A-5.3.2 Effects of Enhanced UVB Radiation on Primary Production in the Ocean

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Abstract

Underwater penetration of ultraviolet radiation (UVB and UVA) was determined in relation to photosynthetically available radiation (PAR) at St. M in Sagami Bay during the period from June 1995 to December 1998. Relative penetration of UVR to the euphotic layer indicated a strong seasonality with high in winter and low penetration in summer. This seasonality was related with spring increase of chlorophyll *a* concentration, which was followed by summer increase of dissolved organic matter. Consequently UVB/(UVA+PAR) ratio indicated maximum in summer and minimum in winter. Inhibition rate of primary production was high from May to August, reaching to 41%, and low from January to April. When smaller cells than 10μm were dominant and UVB increased in summer, the inhibition rate of primary production increased significantly.

UVB exposure experiments indicated the most vulnerable effect on diatoms, medium effect on prasinophyceae, and least effect on green algae. This result strongly suggests species difference in their tolerance to UVB.

Key words Penetration, UVB/(UVA+PAR) ratio, Cell size, Inhibition rate, Primary production

I. Penetration of Ultraviolet Radiation into the Ocean

Solar ultraviolet radiation varies with time not only within a day but also with season. Once it penetrates into the ocean, its variability in spectral composition and intensity is greatly modified by dissolved organic matter and suspended particulate matter[1]. In the present study daily and seasonal variability in UVR is determined to establish empirical equations to model those variabilities.

I-1. Daily variability in ultraviolet radiation and photosynthetically available radiation

1. Introduction

Kirk[2] proposed the following equation (1) to predict the daily variation of PAR,

$$E_d(t) = E_d^{max} \times \sin(\pi t/N) \quad (1)$$

where E_d(t) was downwelling radiation, E_d^{max} was maximum downwelling radiation at local noon, t was day light hours from sunrise to sunset, and N was 24 hours. Ikushima[3] proposed n=2 for fine weather. Since the value of n determined a slope of sin curve, daily radiation depends on the value of n.

2. Research Objectives

Firstly, the value of n is determined for PAR under a fine weather. Secondly, the value of n is estimated for 305, 320, 340, and 380 nm under the same weather condition.

3. Research Methods

Measurements of UVR and PAR were conducted at Manazuru Harbor during the period from June 1995 to August 1996. Biospherical Instruments air and underwater radiometers Model PUV500/510 were employed to determine UVR at 305, 320, 340, and 380 nm, and PAR from 400 to 700 nm. The air sensor was located at the top of the ship to avoid any shade while the underwater sensor was located at 50 cm depth. Fine weather was observed on September 21, December 8, 1995, March 28, April 28, May 25, and August 11, 1996 out of a total of 15 measurements. All data obtained from those 6 observations were employed to the equation (1). Underwater values measured at 50 cm depth were extrapolated to the surface by the following equation (2), and fitted to the equation (1),

$$E_d(-0) = E_d(z)/\exp(k_\lambda z) \qquad (2)$$

where E_d(z) was the radiation at depth z and k_λ was the extinction coefficient of wavelength λ.

Daily radiation (Q_s) was obtained by integrating E_d at time t from sunrise to sunset by the following equation,

$$Q_s = \int_0^N E_d(t)\, dt \qquad (3).$$

4. Results

Average values of n estimated from the equation 1 with the six observations in air were similar among PAR, 380 and 340 nm in air and 1.75±0.017. However the values of n were averaged 2.12±0.20 at 320 nm and 4.09±0.43 at 305 nm. respectively. The underwater values of n did not show much variation among PAR, 380, 340, and 320 nm, and averaged 1.93±0.13 while the value of n was 4.00±0.98 at 305 nm and higher than the values at other wavelengths. But this high value was not much different from one at 305 nm in air.

5. Discussion

Ikushima[3] proposed n = 3 for fine weather and n = 2 for overcast weather. Those values were different from those in the present study. It was probably caused by the difference among instruments and wavelengths. Daily radiations fro PAR, 305, 320, 340, and 380 nm were calculated and compared with the observed values ($_{Raw}Q_s$) by the following equation (4),

$$({}_{Raw}Q_s - {}_{Est}Q_s) / {}_{Raw}Q_s \quad (4)$$

where ${}_{Est}Q_s$ was the estimated value by the equation (3). Since maximum value was -0.04, daily radiation in air or underwater can be estimated within 4% in precision.

I-2. Seasonal variability in ultraviolet radiation and photosynthetically available radiation

1. Introduction

Light penetrated into the ocean is modified by dissolved organic matter and suspended particulate matter regardless wavelength. Although much study has been conducted for the seasonal variability in PAR penetration, UVR penetration into the ocean has been only determined with limited seasons at various locations[4), 5), 6), 7)]. Little study has been made for the seasonal variability in UVR penetration at one location.

2. Research Objectives

Seasonal variability in UVR and PAR was aimed to study monthly at St. M off Manazuru in Sagami Bay (35°9'49"N, 139°10'33"E) during the period from July 1995 to March 1998.

3. Research Methods

A total of 42 monthly cruises on R/V "Tachibana", Marine biological Station, Yokohama National University were conducted at St. M. R/V "Tansei Maru", Ocean Research Institute, University of Tokyo was employed for the observation in June 1996. A field observation was usually made within 2 hours prior to local noon. Biospherical Insturments air and underwater radiometers Model PUV500/510 were employed to determine the downwelling radiation at 305, 320, 340, and 380 nm, and PAR. A special caution was paid to avoid any shadow from the ship during the profiling with a speed of.1 m s^{-1}. Extinction coefficient of downwelling radiation (k_d) was estimated by the following equation (5),

$$E_d(z) = E_d(-0)\, e^{-kd\, z} \quad (5).$$

Whenever necessary, multiple lines were fitted to log-transformed data against depth.

4. Results

The extinction coefficient for PAR was always lower than one for UVR. Minimum value was 0.05 m^{-1} in winter and maximum value was 0.26 m^{-1}. The extinction coefficient for UVR indicated low in winter and high estimates in summer. The extinction coefficients for 305 and 320 nm exceeded 1.0 m^{-1} in summer while they were smaller than 0.3 m^{-1} in winter.

5. Discussion

Phytoplankton can photosynthesize in the euphotic layer which is defined as the depth of 1% of surface radiation. It is critical to understand how deep UVR can penetrate

within the euphotic layer for study of UVR effect on photosynthesis by photoplankton[8]. The present study indicated a distinct seasonality with high in winter and low relative penetration of UVR to the euphotic layer in summer and confirmed the same annual cycle every year from 1996 to 1998 (Fig. 1). This annual cycle was suggested to be controlled by the spring increase of phytoplankton chlorophyll pigments and the summer increase of dissolved organic matter. Since shallow thermocline was formed in summer when solar UVR increased, phytoplankton increased in the surface mixed layer might receive ample UVR and be suffered.

II. Effect of UVR on Primary Production by Natural Assemblages of Phytoplankton

1. Introduction

Most UVR research concentrates their effort to the effect on photosynthesis or primary production[4]. However most study has been carried out for a limited time at various waters without consideration of seasonality.

2. Research Objectives

Firstly, seasonal variability in optical environment including UVR, physical structure of water mass, nutrient supply, community structure and biomass of phytoplankton is aimed to study in relation to the inhibition rate of primary production. Secondly, the UVR effect on annual primary production is studied.

3. Research Methods

In situ experiments were conducted at Manazuru Harbor on the surface water collected at St. M during the period from September 1996 to September 1998. Surface water was collected and prescreened through a plankton net cloth with 183 μm mesh to remove large zooplankton and debris. The prescreened water was distributed into the first plain quartz bottle, the second quartz bottle with lumilar film, and the third dark bottle. Incubation was initiated with addition of $Na_2H^{13}CO_3$ and lasted for 24 hrs. Subsamples at the beginning of incubation were filtered onto glass fiber filter type GF/F for analysis of chlorophyll pigments, particulate organic carbon and nitrogen. Subsamples were filtered through Millipore membrane filter with 10, 2, and 0.2 μm pore size for the size fractionation of chlorophyll pigments. Filtrate was frozen for analysis of nutrients at -20°C. At the end of incubation subsamples were taken as those at the beginning of incubation. Another subsamples were filtered on glass fiber filter type GF/F for analysis of ^{13}C.

Chlorophyll pigments were extracted in N, N-Dimethylformamide (DMF) for 24 hrs[9]. Chlorophyll *a* and pheopigments were determined on Turner Design fluorometer Model 10-AU[10]. Filter samples for particulate organic carbon and nitrogen were dried at 60°C and wrapped into tin foil, and analyzed on Fisons CNS elemental analyzer. Filter samples for ^{13}C were also dried at 60°C and wrapped into tin foil, and analyzed on Finnigan Mat mass spectrometer. Daily assimilation of ^{13}C was calculated by the method of Hama et al.[11].

Inhibition rate of primary production was estimated by the following equation (6),

$$\text{Inhibition rate (\%)} = (P_{-UVB} - P_{+UVB}) / P_{-UVB} \times 100 \quad (6)$$

where P_{-UVB} was primary production without UVB and P_{+UVB} was primary production with UVB.

4. Results

Water temperature showed the minimum of 16°C during the period from January to March and the maximum of 27°C in August. Salinity decreased to less than 31 PSU during rainy season but showed higher than 34 PSU during the rest of the season. Nitrate was high from winter to spring, reaching to 10μM, and decreased to less than 1μM from summer to fall. Phosphate did not much variation and stayed at less than 2μM.

Chlorophyll *a* concentration reached 100 mgChl*a* m^{-3} in May or June but stayed at 1-5 mgChl*a* m^{-3} for the rest of year. Contribution of size fraction to total phytoplankton ranged from 1.4 to 51.1% for 0.2-2.0μm, 1.5-57.3% for 2.0-10μm, and 12.9-97.2% for >10μm. Their average contributions were 23.7±14% for 0.2-2.0μm, 26.8±15.0% for 2.0-10μm, and 49.5±24% for >10μm fraction.

Daily primary production reached the maximum of 200 mgC m^{-3} in March or April. Chlorophyll *a* specific photosynthetic activity showed the maximum of 2.3 mgC $[\text{mgChl}a]^{-1}$ h^{-1}.

Inhibition rate of primary production due to UVR showed the maximum of 41% in September 1996 (Fig. 2). Inhibition rate was high from may to December while low from January to April. High inhibition rate corresponded to the period from the minimum of UVB/(UVA + PAR) ratio in January to 0.005. Low inhibition rate corresponded to the period from 0.005 to the maximum in July or August to low value in December.

5. Discussion

When smaller cells than 10μm were dominant in the natural assemblage of phytoplankton, inhibition rate increased due to UVB. When UVB increased, inhibition rate was accelerated (Fig. 3). Inhibition rate of annual primary production due to UVB was 8.5% during the period from September 1995 to August 1997 and 6.7% during the period from October 1997 to September 1998.

III. Effect of UVB on the Growth of Phytoplankton

1. Introduction

Effect of UVR on the growth of phytoplankton has been studied under a controlled condition in a laboratory[12]. However a number of those study is limited and experimental species are also limited.

2. Research Objectives

Comparison between cells exposed to UVB and cells shielded to UVB is made to estimate the effect of UVB when cells are grown in a batch culture for one week.

3. Research Methods

Green algae *Dunaliella salina* were grown in the filtered seawater enriched by f/2 medium[13]. Plain quartz bottle, quartz bottle with lumiler film, and quartz bottle with

acetate film were prepared. All experimental bottles were rotated with a wheel in the incubator with white and ultraviolet light. Incubation temperature was 25°C and light cycle was 12h light and 12 h dark. Intensity of UVR was controlled by a number of garden screen. UVR was measured on Biospherical Instruments spectrometer Model PUV-500 and PAR was measured on Biosherical Instruments spectrometer Model GMR-610, which had 7 wavelengths such as 412, 443, 490, 555, 665, 683, and 710 nm.

Cells were grown for one week to complete one growth phase. Samples were taken from three experimental bottles every day. Subsamples were withdrawn for the analysis of cell density, chlorophyll pigments, particulate organic carbon and nitrogen, and absorption coefficient. Growth rate was determined from the concentration of chlorophyll *a* during a logarithmic growth period. Cell density was estimated on hematocytometer. Optical density of cells in suspension was determined with 10 cm cell on Beckman spectrophotometer Model DU-640. Absorption coefficient ($a^*_{ph}[\lambda]$) was estimated by the following equation,

$$a^*_{ph}(\lambda) = 2.303\,[OD_p(\lambda) - OD_p(750)]\,X^{-1}\,[Chla]^{-1} \qquad (7)$$

where $OD_p(\lambda)$ was the optical density at wavelength λ, $OD_p(750)$ was optical density at 750 nm, X was the length of cell, and Chl*a* was concentration of chlorophyll *a*.

4. Results

Little difference in carbon:nitrogen ratio was observed between three light conditions Average carbon:nitrogen ratio was 6.6±1.3 for plain quartz bottle, 7.2±0.86 for quartz bottle with lumilar film, and 7.3±1.2 for quartz bottle with acetate film. Average carbon:chlorophyll *a* ratio was 35±13 mgC[mgChl*a*]$^{-1}$ for lumilar film and 35±14 mgC [mgChl*a*]$^{-1}$ for acetate film, respectively. Carbon:chlorophyll *a* ratio for plain quartz bottle was similar to other light treatments below 0.02 of UVB/(UVA+PAR), but the carbon:chlorophyll *a* ratio increased at higher values than 0.034 of UVB/(UVA+PAR). Carbon:chlorophyll *a* ratio was 126 mgC [mgChl*a*]$^{-1}$ at 0.097 and 11,000 mgC [mgChl*a*]$^{-1}$ at 0.46. Chlorophyll *a* specific absorption coefficient was similar among three light treatments under 0.02 of UVB/(UVA+PAR), and 0.058±0.00097 m^2 [mgChl*a*]$^{-1}$. This value for plain quartz bottle increased above 0.034 of UVB/(UVA+PAR) and was about 1,000 times higher than quartz bottle with acetate film. No difference was observed between quartz bottle with lumilar and acetate films below 0.97 of UVB/(UVA+PAR). The value for quartz bottle with lumilar film increased above 0.46 of UVB/(UVA+PAR) and was almost 100 times higher than one for quartz bottle with acetate film.

Little difference in the growth rate was observed below 0.02 of UVB/(UVA+PAR) and average was 0.86±0.02 d^{-1}. The similar values were observed for the quartz bottle with acetate film when UVB/(UVA+PAR) reached 0.46. The growth rate for the quartz bottle with lumilar film started decreasing at 0.062 of UVB/(UVA+PAR). The growth rate for plain quartz bottle started decreasing at 0.034 and no growth was observed at 0.46 of UVB/(UVA+PAR).

5. Discussion

Relative growth rate was calculated to compare the growth rates obtained from the present study and plotted against UV/(UVA + PAR) (Fig. 4). Comparison reveled distinctly species difference among four species. UVB/(UVA + PAR) for 50% of growth rate was 0.02 for *Chaetoceros gracilis* and 0.008 for *Thalassiosira weissflogii*. This indicated some difference even within diatoms. It was 0.04 for *Isochrysis glabana* while the highest value was 0.09 for *Dunaliella salina*. The present results strongly suggested different response of growth rate to UVB/(UVA + PAR). *Dunaliella salina*, which is often found in tide pool, can be interpreted as a species which adapted to UVR during evolution.

6. References

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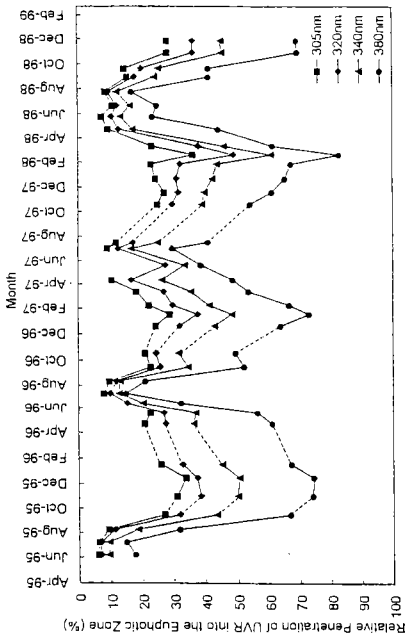

Fig. 1. Seasonal variation of the percent penetration of relative UVR within the euphotic layer at St. M from June 1995 to November 1998. Broken line indicates unavailable data.

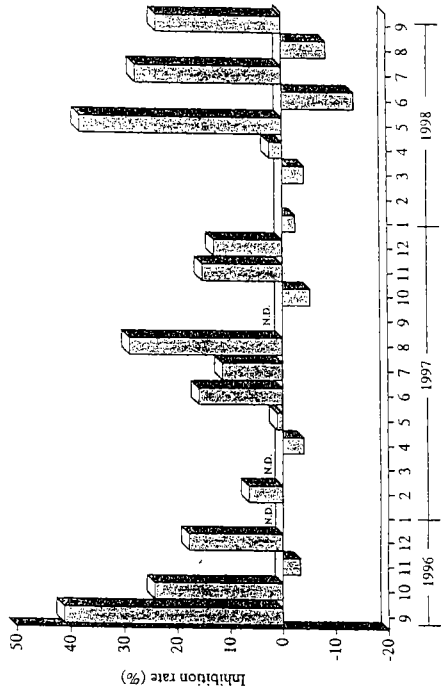

Fig. 2. Seasonal variation of inhibition rate at St. M from September 1996 to September 1998.

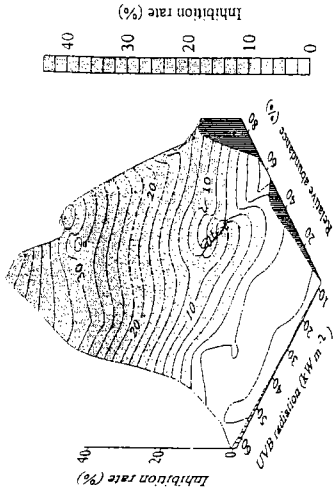

Fig. 3. Relationship among >10μm relative abundance, UVB radiation and inhibition rate.

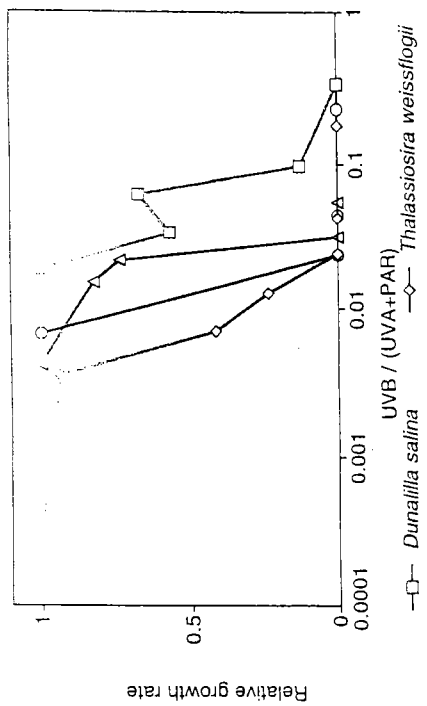

Fig.4. Relationship between the relative growth rate and UVB/(UVA+PAR) ratios.