents and dynamic hydrological conditions. The spatial distribution of chlorophyll was governed by water stability, although during our survey, areas with enhanced vertical stability could not be described in terms of a sea-ice edge influence.

Key words: Antarctica, phytoplankton, sea-ice zone.

Introduction

Marginal ice edge zones in Antarctica have been reported as regions of increased phytoplankton biomass since the time of the first sporadic measurements done by Hart (1934), El Sayed (1971), El Sayed and Taguchi (1981) and many others. This phenomenon is attributed to meso-scale variations (more than 100 km), and weather variations time scale (few days) with large scale seasonal changes (Smith 1987). The complex physical interactions between sea water, ice and air create, within these zones, unique oceanographic conditions favourable for phytoplankton growth (Niebauer and Alexander 1985). A receding ice edge zone, generated by seasonal changes during austral spring and summer, possesses oceanographic features that are particularly favourable for phytoplankton development. The hypothesis most consistent with the available data is that the strong salinity gradients caused by the melwater released from sea ice enhances vertical stability and provides optimal oceanographic conditions for phytoplankton (Smith and Nelson 1986, Sullivan, McClain and Smith 1988). This general meso-scale picture was found in the Ross Sea (Smith and Nelson 1985a, b), the Weddell-Scotia Sea during AMERIEZ 1983 (Nelson *et al.* 1987), and the Weddell Sea during EPOS leg 1 (ed. Larsson 1990).

Many new possibilities exist now for researches working on the influence of environmental conditions on phytoplankton distribution. The *in situ* measurements of chlorophyll, oceanographic and hydrochemical parameters can be combined with the ocean color (CZCS) and the passive microwave images (SMMR) from satellites (Sullivan, McClain and Smith 1988). On the basis of these different sources of information it is possible to give a reliable interpretation of data obtained from widely distributed oceanographic stations, and to estimate the horizontal range of the observed phenomena.

The area between Elephant I. and the South Orkney Is., where the oceanographic stations were located during this work, is known to be a part of the Weddell-Scotia Confluence (Deacon and Foster 1977, Patterson and Sievers 1980). Its hydrological structure is very dynamic and complex, undergoing great seasonal and weather scale variations as evidenced by CSCZ images (El Sayed and Hofmann 1986). On the basis of hydrographic data collected in this area during 10 years (Stein 1988) the pattern of geostrophic circulation can be drawn (Fig. 1). At the time of our cruise, the pack ice drift generally followed the direction of the geostrophic currents.

The main aim of this paper is to discuss the influence of the environmental conditions, that were found in the Scotia Sea during the 1988/1989 cruise, on phytoplankton biomass and to show that the investigated area does not exhibit oceanographic patterns characteristic for marginal sea-ice edge zone.

Material and methods

From 26th December 1988 to 13th January 1989 44 oceanographic stations were occupied in the vicinity of pack ice edge located between Elephant I. and the South Orkney Is. Three additional stations were situated in Bransfield Strait just outside Admiralty Bay, King George Island. The grid of the stations consisted of 50 to 70 km long transects of three stations each from near the ice to the open sea (Fig. 1). Because of the lack of ice protection it was not possible for r/v „Profesor Siedlecki" to enter the pack. A detailed description of the cruise and precise locations of the stations are given in the expedition report (Rakusa-Suszczewski 1991), oceanographic and hydrochemical data are presented by Tokarczyk *et al.* (1991). Phytoplankton standing crop was measured as a concentration of chlorophyll *a* according to the recommendations of Evans, O'Reilly and Thomas (1987), but the chlorophyll contents were determined spectrophotometrically, using the equation after Jeffrey and Humphrey (1975). Chlorophyll *a* data were obtained at 31 stations. To recognize fine scale vertical distribution of chlorophyll the near surface water layer was sampled at each 10 meters to the depth of 50 m, then standard sampling depths were used.

Table 1

Results of chlorophyll *a* determinations (mg/m^3). Integrated values 0–150 m (mg/m^2)

Depth (m)	Stations number																													
	21	23	24	25	26	27	29	30	31	33	34	35	37	38	39	42	43	45	46	48	49	50	52	53	54	57	58	59	61	62	63
0	0.20	0.15	0.49	0.53	0.38	0.48	0.80	0.44	0.36	0.58	0.36	0.27	0.61	0.60	0.19	1.29	0.83	0.26	0.88	0.31	0.85	1.23	0.84	1.68	1.34	1.95	1.53	1.29	1.41	1.10	4.04
10	0.21	0.26	0.49	0.60	0.37	0.50	0.88	0.49	0.36	0.73	0.39	0.28	0.64	0.55	0.21	1.27	0.92	0.27	0.96	0.31	1.33	1.22	0.85	1.90	1.47	2.08	1.50	1.25	1.49	1.12	3.56
20	0.28	0.26	0.52	0.47	0.43	0.55	0.91	0.48	0.38	0.58	0.48	0.25	0.66	1.17	0.22	1.30	0.92	0.25	0.87	0.31	1.34	1.22	0.85	2.16	1.46	3.04	0.54	1.18	1.26	1.16	2.65
30	0.27	0.27	0.45	0.40	0.43	0.57	1.01	0.50	0.45	0.52	0.36	0.24	0.64	0.90	0.19	0.81	0.91	0.23	0.46	0.31	1.34	1.20	0.85	1.76	1.39	1.99	0.29	0.92	1.12	1.29	1.94
40	0.23	0.16	0.48	0.41	0.42	0.57	1.16	0.50	0.40	0.43	0.19	0.17	0.62	0.95	0.18	0.58	0.81	0.23	0.42	0.31	1.08	1.15	0.80	1.70	0.29	0.53	0.23	0.58	0.27	0.64	1.36
50	0.24	0.16	0.49	0.26	0.32	0.48	1.04	0.40	0.41	0.31	0.15	0.15	0.54	0.50	0.18	0.26	0.48	0.23	0.40	0.31	0.31	1.15	0.63	0.35	0.26	0.25	0.23	0.45	0.21	0.58	0.60
75	0.20	0.12	0.44	0.11	0.10	0.27	0.41	0.28	0.24	0.25	0.15	0.12	0.27	0.42	0.12	0.17	0.28	0.17	0.30	0.34	0.18	0.83	0.30	0.21	0.19	0.13	0.19	0.16	0.11	0.24	0.21
100	0.15	0.10	0.30		0.12	0.19	0.29	0.19	0.14	0.22	0.13	0.12	0.14	0.14	0.10	0.09	0.13	0.16	0.22	0.27	0.18	0.33	0.18	0.13	0.09	0.08	0.12	0.10	0.07	0.14	0.12
150	0.11	0.10	0.13	0.01	0.03	0.13	0.10	0.15	0.07	0.12	0.09	0.12	0.08	0.08	0.08	0.06	0.11	0.10	0.11	0.05	0.09	0.08	0.06	0.06	0.06	0.05	0.05	0.03	0.04	0.05	0.07
Integr. values	28.4	22.3	55.9	29.4	31.8	49.8	85.4	46.8	37.9	48.4	29.5	23.9	52.1	65.2	20.9	59.7	62.8	27.9	57.0	39.3	74.1	109.3	64.5	101.4	67.0	98.0	47.8	62.1	58.5	70.3	137.3

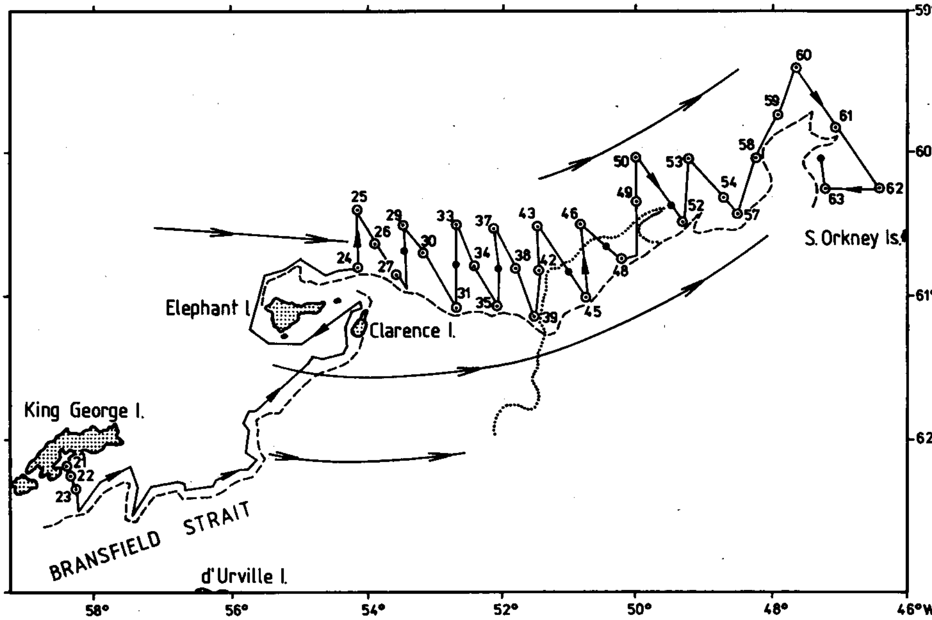

Fig. 1. Oceanographic stations occupied during r/v „Profesor Siedlecki" cruise (Dec. 1988-Jan.1989).
Solid dotts — stations where chlorophyll *a* was not determined. Dashed line indicate pack ice edge; dotted line — stands for pack ice edge during second part of the cruise. Thick arrows indicates directions of surface currents (after Stein 1988).

Results

Within the surface water layer, which is important for phytoplankton growth (0–150 m), three different water masses were distinguished (Tokarczyk *et al.* 1991). The stations on the first two transects (to station No. 27), including stations located in Bransfield Strait, were occupied by the surface water of the Bellinshausen Sea origin. The central part of the investigated area was occupied by the Weddell Sea water of winter modification. This type of water is characterised by very homogenous T and S values. The eastern part, covering the area of pack ice eddy (Fig. 1), in shallow layer to a depth about 45 m, had distinctly warmer water recognised as a summer modification of Weddell Sea surface water. All of the recognised water masses had high nutrient concentrations, ranging for nitrates from 23 to 31 µgat/m^3, and for silicates from 36 to 84 µgat/m^3 (Tokarczyk *et al.* 1991). These concentrations were much higher than the values limiting phytoplankton growth.

Each of the water masses exhibited a characteristic vertical stability pattern. Stations No. 24–27 were located in a frontal zone area and had a very disturbed temperature structure. Weddell Sea surface water of winter modification with its small and uniformly changing T and S, located at stations from No. 29 to No. 48, had very low stability. Sharp temperature gradients characteristic for summer modification of the Weddell Sea surface water created the conditions of stability favourable for phytoplankton growth at the stations No. 49 to 63 and partially at station No. 46. The direct influence of the sea-ice melwater was very weak. Salinity gradients at the stations located close to the sea-ice edge were usually about 0.06 from 0–10 m. Only at stations No. 24 and 48 ΔS were >0.10. Also, the horizontal distribution of surface salinity values did not exhibit the pattern, that the sea water close to sea-ice edge was less saline.

Results of chlorophyll *a* determinations are presented in Table 1. Concentrations ranged at the surface from 0.15 mg/m^3 to 4.04 mg/m^3. Minimal concentration at the surface was allied with the lowest value for the water layer from the surface to 50 m. In many cases slightly higher concentrations were found at 20–30 m. Usually below the depth of 50 m, chlorophyll concentrations sharply decreased to the values close to 0.2 mg/m^3. This phenomenon occurred deeper, i.e. between 75 and 100 m depth at stations Nos. 24, 29, 38 and 50.

Chlorophyll *a* content integrated from the surface to 150 m, ranged from 20.85 mg/m^2 at station No. 39, to 137.3 mg/m^2 at station No. 63. The highest chlorophyll *a* contents, both in concentration and integrated values, were found in the Weddell Sea surface water of summer modification. In some cases however, namely at stations Nos. 42, 54, 58, 59 and 61, where the surface concentrations were high and close to 1.5 mg/m^3, the integrated values appeared to be relatively low, close to 60 mg/m^2.

Discussion

It is not surprising that the spatial distribution of the oceanographic data and chlorophyll *a* values in the investigated area appeared to be complex and difficult to interpret. The first conclusion that can be drawn from consideration of the hydrological features presented on Fig. 1 is that the waters adjacent to the sea-ice edge were not hydrologically connected with sea ice area. Also, a coarse scale distribution of salinity values at the stations located close to sea-ice edge does not suggest a direct influence of ice melwater. Both pack ice and sea water were drifting in the east-northeast direction. South of Elephant I. the pack ice drift velocity was estimated during our cruise as 10 cm/s, that is nearly the some value like the surface current recorded for this area (Stein 1988). The lack of the hydrological link between the sea and the pack ice distinguished our survey area from a typical marginal sea-ice zone. The length of the transects followed by r/v „Profesor Siedlecki", max. 70 km from the ice edge, seemed to have been too short to differentiate area with increased phytoplankton biomass attributable to the marginal sea-ice zone. According to Sullivan, McClain and Smith (1988) this phenomenon is usually marked 100–150 km from the sea-ice edge, but can be greatly modified by local ice and sea dynamics. Nelson *et al.* (1987) reported a well established bloom in waters of the Weddell-Scotia Confluence in mid-November 1983 and explained it as being caused by hydrological conditions typical for ice edge zones. Our cruise was carried out much later in the summer season (December 1988/January 1989) and the ice we encountered was drifting fields not directly connected with a receding ice edge. The oceanographic conditions that can be found in the waters adjacent to drifting pack ice fields are much more dependent on local hydrology than factors associated with marginal sea-ice zones.

The spatial distribution of chlorophyll *a* during our cruise was dependent on water stability. Lutjeharms, Walters and Allanson (1985) pointed out that the increased stability of Antarctic Surface Water caused by density stratification creates favourable conditions for phytoplankton development. This was found at stations No. 49 to 63 located in the summer modification of the Weddell Sea surface water, where on the surface average chlorophyll concentration was 1.56 mg/m^3. Increased stability of the water column at these stations was caused by a sharp thermocline and not by a salinity gradient, which is characteristic for marginal sea-ice zones. The weak interdependence between surface chlorophyll concentrations and integration values supports Hayward and Wenrick's (1982) cautions that in some cases surface chlorophyll data are not precise indicators of biological state of pelagic ecosystem. The differences in correlations between these two phytoplankton measures can be found in both directions. With a sharp and shallow located density gradient, the overall content of chlorophyll can be low despite the high surface concentration, as was the case during our cruise. When the water stability is very low, i.e. during the early summer blooms, chlorophyll is distributed more homogeneously and to greater depths within the water column. Its integrated values can be very high but surface concentrations are only of medium or low range. Such cases were found in the Bransfield Strait at the beginning of November 1986 (Lipski and Rakusa-Suszczewski 1990).

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Streszczenie

Rezultaty badań oceanograficznych prowadzonych w okresie od 26.XII.1988 do 13.I.1989 w okolicach paku lodowego dryfującego na obszarze pomiędzy wyspą Elephant a archipelagiem Orkadów Południowych pokazały, że bezpośredni wpływ lodu morskiego na parametry oceanograficzne wody morskiej był zaznaczony bardzo słabo. Na obszarach o dynamicznej hydrografii

i silnych prądach powierzchniowych, jakimi są niewątpliwie badane przez nas obszary Weddell--Scotia Confluence, nie ma możliwości wykształcenia się struktury oceanograficznej typowej dla marginalnej strefy przylodowej (marginal sea-ice zone). Wyniki oznaczeń chlorofilu *a* przedstawione są w Tabeli 1. Zawartość chlorofilu *a* zależna była od stabilności kolumny wodnej. Wśród trzech różnych typów wód, które zalegały na badanym przez nas obszarze tylko wody Morza Weddella o letniej modyfikacji zapewniały warunki stabilności sprzyjające rozwojowi fitoplanktonu. Wody te miały najwyższą zawartość chlorofilu zarówno w stężeniach na powierzchni (max. 4.04 mg/m^3), jak i w wartościach integrowanych 0–150 m (max. 137.3 mg/m^2).