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Relationship Between Water Masses and Chlorophyll *a* Concentration in Bottom Water on the Northern Bering Shelf in Summer

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Abstract

Vertical distributions of temperature, salinity, and concentration of chlorophyll *a* were investigated on the northern Bering Shelf in the summers of 1991, 1992 and 1993. Bottom waters were classified into three water masses based on salinity, Anadyr Water (salinity higher than 32.5), Bering Shelf Water (salinity of 31.8-32.5), and Alaska Coastal Water (salinity less than 31.8). Nutrient concentrations were high in the former two and low in the latter. High chlorophyll *a* concentrations occurred between 30 m depth and the bottom in Anadyr and Bering Shelf Waters, but not in Alaska Coastal Water. The present results show that the vertical profile of phytoplankton abundance is largely affected by the distribution of these water masses.

Key Words: Chlorophyll *a*, Anadyr Water, Bering Shelf Water, Alaska Coastal Water

Introduction

The Bering Sea has a wide continental shelf and is an important fishing ground (Ohtani, 1969). In the northeastern part of the sea, primary organic carbon is produced by non-planktonic algae beneath the sea ice in spring and phytoplankton in the water column in summer after the sea ice has receded (McRoy et al., 1972). The primary production from spring to summer sustains higher trophic levels in the food chain (Springer et al., 1987, 1989, 1993).

South of St. Lawrence Island, polynya, which is an open water area within ice-covered sea surface, is formed by northerly offshore winds and wind sheltering effects (Smith et al., 1990 ; Ushio and Wakatsuchi, 1989). In polynya regions, dence water is produced during winter when surface water exposed to the atmosphere is intensely cooled. The cold, dense water can be found in summer on the sea bottom (Azumaya and Ohtani, 1995 ; Ohtani, 1969). The size of the polynya and the volume of the dense water produced polynya change with inter-annual variations of meteorological conditions in winter (Azumaya and Ohtani, 1995: Ohtani, 1969). Consequently, particularly south of St. Lawrence Island, variations are found in the distribution of the bottom water masses. Biological properties will presumably be affected by the water mass structure. The subject of the present study is to reveal the relationship between phytoplankton abundance and the water mass structures south of St. Lawrence Island in the Bering Sea.

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Material and Methods

Oceanographic observations and seawater samplings were conducted south of St. Lawrence Island on the northern shelf of the Bering Sea aboard the T/S Oshoro Maru (Fac. Fish. Hokkaido University) in July of 1991, 1992 and 1993 (Fig. 1). Stations OS91136, OS92113, OS93111, and OS93123 (Fig. 1) were located at the same position (62°20N, 171°20W).

Vertical distributions of temperature and salinity were profiled with a CTD (Neil Brown MK III B). Seawater was collected using Niskin Bottles equipped on a rosette multiple sampler on the CTD. Aliquots of the seawater were frozen (−30°C) for later analyses of nitrate and silicate concentrations with a Technicon AutoAnalyzer II. At Stations OS91136, OS92113, OS93111, OS93123, OS93120, OS93112, OS93116 and OS93124, seawater samples were collected with a Van Dorn bottle for measuring chlorophyll *a*. An aliquot of the seawater subsamples was

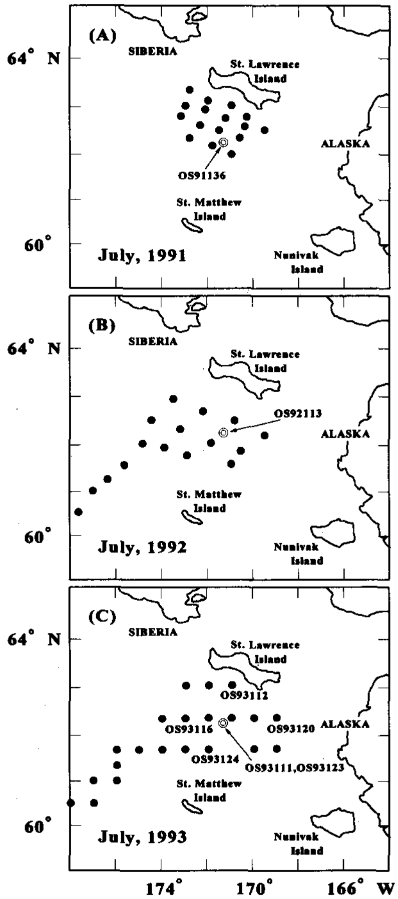

Fig. 1. Sampling stations on the northern Bering shelf in July of 1991 (A), 1992 (B) and 1993 (C). Stations OS91136, OS92113, OS93111 and OS93123 indicated by diploid circles are located at the same position (62°20N, 171°20W).

filtered through a precombusted glass fiber filter (Whatman GF/F) and frozen (−30°C). Chlorophyll *a* was extracted onshore in 90% acetone and measured by fluorometry (Parsons et al., 1984) using fluorescent spectrophotometer (Shimazu: RF-540).

Data on water temperature and salinity have been published (Fac. Fish. Hokkaido Univ., 1992, 1993, 1994). In the present study, concentrations of nutrients were used for some stations of the 1993 cruise (Fac. Fish. Hokkaido Univ., 1994).

Result

The water columns were thermally stratified, with developed seasonal thermoclines (Fig. 2). Surface water temperature was approximately 8–10°C, although cold water occurred below 20 or 25 m depth. The surface layer of salinity was

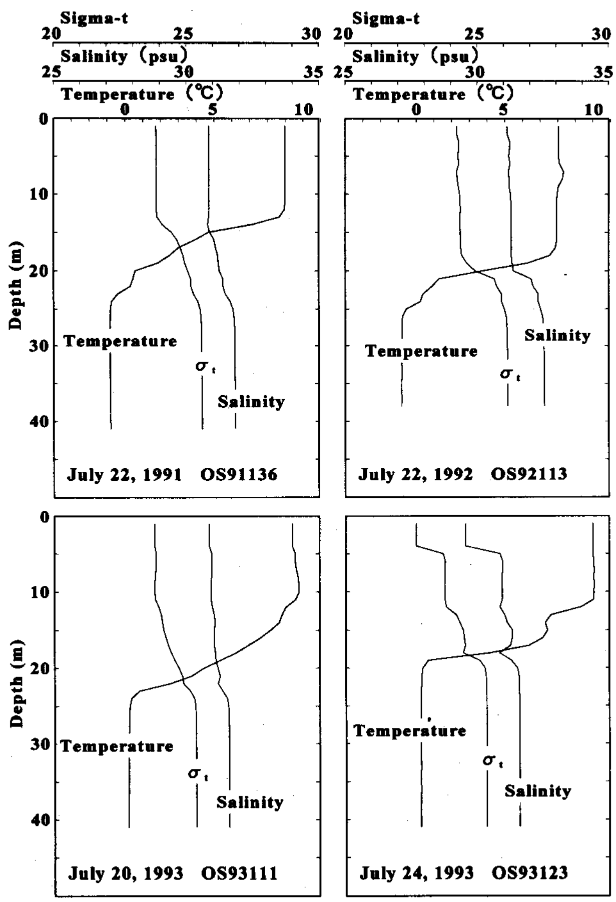

Fig. 2. Vertical distributions of temperature, salinity and sigma-t at Stations OS91136, OS92113, OS93111 and OS93123 (62°20N, 171°20W) in July of 1991 (Station OS91136), 1992 (Station OS92113) and 1993 (Stations OS93111 and OS93123).

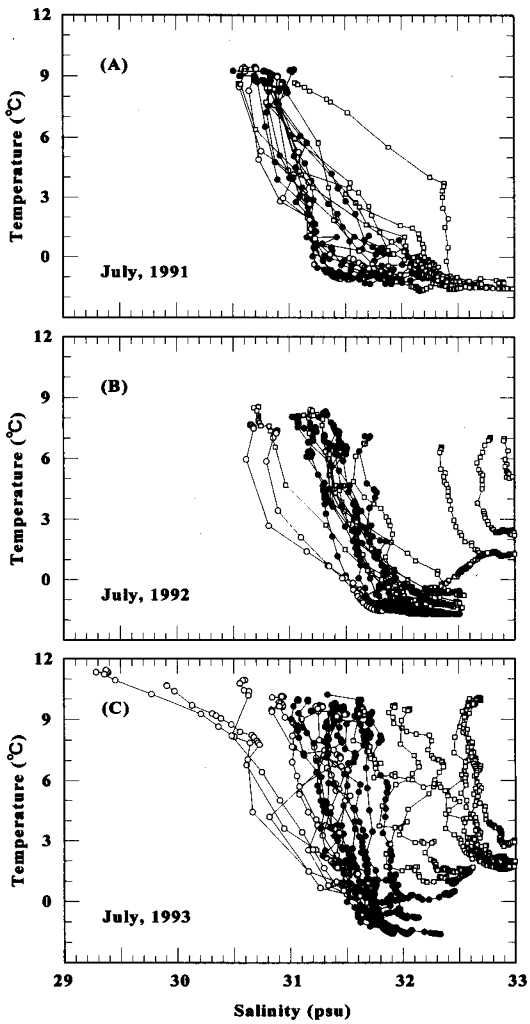

Fig. 3. T-S diagrams at stations on the northern Bering shelf in July of 1991 (A),1992 (B) and 1993 (C). Open square, closed circle and open circle represent Anadyr Water (salinity higher than 32.5), Bering Shelf Water (salinity between 31.8-32.5), and Alaska Coastal Water (salinity less than 31.8), respectively, as defined by Walsh et al. (1989).

approximately 29-33. CTD temperature-salinity curves are illustrated in Fig. 3. Three water masses in the bottom layer were classified based on salinity, Anadyr Water (salinity higher than 32.5), Bering Shelf Water (salinity between 31.8-32.5), Alaska Coastal Water (salinity less than 31.8) (Walsh et al., 1989).

The horizontal distribution of the three water masses near the bottom (depth range: 34-139 m) is shown in Fig. 4. Three water masses were consistently distributed from west to east in the survey area each year. However, the inter-annual distribution of the water masses varied south of St. Lawrence Island. In 1991, Anadyr Water occurred near St. Lawrence Island. Station OS91136 was occupied

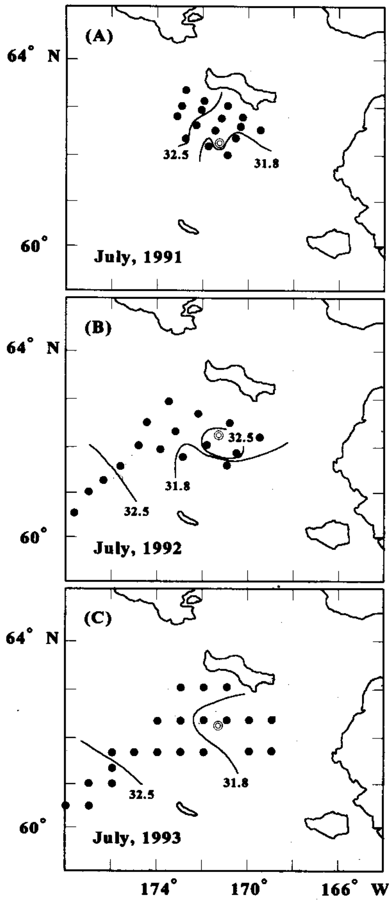

Fig. 4. Spatial distributions of salinity near the bottom on the northern Bering shelf in July of 1991 (A), 1992 (B) and 1993 (C). Stations OS91136, OS92113, OS93111 and OS93123, indicated by diploid circles are located at the same position (62°20N, 171°20W).

with Bering Shelf Water. In 1992 and 1993, this water mass occurred in the southwestern part of the survey area, although a separated body of this water mass was found near Station OS92113. In 1993, Alaska Coastal Water occurred south of St. Lawrence Island. Stations OS93111, OS93123, and OS93120 were covered by this water mass.

Relationships between salinity and concentrations nitrate and silicate in the summer of 1993 are shown in Fig. 5. Surface nitrate concentrations were under the detectable limit for the three sampling periods. Nitrate was detected below the thermocline and concentrations increased with depth, as did silicate concentrations. The Anadyr Water and Bering Shelf Water contained more nutrients than the Alaska Coastal Water.

Vertical distributions of chlorophyll *a* at Stations OS91136, OS92113, OS93111 and OS93123 are shown in Fig. 6. In 1991 and 1992 (Stations OS91136 and OS92113, respectively), although the surface concentrations of chlorophyll *a* were

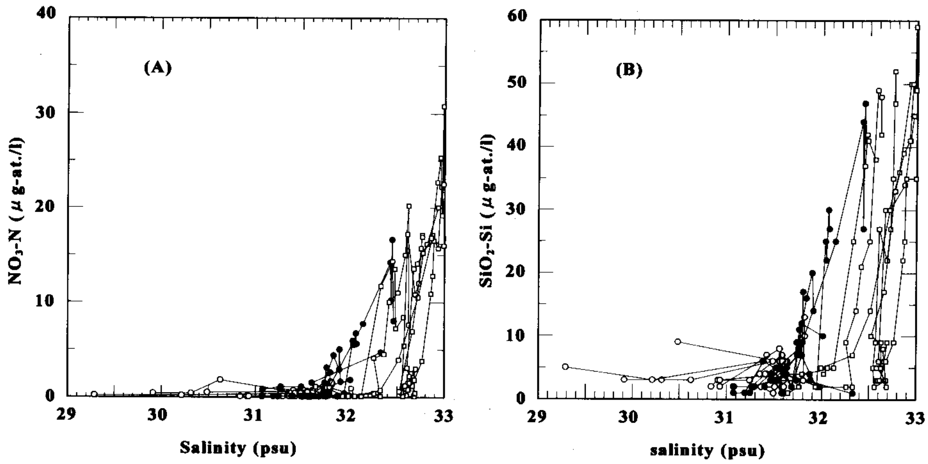

Fig. 5. Relationship between salinity and nitrate (A) and silicate (B) on the northern Bering shelf in July of 1993. Open square, closed circle and open circle represent Anadyr Water (salinity higher than 32.5), Bering Shelf Water (salinity between 31.8–32.5), and Alaska Coastal Water (salinity less than 31.8), respectively (Walsh et al., 1989).

less than 0.2 $\mu g\ l^{-1}$, the concentrations increased below 20 m depth and reached a maximum in the bottom layer (about 3 $\mu g\ l^{-1}$). In 1993 (Stations OS93111 and OS93123), the concentrations of chlorophyll *a* was consistently less than 1.0 $\mu g\ l^{-1}$ throughout the water column. The maximum concentration of chlorophyll *a* was not observed at this position. At the same station the vertical distributions of chlorophyll *a* were different between first two years and the third year. In 1993, a similar vertical profile of chlorophyll *a* at Station OS93116 was observed all 3 years where the bottom layer was occupied with Bering Shelf Water (Fig. 7). At this station, the maximum concentration in the bottom layer (=about 4 $\mu g\ l^{-1}$) was higher than that observed at Stations OS91136 and OS92113, where Bering Shelf Water and Anadyr Water prevailed in the bottom layer, respectively.

Discussion

In the area south of St. Lawrence Island, water masses near the bottom were classified into three types according to Walsh et al. (1989) ; Anadyr Water, Bering Shelf Water, and Alaska Coastal Water. The horizontal distribution of these water masses in summer showed various patterns during each year surveyed. Previous studies also showed that the horizontal distributions of salinity obtained in different years in the same area were not the same (Grebmeier and Cooper, 1995 ; Miyake et al., 1994 ; Walsh et al., 1989). This indicates that the water mass structure is considerably complex south of St. Lawrence Island.

The vertical distribution of chlorophyll *a* was characterized by the occurrence of a maximum concentration in the bottom layer. The occurrence of the bottom maxima seems to be related with the distributed water masses. At the same position (Stations OS91136, OS92113, OS93111 and OS93123 ; 62°20N, 171°20W), the vertical

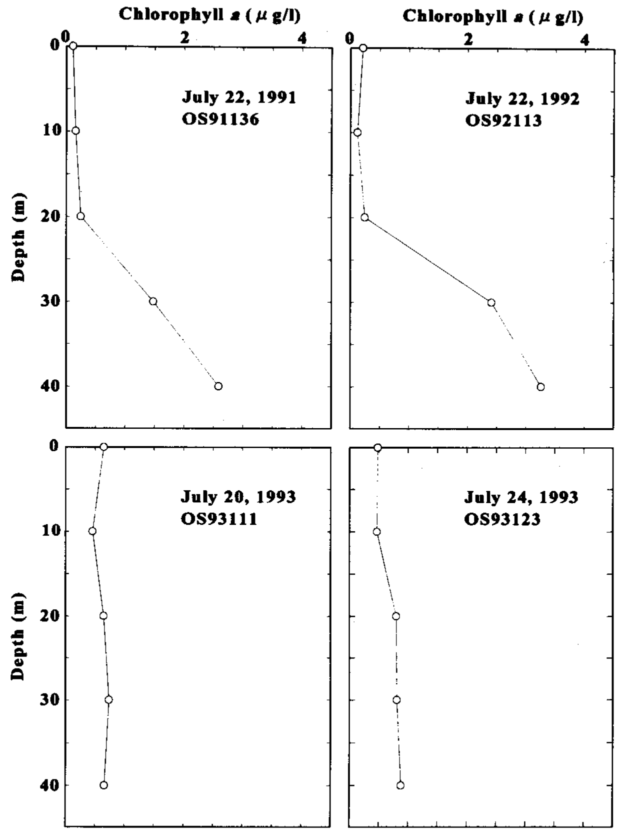

Fig. 6. Vertical distributions of chlorophyll *a* at Stations indicated by diploid circles (62°20N, 171°20W) on the northern Bering shelf in July of 1991 (Station OS91136), 1992 (Station OS92113) and 1993 (Stations OS93111 and OS93123).

distributions of chlorophyll *a* showed different properties from year to year. Bering Shelf Water, Anadyr Water, and Alaska Coastal Water occurred near the bottom in 1991, 1992, and 1993, respectively. Concentrations of chlorophyll *a* were high in Anadyr Water and Bering Shelf Water, but low in Alaska Coastal Water. Similar vertical and horizontal distribution patterns of chlorophyll *a* have been reported (Grebmeier and Cooper, 1995). The maximum concentrations of chlorophyll *a* (about 3 $\mu g\ l^{-1}$) measured in this study were lower than the previously reported values (about 10 $\mu g\ l^{-1}$) (Grebmeier and Cooper, 1995). Because the present study were conducted in June and July, it is considered that phytoplankton cells were removed by sinking down to the floor, they were grazed by zooplankton during one month or the bottom water masses were displaced.

The present results show that Anadyr Water and Bering Shelf Water were more saline and nutrient rich than Alaska Coastal Water. These observations are consistent with the previous studies that showed that nutrient concentrations in Anadyr Water in the northwest Bering Sea are higher than in Alaska Coastal Water in eastern areas (Grebmeier and Cooper, 1995; Springer et al., 1989, 1993; Walsh et al.,

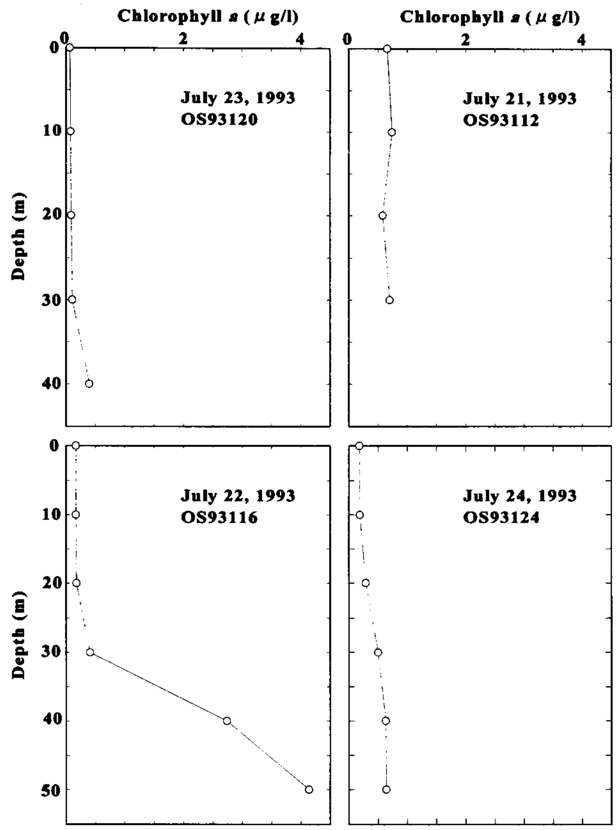

Fig. 7. Vertical distributions of chlorophyll *a* at Stations OS93120 (63°00N, 171°00W), OS93112 (62°20N, 169°00W), OS93116 (62°20N, 173°00W) and OS93124 (61°40N, 172°00W) on the northern Bering shelf in July of 1993.

1989). Nutrient levels in the three water masses are one factor that determine the maximum abundance of phytoplankton. Therefore the areas dominated by Anadyr Water and Bering Shelf Water are regarded as those having potentially a high primary productivity.

Cold dense water produced in the polynya south of St. Lawrence Island during winter remains near the bottom on the shelf of the northeast Bering Sea during the summer (Azumaya and Ohtani, 1995; Ohtani, 1969). The summer distribution of the bottom cold water depends upon the inter-annual variations of meteorological conditions in the previous winter season (Azumaya and Ohtani, 1995; Ohtani, 1969). The complex spatial distribution of water masses may result from the magnitude of the volume of the cold water produced in the polynya. Consequently, we conclude that the vertical distribution and abundance of phytoplankton in the sea area south of St. Lawrence Island is strongly affected by the weather conditions during the previous winter.

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