A－5．2 Evaluation of Effects of Increased Ultraviolet Radiation on Marine Phytoplankton Community

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Abstract Computer controlled incubator with ultraviolet radiation and visible light was constructed for a laboratory experiment. Incubation experiments under UV-B radiation were conducted with green algae *Tetraselmis* sp. at 32°C, 23°C, and 13°C which corresponded to the maximum, medium, and minimum growth temperature of this species. Loss of chlorophyll a due to UV-B radiation was the largest at 13°C. While *Tetraselmis* sp. lost chlorophyll a and b under UV-B radiation, the cells might reduce the UV-B effect by producing carotenoid pigments in their cells. Incubation experiments under the natural solar radiation were conducted with the natural assemblages of phytoplankton in the eutrophic Akkeshi Bay. Enhancement in the photosynthetic activity and biochemical synthesis was observed in the absence of UV-B. Recovery of the enhancement was not always observed in the photosynthetic activity but in the biochemical properties within 24 hr period.

Spectral distribution was determined with underwater UV spectrometer and visible light spectrometer in open and coastal water. Estimation of extinction coefficient of downwelling UV was established from the extinction coefficient of blue light. The extinction coefficient of UV was related with decrease of UV wavelength and increase of chlorophyll a concentration. One percentage of the surface UV-B at 305 nm and 320 nm was found at 12.2 m and 16.0 m in the open water while at only 1 m in the coastal water. The UV-B effective layer occupied 23-30% in the open water and 16-19% of the euphotic layer in the coastal water. This might suggest that the natural assemblages of phytoplankton in the open water seemed to be more receptive than one in the coastal water.

Comparison of the species composition of natural assemblages of phytoplankton in the coastal water with one previously published might suggest little change for a period of 20 years. This comparison might suggest that phytoplankton cells may go through a damage-recovery phase by a combination of vertical mixing of water and day-night cycle.

Key Words: UV-B, Phytoplankton, Chlorophyll a, *Tetraselmis* sp., Extinction Coefficient

1. Introduction

UV-B has a destructive effect on biological activity. Most half a century ago, it was shown to also penetrate into seawater by Jerlov[1]. However relatively slow progress in the development of an underwater ultraviolet spectrometer limited the opportunity to make refined measurements of ultraviolet radiation penetration into the sea. The inhibitory effect of UV-B radiation on primary production by natural phytoplankton assemblages has been studied extensively in the Southern Ocean in relation to the possible increase of UV-B radiation due to the occurrence of major springtime reductions in atmospheric UV-B absorbing ozone in the polar vortex. A similar effect has been also reported in the Northern Hemisphere[2), 3), 4), 5)]. However these studies were limited to the west coast of North America. Since the regional variation in the thickness of ozone is also expected over the Northern Hemisphere[6)], the present knowledge of the inhibitory effect of UV-B radiation on the natural assemblages of phytoplankton should be accumulated in other areas also in order to predict future events prior to the major increase of UV-B radiation. Information on this aspect therefore has been scarce. Recently an underwater ultraviolet spectroradiometer became commercially available.

In this study the penetration of ultraviolet radiation was determined with a commercially available model at two sites with optically different water masses namely Oyashio (oceanic water) and Akkeshi Bay (coastal water) in the western subarctic Pacific. Incubation experiments with the natural assemblages of phytoplankton were conducted for 24 hours in the coastal water. Species composition of the natural assemblages of phytoplankton was determined. Laboratory experiments with green algae *Tetraselmis* sp. were conducted for a long term.

2. Research Objectives

(1) To determine the variability of UV–B effects on photosynthesis of surface phytoplankton in Akkeshi Bay, Hokkaido, located at 43°N.
(2) To characterize the water type by a spectral distribution of UV–B and visible light.
(3) To study the temperature effect on damaged cells caused by UV–B radiation and recovered cells without UV–B radiation.
(4) To make a model of UV–B effect on the surface phytoplankton in the ocean.

3. Research Method

(1) Optical Instruments

Underwater ultraviolet spectroradiometer was employed to determine the downwelling radiation at wavelengths of 305, 320, 340, and 380 nm. The former two and latter two corresponded to UV–B and UV–A, respectively. Underwater visible light spectroradiometer was employed to determine the downwelling radiation at wavelengths of 410, 441, 465, 488, 520, 560, 589, 625, 656, 683, and 894 nm. Underwater Photosynthetically Active Radiation (PAR) meter was employed to determine the PAR.

(2) Field Measurements

Five stations in the oceanic water and two stations in the coastal water were occupied to conduct the field measurements. The field measurements included optical determination in air and water, water temperature and salinity measurement, nutrient analysis, pigment analysis, and particulate organic carbon and nitrogen analysis.

(3) Field Experiments

Photosynthetic activity was studied using quartz and pyrex bottles at the station in the coastal water in March and October. Those periods corresponded to spring and fall bloom[7]). Incubation was started with inoculation of stable isotope of $Na_2{}^{13}CO_3$ at the sunrise. Subsamples were taken at the sunrise, local noon, sun set, midnight, and sunrise.

(4) Laboratory Experiments

Green algae *Tetraselmis* sp. was grown in quartz and pyrex bottles under PAR with ultraviolet radiation (UV–B) for 35 days and without UV–B for 21 days. F/2 medium was used for the experiment[8]). Incubation temperature was chosen 32, 23, and 13°C, which corresponded to the near maximum, the medium, and the near minimum temperature for active growth. The incubation culture was diluted every day by 25% of volume in the morning.

4. Results

(1) Field Measurements

UV–B at 305 nm was decreased most sharply at all stations. The extinction coefficient of UV–B at 305 nm was 0.38 m^{-1} in the oceanic water and 4.2 m^{-1} in the coastal water, respectively. The minimum extinction coefficient (0.063 m^{-1}) was observed at 488 nm in the oceanic waters. The minimum extinction coefficient (0.45 m^{-1}) was observed at 560 nm in the coastal water.

(2) Field Experiments

Field incubation experiments were conducted in the coastal water. Water temperature was almost 0°C in March and 14°C in October. PAR was 32 E m^{-2} d^{-1} on March and 18 E m^{-2} d^{-1} in October. The concentration of chlorophyll a was higher than 4 mgCHLa m^{-3} in all experiments.

Despite of different environmental conditions, photosynthetic activity of the natural assemblages of phytoplankton increased in both quartz and pyrex bottles with time during day time and stayed at the maximum or decreased a little during night time. Concentrations of chlorophyll a, organic carbon and nitrogen did not usually change during the incubation.

(3) Laboratory Experiments

Cell numbers of *Tetraselmis* sp. were same in the quartz and pyrex bottles without UV-B radiation. Once the cells were exposed to UV-B, they stopped dividing. Chlorophyll a concentrations showed the similar change to the cell numbers. The chlorophyll a concentrations increased with cell numbers in the pyrex bottle. The exposed cells in the quartz bottle showed the similar relation after UV-B exposure was terminated. The slope of these relationships indicated chlorophyll a contents. The slope was different in the conditions with and without UV-B radiation. Pigment analysis indicated that cells responded by producing carotenoids to UV-B exposure even though they lost chlorophyll a and b.

5. Discussion

In situ determination of ultraviolet radiation in the sea has been limited to small numbers due to less availability of underwater ultraviolet spectroradiometer. Blue light has been frequently determined at the various waters since it has been easy. When a reliable relationship between the extinction coefficient of blue light and one of ultraviolet radiation is established, the extinction coefficient of ultraviolet radiation can be estimated. All four wavelengths of ultraviolet radiation determined in the present study seem to have strong correlation with the extinction coefficient of downwelling radiation at 465 nm. These relations would be very useful to estimate the extinction coefficient of ultraviolet radiation when it was not determined at sea.

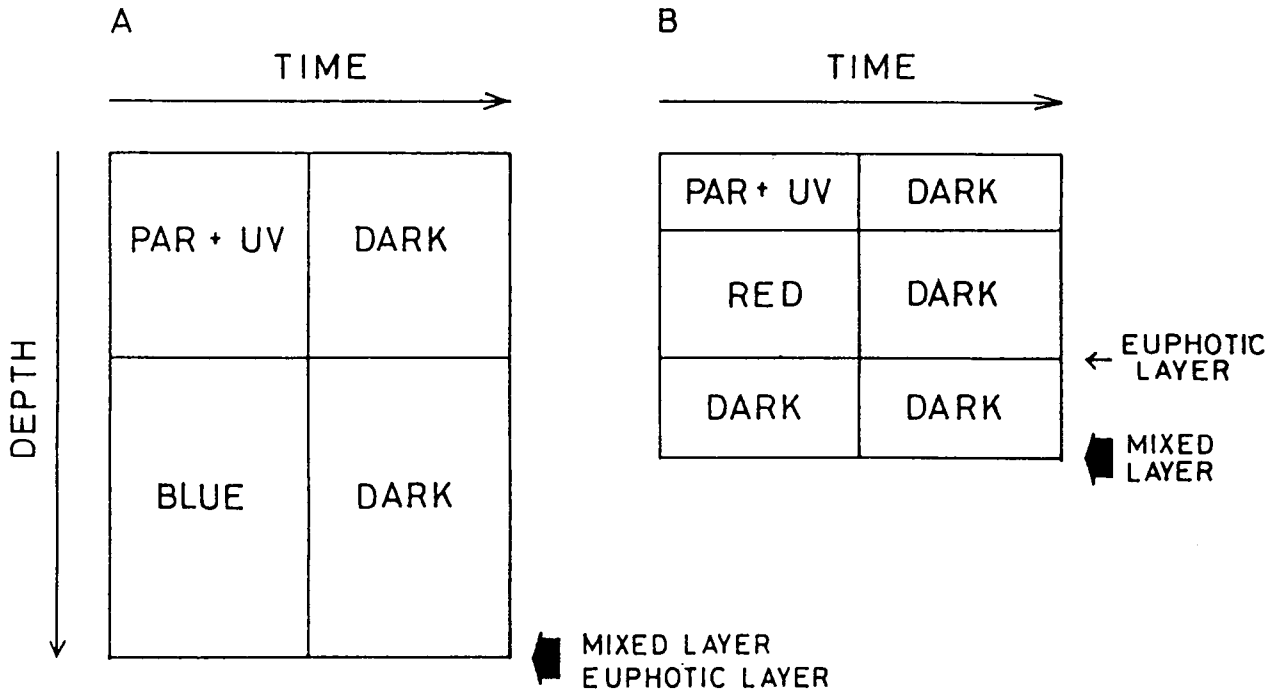

Figure 1. Schematic diagram of bio-optical structure of surface layer of the ocean and a position of the surface mixed layer. Oceanic water (A) and coastal water (B).

When a depth of 1% of the surface UV-B radiation is defined as UV effective depth, the UV effective depth is the important for biological processes in relation to the euphotic layer. Penetration of ultraviolet radiation is highly related with the concentrations of chlorophyll a. UV-B at 305 nm and 320 nm can penetrate to 12.2 m and 16.0 m in the oceanic station with a low concentration of chlorophyll a. They can penetrate only to 1.1 m and 1.2 m in the coastal water with a high concentration of chlorophyll a. The proportion of UV-B effective layer in the euphotic layer was 23-30% in the oceanic water and 16-19% in the coastal water. This suggests that the natural assemblages of phytoplankton in the oceanic water can be more receptive to UV-B effect than those in the coastal water as shown in Figure 1.

Both the field and laboratory experiments showed that the damaged cells by UV-B radiation could recover to a normal cells when UV-B radiation was removed. In order to evaluate the role of no UV-B radiation, the enhancement index (EI) is defined as EI = SR/ER, where SR and ER are ratios of biochemical properties, e.g., CHLa:Carbon and Nitrogen:Carbon ratios, or carbon assimilation rate (mgC $[mgCHLa]^{-1}h^{-1}$) of cells shielded from and exposed to UV-B radiation, respectively. An increasing EI indicates damage and a decreasing EI indicates recovery. Incomplete recovery in the photosynthetic activity by natural assemblages of phytoplankton within 12 h dark period was observed in the coastal water, although biochemical properties of phytoplankton cells were usually restored by the end of 12 h dark period. If one cycle of the water circulation is less than the light period of a day, phytoplankton cells may not be able to recover completely from the damage caused by UV-B radiation in the UV effective layer. When the damage is caused, the community structure of phytoplankton species may be changed. However the comparison of species composition of phytoplankton examined in the present study with one obtained in 1970[7] indicates little change. These observations may suggest that the natural assemblages of phytoplankton can recover from the damage by repair processes which may take place at night, or via the vertical mixing even they are periodically severely damaged by UV-B radiation. Thus vertical mixing of phytoplankton cells is important not only for phytoplankton photosynthesis but also for phytoplankton damage-recovery processes following exposure to UV-B radiation.

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