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Distribution and Dynamics of Dissolved Inorganic Nutrients in the Bransfield Strait, Antarctica during Austral Summer 1993

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Distribution of plant major inorganic nutrients and Chlorophyll a in the Bransfield Strait between the Antarctic Peninsula and the South Shetland Islands was investigated during February 1993. In general, contents of nitrate, phosphate and silicate are > 25 μM, > 3.0 μM, > 60 μM, respectively in both a warm and saline Upper Circumpolar Deep Water (T > 0.2 °C, 34.3 ‰; depth > 700 m) and a cold and saline Weddell Sea Surface Water (T < 0.6 °C, S > 34.4 ‰; depth > 500 m). In Bellingshausen Sea Water of higher temperature and lower salinity (T > 1.6, S < 34 ‰), contents of nitrate, phosphate, and silicate are < 20 μM, < 2.0 μM, < 30 μM, respectively. In general chlorophyl-a concentration is higher (0.8 g/l) in the surface mixed layer (50 m) and lower (0.2 g/l) below the surface mixed layer. Despite of the richness of nutrients, phytoplanktonic biomass is quite small. If we assume that carbon to Chlorophyll a ratio is 50, 19 μM of nitrate should support 30 g/l of Chlorophyll a according to Mitchell and Holm-Hansen Model (1991). Chlorophyll a concentration is lower 2 g/l in all the stations occupied during survey period. Therefore, phytoplankton growth is not limited by the availability of major inorganic nutrients in this region. Approximately 80 % of total chlorophyl-a standing crop is found in the upper 30 m of water column. But chlorophyl-a concentrations in productive less unproductive stations with the comparatively low stability of surface water are nearly uniform in the upper 100 m below the 1 % light level. The comparatively low stability of surface waters prevent the organisms from remaining in the optimum light zone long enough for extensive production. This may partly answer one of possibilities of relatively poor productivity despite high nutrient level in the Antarctic waters. Owing to the subdued utilization of nutrients, salinity-nutrients property plots in the western Bransfield Strait show similar characteristic features to those of T-S diagrams. Therefore, nutrient concentrations are proposed here as a useful tracer to identify the water masses in the Bransfield Strait.

Key words: dissolved inorganic nutrients, Chlorophyll a, Bransfield Strait

INTRODUCTION

The western Bransfield Strait is a deep water passage between the Antarctic Peninsula and the South Shetland Islands, the entrance to Drake Passage. The Bellingshausen Sea is located in the west of the Strait and the Weddell Sea is located in the east. The coastal waters of the Antarctic Peninsula is composed of various waters originated from the Bransfield Strait, Weddell Sea, Bellingshausen Sea and Drake Passage waters. In the austral summer the Bellingshausen Sea Water flows into the Bransfield Strait through the inlet between Low, Smith and Snow Islands in the west and the Weddell Sea Water penetrates the Strait over the broad shelf of d'Urville and Joinville Islands in the east (Clowes, 1934; Gordon and Nowlin, 1978). In contrast to most open ocean surface water, the water masses originated from the Antarctic region is enriched in plant major nutrients. The global ocean chemistry

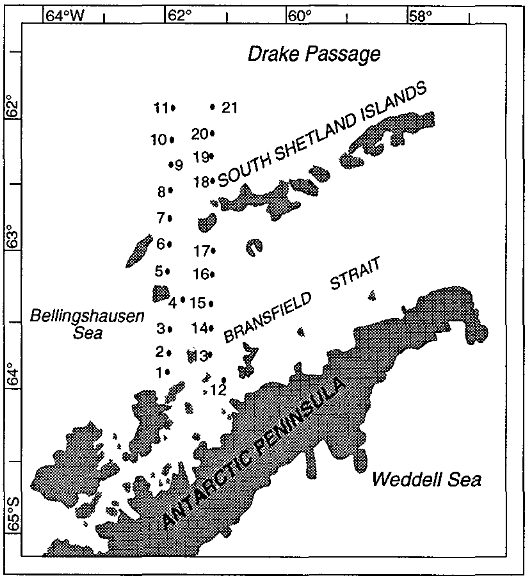

Fig. 1. Oceanographic sampling stations in the Bransfield Strait, Antarctica during February 1993.

is greatly influenced by the water masses originated from the Antarctic region. Therefore, many oceanographers have been interested in this Strait for many years (Marin *et al.*, 1985; Holm-Hansen and B.G. Mitchell, 1991; Niiler *et al.*, 1991; Ledford-Hoffman *et al.*, 1986). The most widely used conservative tracers of water masses are temperature and salinity, whereas informations that could be obtained from the concentrations of nutrients were poorly exploited in the Bransfield Strait. In order to overcome salinity change due to the ice melting and freezing of sea ice, oxygen isotopic composition of seawater was also utilized in order to trace the origin of water types (Kang *et al.*, 1992). Like temperature and salinity, the nutrients reflect the general circulation pattern. Therefore, nutrients in the ocean can be used extensively to provide insight into processes of water mass formation. The purpose of this study is to describe a general feature of distribution of dissolved inorganic nutrients in relation to water masses in the Bransfield Strait during austral summer.

MATERIALS AND METHODS

Hydrographic survey and water samples were taken in the Bransfield Strait during February 1993 (Fig. 1). Temperature and salinity were determined using CTD (MK5) casts. Water samples were collected with Niskin bottles mounted on a rosette samplers at the surface, 10, 30, 50, 75, 100, 200, 300, 500, 1000, 1200, 1500 and 2000 meter depths for the determination of nutrients and Chlorophyll a. Water samples were immediately filtered through a 47mm glass fiber filter (GF/F) and the filtrate stored in acid-cleaned polyethylene bottles at –45 °C on board. In vivo fluorescence was also determined with Turner Design field fluorometer (Model 10-005R) on board, and later calibrated to the chlorophyll (acetone extracts, Parsons *et al.*, 1984) in the laboratory (Ansan, Korea) using a limited number of frozen samples. Nutrient concentrations were determined by using an autoanalyzer Technicon Autoanalyzer II following the method described by Grasshoff *et al.*, (1976).

RESULTS

Sampling stations were occupied in the continental shelf, island shelves, continental shelf break and Drake passage. The vertical distributions of temperature, salinity, nutrients and Chlorophyll a along the north-south transacts were occupied in the western Bransfield Strait (Figs 2-6). The sampling station in northern end of the transacts is in the Drake Passages and the southern end is near the Brabant Island.

In general, temperature is higher in the surface and decreases with depth. Upper waters at the northern stations off the shelf break are relatively warmer and less saline than at the southern stations. There is a strong thermocline development. They are probably due to the melting ice from Bellingshausen Sea. Also an intrusion of very cold water of temperature below –1.0 °C is also seen near the depth of 100 m. This cold water may be originated from the Weddell Sea. Below this cold water, Circumpolar Warm Water exists. In the shelf region, low salinity water, less than 34 ‰, prevails due to the freshwater input from meltwater.

Nitrate contents increase with depth (Fig. 4). Nitrate concentrations near the surface water appear to be due to the dilution of nutrient-depleted ice melt water. Nitrate contents in the surface waters are higher in the northern part than in the

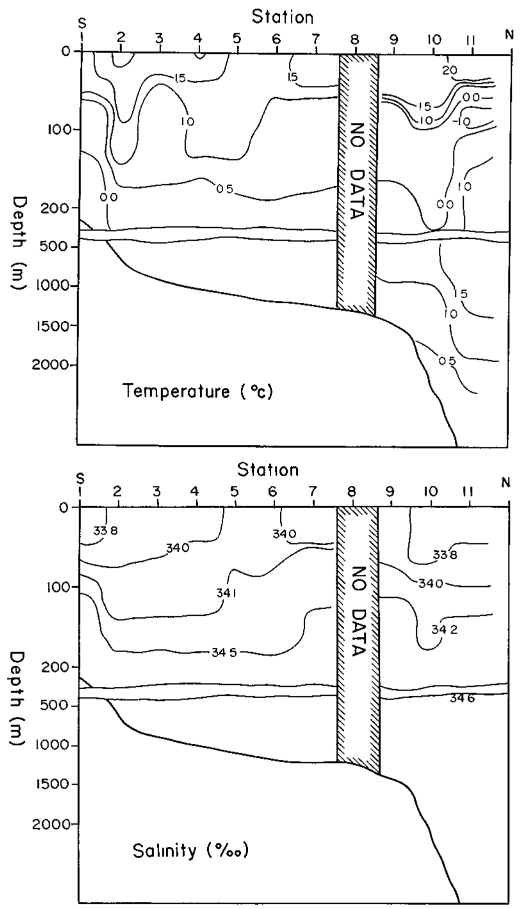

Fig. 2. Vertical distribution of temperature and salinity along the north-south transactions of 1 in the western Bransfield Strait during February 1993.

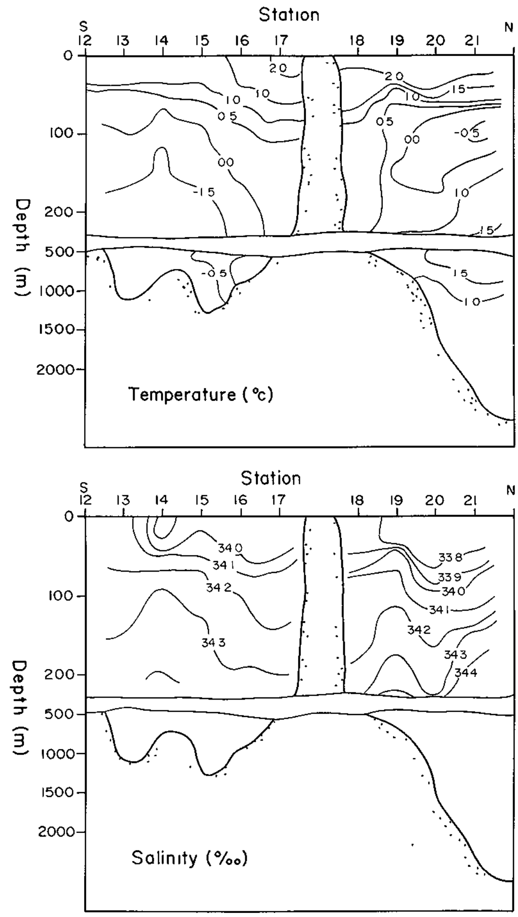

Fig. 3. Vertical distribution of temperature and salinity along the north-south transactions of 2 in the western Bransfield Strait during February 1993.

southern part of the Bransfield Strait. The intrusion of relatively nutrient-rich Weddell Sea originated water appears in the depth of 100-300 m region in the southern and northern part. An intrusion of nitrate-rich Circumpolar Warm Deep Water are also seen below 200 m depth in the northern part.

Vertical distribution of silicic acid are shown in Fig. 5. Concentrations are higher in the southern part than in the northern part. This is the opposite trend we observed in the nitrate distribution. In the northern part of the Bransfield region, a reduced level of silicate was observed due to the abundant diatoms growing in that region (Kang *et al.*, 1993).

Chlorophyll a concentrations averaged 0.6 g/l and highest concentrations (1.7 g/l) were measured at the depth of 10 m of station 6, just to the east of the Smith Island (Fig. 6). Unfortunately, Water sample for analysis of Chlorophyll a were not collected at Station 8 where the highest phytoplankton density was observed during this study.

The southern sampling stations near the Antarctic Peninsula was generally poor in Chlorophyll a (i.e., < 0.4 μg/l) with more or less uniform distribution in the upper 100 m of water column.

DISCUSSION

Nutrient Rich Antarctic Shelf Water

The most outstanding characteristics observed during the survey period is the comparatively high inorganic nutrients. In the western Bransfield Strait, contents of nitrate, phosphate and silicate in

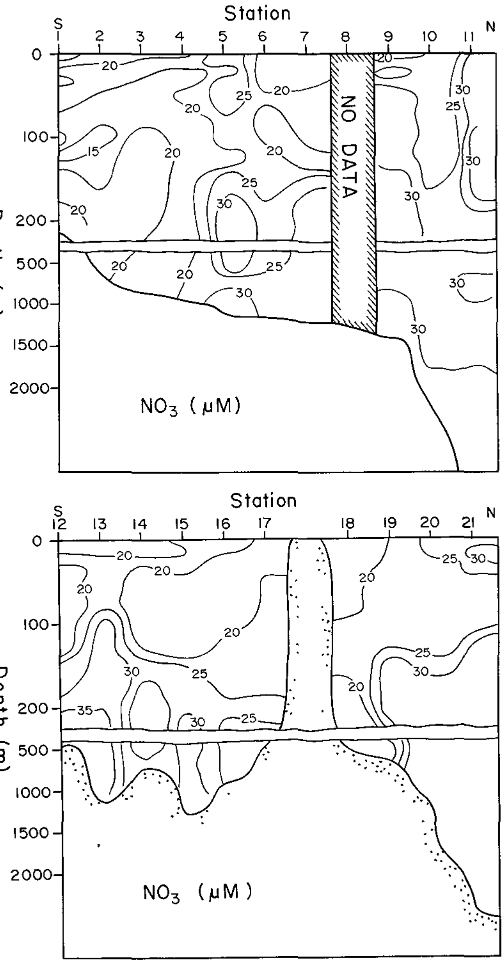

Fig. 4. Vertical distribution of nitrate along the north-south transactions of 1 and 2 in the western Bransfield Strait during February 1993.

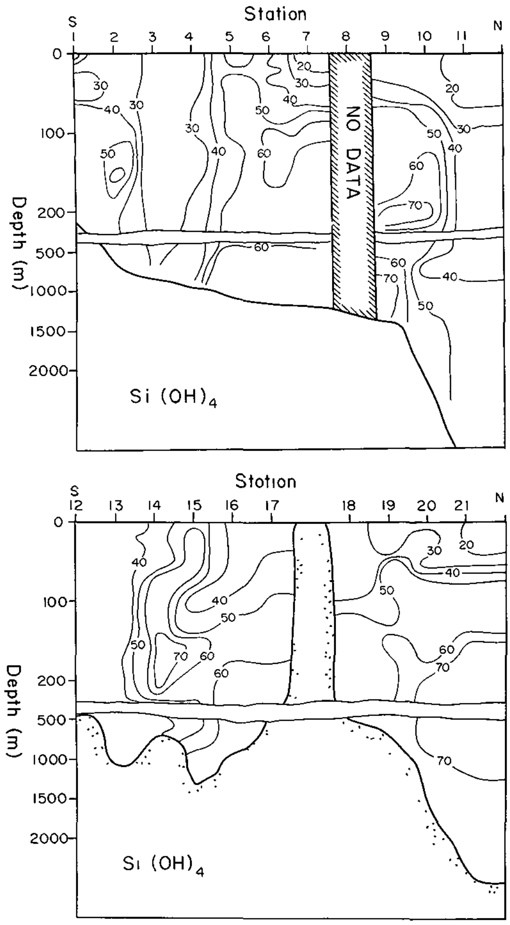

Fig. 5. Vertical distribution of silicate along the north-south transactions of 1 and 2 in the western Bransfield Strait during February 1993.

the upper 100 m of water column average 21.0, 2.1, 37.0 µM, respectively. The water are rich in inorganic nutrients that do not fall below 10, 1 and 20 µM of nitrate, phosphate and silicate, respectively, even in productive coastal regions, so that it is unlikely that major nutrients are limiting in the western Bransfield Strait during the survey period. The enrichment of the surface layer results from an oceanic divergence that brings the deep waters, originating mainly from the North Atlantic, to the surface.

Mole ratios of Nitrate and phosphate in the upper 100 m are ca. 9 at the southern stations and ca. 11 at the northern stations off the shelf break. These values are similar to that of around 10 determined by Holm-Hansen and Mitchell (1991) in the western Bransfield Strait in February 1987. But this value is under the global average (Broecker, 1974). These values suggest that phytoplankton at the southern province seem to utilize more nitrate than at the northern stations off the shelf break.

Primary Productivity and Stratification

The unresolved enigma in the Antarctic marine ecosystem is the fact that these waters are relatively less productive. despite its high nutrient levels.

Chlorophyll a concentration is higher (0.8 g/l) in the surface mixed layer (50 m) and lower (0.2 g/l) below the surface mixed layer (Fig. 8). Despite the

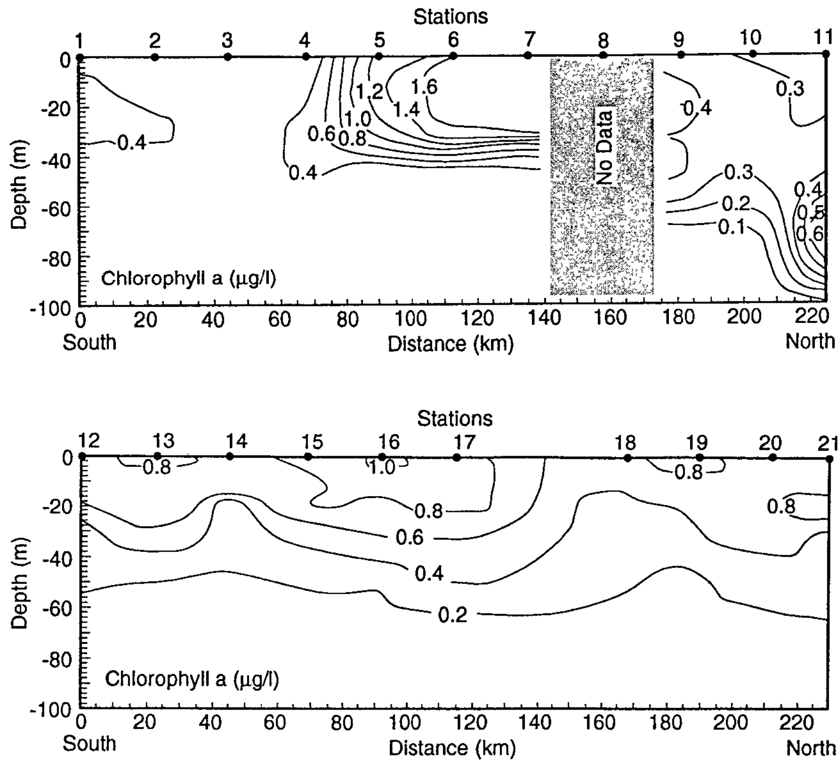

Fig. 6. Vertical distribution of chlorophyll a (μg/l) of along the north-south transactions of 1 and 2 in the western Bransfield Strait during February 1993.

richness of nutrients, planktonic biomass is quite small. If we assume that carbon to Chlorophyll a ratio is 50 described by Hewes *et al.* (1990), 19 μM of nitrate should support 30 g/l of Chlorophyll a, according to a model proposed by Mitchell and Holm-Hansen (1991). However, in all the stations occupied during February 1993, contents of Chlorophyll a is less than 2 g/l . This value lies within the reported values by Mullins and Priddle (1987).

There are no significant correlations between Chlorophyll a and three major nutrients, respectively in the upper 100 m depth (Fig. 7). Also, no significant correlations between major nutrients contents and phytoplankton organic carbon content estimated from cell counts and cell volume were not observed (KORDI, 1993). Therefore, major nutrients such as nitrate, phosphate and silicate are unlikely serious limiting factors for phytoplankton growth during the survey period.

In general, primary production in the Antarctic waters have been thought not to be limited by concentration of major inorganic nutrients, because waters south of the Antarctic Convergence usually have concentrations of inorganic nutrients far in excess of those required for maximal phytoplankton growth (Hayes *et al.*, 1984).

The environmental factors which may influence the primary productivity by phytoplankton in Antarctic waters are trace elements, light intensity, zooplankton grazing and stabilization of surface waters (El-Sayed, 1966; Martin and Fitzwater, 1988; Hong *et al.*, 1992; Kang *et al.*, 1993). The light regime is particularly important in the Antarctic where the upper water column is usually much more unstable than in temperate, tropical, or Arctic waters (Sakshaug and Holm-Hansen, 1986). Euphotic zone depth around the Bransfield Strait is approximately 55 m in the Antarctic Sound, 12 m in the Anvers Island, 10 m in the Gerlache Strait and 30 m in the Bransfield Strait (El-Sayed and Taguchi, 1981; Holm-Hansen *et al.*, 1989; Mandelli and Burkholder, 1966). Approximately 80% of whole water column chlorophyll a standing stocks

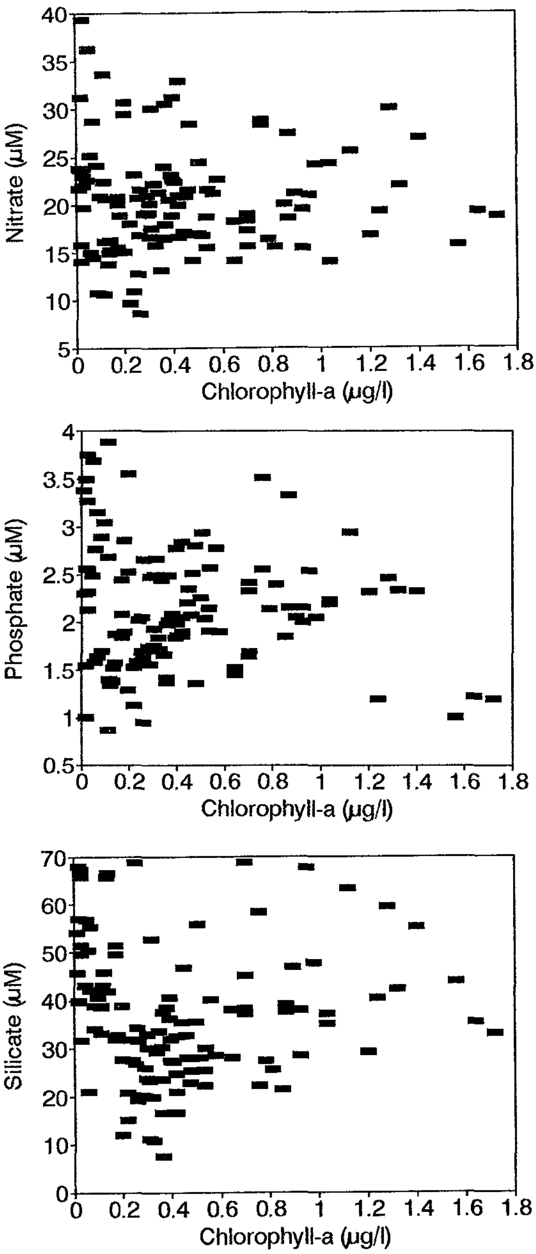

Fig. 7. Relation between chlorophyll a and major inorganic nutrients in the western Bransfield Strait during February 1993.

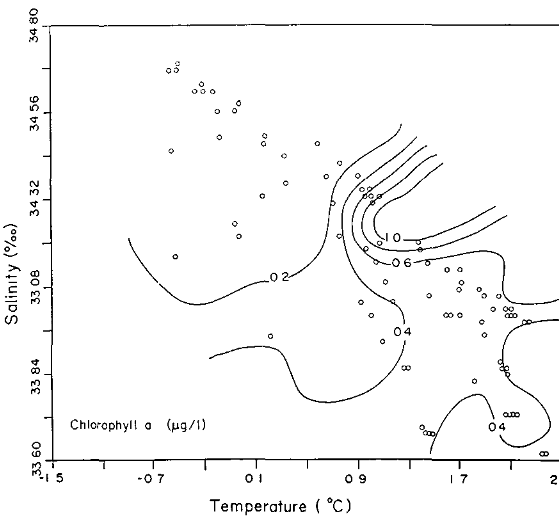

Fig. 8. Distribution of the chlorophyll a concentration on the T-S diagram in the western Bransfield Strait during February 1993.

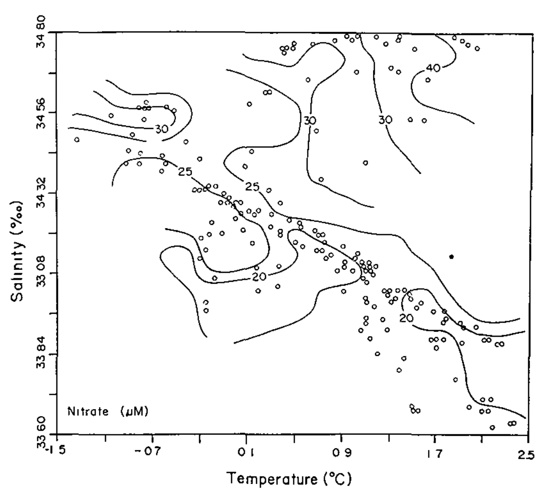

Fig. 9. Distribution of the nitrate concentration on the T-S diagram in the western Bransfield Strait during February 1993.

in productive areas between the Smith Island and Low Island is found in the upper 30 m of water column. But chlorophyll a concentrations in the less stratified areas are nearly uniform in the upper 100 m down to depth of the 1% light level. The comparatively low stability of surface waters prevent the organisms from remaining in the optimum light zone long enough for extensive production. This may partly answer one of possibilities of relatively poor productivity despite high nutrient level.

Nutrients as a Water Mass Tracer in the Antarctica Waters

The three dimensional diagrams of nitrate content against temperature and salinity for the whole water column in the western Bransfield Strait (Fig.

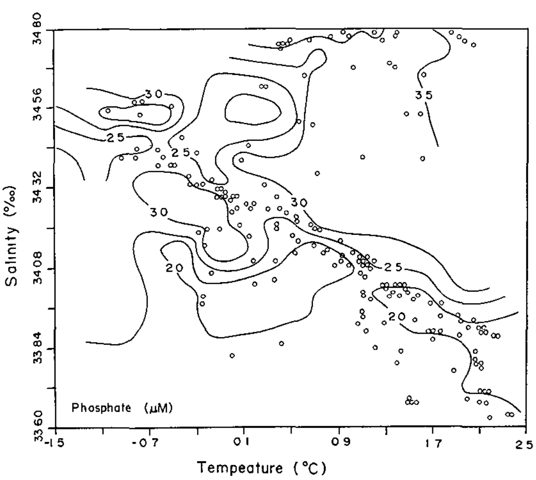

Fig. 10. Distribution of the phosphate concentration on the T-S diagram in the western Bransfield Strait during February 1993.

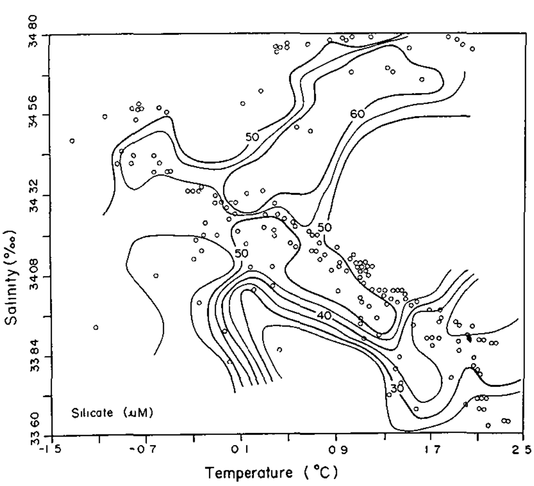

Fig. 11. Distribution of the silicate concentration on the T-S diagram in the western Bransfield Strait during February 1993.

9). Three major distinctive water mass is identified in this diagram: Circumpolar Warm Deep Water (CWDW), Weddell Sea originated Intermediate Water (WSIW) and Bellingshausen Sea Water (BSW). Circumpolar Warm Deep Water is characterized as a warm and saline (temperature is higher than 0.2°C; salinity is higher than 34.4‰) and rich in nitrate (> 30 μM). This Circumpolar Warm Deep Water resides in the waters deeper than 700 m depth. Weddell Sea originated water is characterized as cold and saline (temperature < –0.6°C; salinity > 34.4‰) and abundant in nitrate (> 25 μM). Weddell Sea originated water resides in the depth deeper than 100 m. Bellingshausen Sea Water is characterized as a warm and less saline (*temperature > 1.6°C; salinity < 34.0‰*), and low nitrate concentration (< 20 μM).

Surface water at Station 1 is a nitrate-depleted Gerlache Strait Water, nitrate concentration increases with depth due to the presence of Weddell Sea Water. Waters of Station 6 composed of Bellingshausen Sea Water and Weddell Sea Water. Concentration of nitrate is relatively homogeneous throughout the water column due to the lack of vertical segregation of rapid mixing of surface and deepwater. At Station 10, the water masses are apparent. The nitrate (< 20 μM) depleted Bellingshausen Surface Warm Water occupies in the surface. however, nitrate concentration increases with depth. Nitrate rich (> 25 μM) Weddell Sea water resides in the 100-200 m depth, and the most nitrate richest (> 30 μM) Circumpolar Warm Deep Water presents in the depth deeper than 200 m.

Distribution pattern of phosphate concentration is similar to that of nitrate. Dissolved phosphate concentration higher than 3.0 μM is observed in the Circumpolar Warm Deep Water and Weddell Sea water (Fig. 10). Dissolved phosphate concentration lower than 2.0 μM is observed in a warm and less saline surface water of Bellingshausen Sea Water.

Dissolved silicate contents are higher than 60 μM in the waters deeper than 700 m in the northwestern and deeper than 500 m in the southwestern Bransfield Strait (Fig. 11). However, in the surface water in the northwestern Bransfield Strait, silicate concentrations are less than 30 μM.

The water mass tracers are classified four classes according to their own marine chemistry, stable or radioactive and conservative or non-conservative (Craig, 1969). In the typical advection-diffusion model, the continuity equations for total fluid and for a component with specific concentration(C) are

$$\frac{\partial C}{\partial t} = D \cdot \frac{\partial^2 C}{\partial t^2} - W \cdot \frac{\partial C}{\partial t} - \lambda \cdot C + J$$

where D and W are the eddy-diffusion coefficient and advection velocity, λ is a radioactive decay constant, J is a zero-order, concentration-independent production rate.

As nutrients do not decay radioactively, is zero.

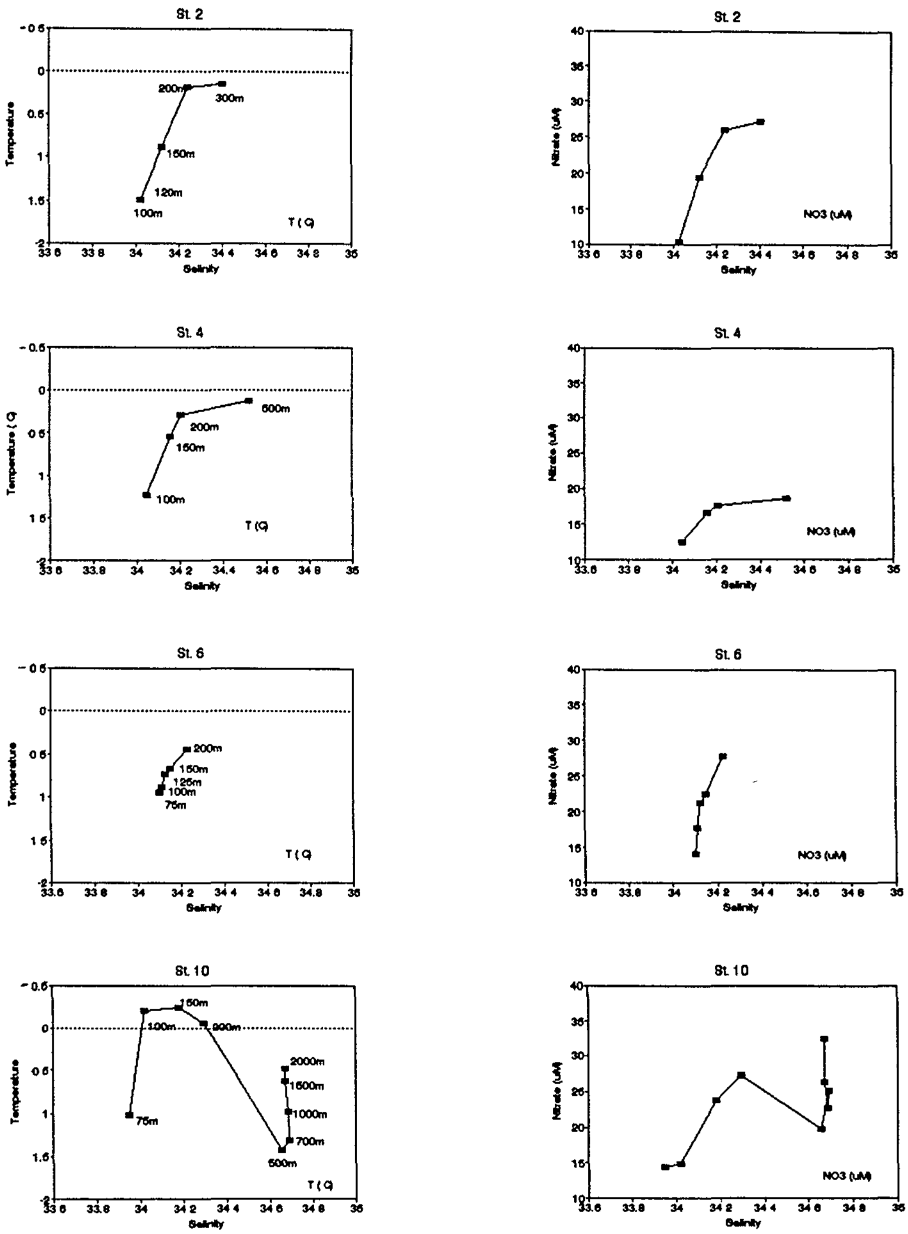

Fig. 12. Temperature-salinity and nutrient-salinity diagrams of St. 2, 4, 6 and 10 in the western Bransfield Strait, Antarctica (Feb. 1993).

In general, we regard that J is not negligible as for the inorganic nutrients. The inorganic nutrients belong to the stable and non-conservative tracer. Many researchers have been tried to convert the nutrients as a conservative water mass tracer (J = 0). Initial nutrient contents are one of the example to convert the nonconservative tracer to conservative, i.e. to remove J term using dissolved oxygen concentration in seawater (Broecker, 1974). In the Antarctic area, the concentrations of nutrients are very high, as mentioned before, while the primary production and/or other biological activities are so small compared with the nutrients concentration. Therefore the inorganic nutrient concentration can be used as a stable-conservative water mass tracer in the Antarctic region.

Property plots of salinity and nutrients observed in the western Bransfield Strait showed a characteristic feature, which are similar to the one shown by the T-S diagram (Fig. 12). Therefore, nutrient contents serve as conservative tracer of water masses where the uptake and/or release of dissolved nutrient by organisms is insignificant with respect to the total concentration of nutrient, such as the Bransfield Strait of Antarctica. In the future, preformed (initial) nutrient concentrations will be estimated using dissolved oxygen content, and stable isotopic composition of oxygen and hydrogen of water are will be utilized to determine the origin of water masses in the Bransfield Strait where the water masses is melting and freezing of sea ice as well as mixing of different water masses.

CONCLUSIONS

1. In the surface mixed layer, contents of nitrate, phosphate and silicate do not go below 10, 1 and 20 μM, respectively, even in productive coastal regions during survey period. .

2. Despite of the richness of nutrients, phytoplanktonic biomass is quite small. The comparatively weak stability of surface water column prevents the organisms from remaining in the optimum light zone long enough for extensive production. This may partly answer one of possibilities of relatively poor productivity despite high nutrient level.

3. Contents of nitrate, phosphate and silicate are > 25 μM, > 3.0 μM, > 60 μM, respectively in both a warm and saline low salinity Upper Circumpolar Deep Water (T > 0.2°C, 34.3‰; Depth > 700 m) and a cold and saline Weddell Sea Surface Water (T<0.6°C, S > 34.4‰; Depth > 500 m). In a highly warm and more fresher Bellingshausen Sea Water (T > 1.6, S < 34‰), contents of nitrate, phosphate, and silicate are < 20 μM, < 2.0 μM, < 30 μM, respectively.

4. Property plots of salinity and nutrients observed in the western Bransfield showed a characteristic feature, which are similar to the one shown by the T-S diagram. Therefore, nutrient contents serve conservative tracer of water masses where the uptake and/or release of dissolved nutrient by organisms is insignificant with respect to the total concentration of nutrient, such as the Bransfield Strait of Antarctica.

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