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Effects of Solar UV Radiation on Diatom Assemblages of the Mediterranean

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ABSTRACT

Three UV treatments (PAR; PAR + UVA; PAR + UVA + UVB) were performed by placing different UV-absorbing filters over communities developing on ceramic tiles in a natural marine habitat near Korinthos, Greece. The experiment was repeated at three depths (0.5 m, 1 m, 1.5 m) below the surface of the sea. Differences in community structure due to UV radiation exposure were more pronounced during the early stages of community development. After the first 3 weeks of growth, the productivity of the PAR + UVA + UVB treatment was significantly lower than the PAR + UVA but not than the PAR treatment. This difference did not persist thereafter. At 5 weeks of growth, the productivity at 0.5 m was significantly lower that at 1.0 m. No other significant differences were observed. The findings of the present study suggest that periphytic communities occurring at the upper layers of the euphotic zone may be capable of adjusting to changes in environmental stresses such as by increased solar UVB irradiance.

INTRODUCTION

The rapid decline in stratospheric ozone concentrations has been confirmed by satellite measurements (1). Recent mathematical models predict a further increase in solar UVB irradiation in the following years (2). The total dose at the surface mainly depends on solar angle of incidence (determined by the latitude, season and time of day) and on atmospheric transparency (*e.g.* thickness of overlying ozone layer, aerosols, altitude, cloud cover, *etc.*).

Light attenuation in the water column has been the basis for categorizing oceanic waters (3). Ultraviolet-B penetration, measured as radiation at 310 nm, is reduced by only 14% per meter depth in the East Mediterranean (3), whereas for UVA (at 375 nm) the corresponding value is 5%. The band of the solar spectrum with the lowest attenuation rate is blue (3% per meter depth, measured at 465 nm) while up to 90% of red light is absorbed by the first meter of water. The same author classified these waters among the earth's clearest, rivalling the clarity of the Sargasso Sea (type I). Compared to the high absorption rates of UVB radiation encountered in other areas of the world (*e.g.* 90% per meter or more off the Swedish west coast), UV penetration in the East Mediterranean stands out as very effective. Due to the high transparency of these waters to UV, the active region, where photochemical processes can be carried on, extends as far as 20 m below surface.

The impact of solar UV radiation on aquatic ecosystems and their primary productivity has been the subject of intensive investigations in recent years (4–9). Because marine habitats exceed in size the terrestrial habitats almost by a factor of two, severe UV effects in the marine environment are expected to have a significant climatic impact of global scale (10,11). Marine phytoplankton populates the upper layers of the water column and thus may be affected by increased solar UV irradiation even in turbid coastal waters. Due to the great ecological importance of phytoplankton, UV effects on phytoplankton productivity have been the subject of several investigations (12–14), while other studies focus on changes in motility, photoorientation and velocity caused by UV (15–19).

In contrast to the plethora of phytoplankton studies, literature on the effects of UV radiation on periphyton, *i.e.* algae found attached to many types of substrates, is rather scarce (20,21). In the same respect, the Mediterranean Sea has been largely unexplored.

MATERIALS AND METHODS

The present study investigates the role of solar UV radiation during the process of ecological succession and establishment of marine diatom assemblages in the Mediterranean basin. The experiment was conducted at a distance of 50 m from an east-facing rocky shore of Saronikos Gulf, near Korinthos, Greece (37°58′N, 23°0′E). Each experimental unit consisted of eight 10 × 10 cm ceramic tiles placed on a polypropylene screen fixed onto a ¾″, 45 × 90 cm PVC frame. Using UV-transmitting Plexiglas and plastic foil filters, nine treatment combinations (three UV regimes × three depths) were established as shown in Table 1. The 18 units were suspended in pairs from nine 1 × 1 m rafts at the three depths indicated in Table 1. The rafts were constructed from 2.5″ PVC pipe filled with isofoam

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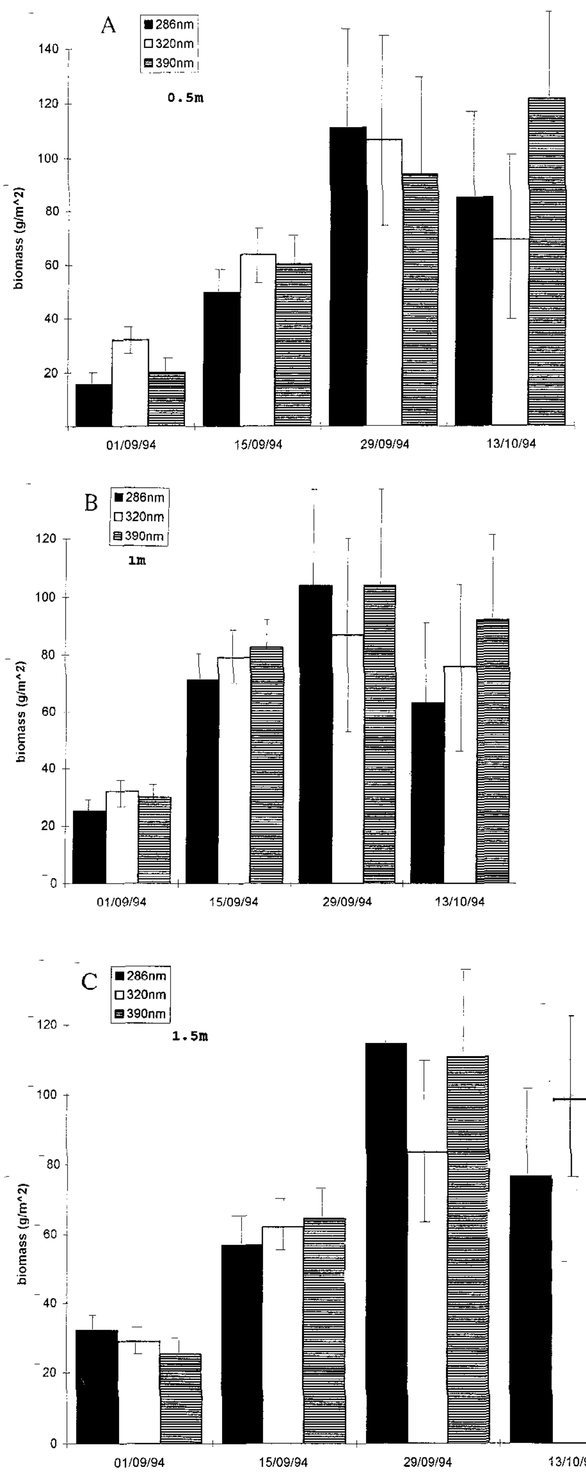

Figure 1. Mean biomass values of diatom assemblages (n = 2). A: assemblages at 0.5 m; B: 1.0 m; C: 1.0 m. Bars: Just significant confidence intervals ($P < 0.5$). A two-way ANOVA indicated that on 1/9/94, at 0.5 m, the PAR + UVA + UVB treatment had a significantly lower biomass than the PAR + UVA treatment. No other significant differences were observed thereafter.

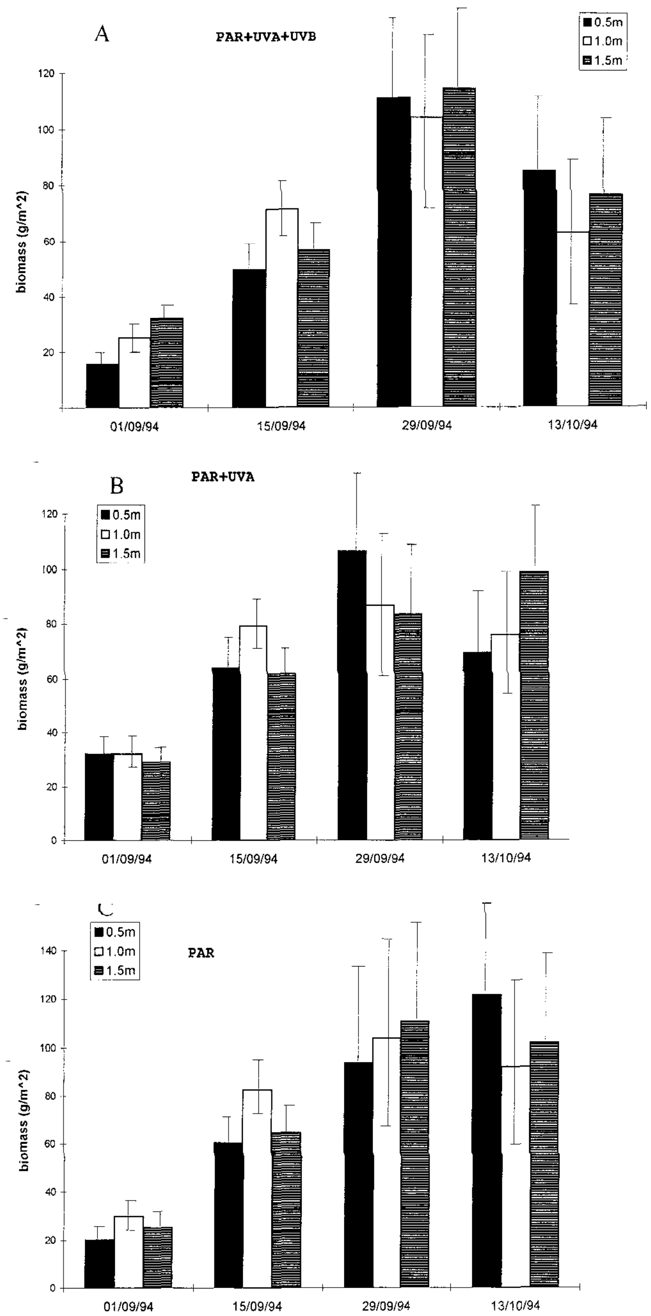

Figure 2. Mean biomass values of diatom assemblages (n = 2). A: Assemblages grown under PAR + UVA + UVB; B: PAR + UVA; C: PAR. Bars: Just significant confidence intervals ($P < 0.5$). On 15/9/94 under the PAR + UVA + UVB treatment, the assemblage grown at 0.5 m had a significantly lower biomass than that at 1.0 m. No other significant differences were observed.

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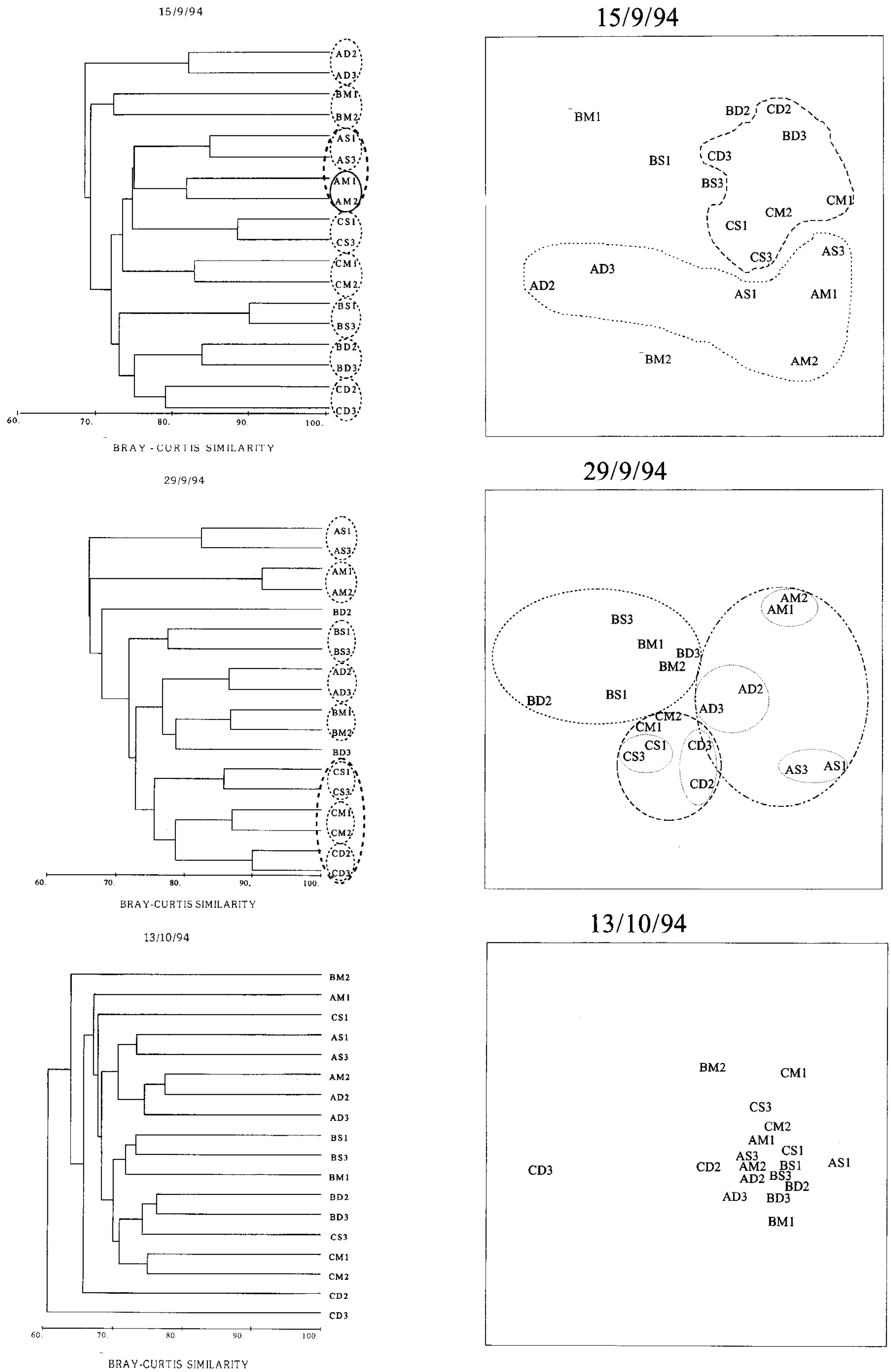
Figure 3. Clustering of diatom assemblages. Top: PAR + UVA (320 nm); middle: PAR (390 nm); bottom: PAR + UVA + UVB (286 nm); S: 0.5 m; M: 1.0 m; D: 1.5 m; 1, 2, 3: relative position of sample. On 15/9/94 (top) there is a remarkable similarity between the replicates of all treatments at all depths. On 29/9/94 there replicate similarity is high (middle), while on 13/10/94 no distinct pattern is observed.

Figure 4. Ordination of diatom assemblages. On 15/9/94 (top) there is a moderate association between the three UV treatments. On 29/9/94 (middle) the association becomes very clear, but disappears 2 weeks later (bottom).


15/9/94
AD2
AD3
BM1
BM2
AS1
AS3
AM1
AM2
CS1
CS3
CM1
CM2
BS1
BS3
BD2
BD3
CD2
CD3
60. 70. 80. 90. 100.
BRAY-CURTIS SIMILARITY
29/9/94
AS1
AS3
AM1
AM2
BD2
BS1
BS3
AD2
AD3
BM1
BM2
BD3
CS1
CS3
CM1
CM2
CD2
CD3
60. 70. 80. 90. 100.
BRAY-CURTIS SIMILARITY
13/10/94
BM2
AM1
CS1
AS1
AS3
AM2
AD2
AD3
BS1
BS3
BM1
BD2
BD3
CS3
CM1
CM2
CD2
CD3
60. 70. 80. 90. 100.
BRAY-CURTIS SIMILARITY
15/9/94
BM1
BD2
CD2
BD3
BS1
CD3
BS3
CM1
CM2
CS1
CS3
AS3
AD3
AD2
AS1
AM1
BM2
AM2
29/9/94
AM2
AM1
BS3
BM1
BD3
BM2
AD2
BD2
BS1
AD3
CM2
CM1
CS1
CD3
CS3
AS3
AS1
CD2
13/10/94
BM2
CM1
CS3
CM2
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AS1
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BS3
BD2
AD3
BD3
BM1

Table 1. Experimental design of the mesocosms (n = 2)

Depth	Cutoff filter 286 nm	320 nm	390 nm
0.5 m	PAR + UVA + UVB @ 0.5 m	PAR + UVA @ 0.5 m	PAR @ 0.5 m
1.0 m	PAR + UVA + UVB @ 1.0 m	PAR + UVA @ 1.0 m	PAR @ 1.0 m
1.5 m	PAR + UVA + UVB @ 1.5 m	PAR + UVA @ 1.5 m	PAR @ 1.5 m

for waterproofing and tied together in tiers of three. Each raft tier was anchored at one end only to allow free swinging of the apparatus with the current. In order to prevent alteration of the transmittance properties due to overgrowth, the filters were cleaned regularly every 2–3 days. Transmittance was periodically checked for replacement of defective filters.

Four sample sets of 18 tiles were collected by removing one tile from each experimental unit every 2 weeks for the period of September 1 through October 13, 1994. The collected algal biomass was strained free of salt water and dried to constant weight at 80°C. To analyze the structure of the diatom assemblage a part of the harvested biomass was processed for microscope observation using mild digestion of the cell contents with H_2SO_4. In order to determine irradiance in the water column the following measurements were made with a 752 Optronic double monochromator spectroradiometer using a newly developed sensor in 4π geometry (22): (a) spectral measurements of the scalar (spheric) irradiance between 290 and 800 nm and (b) measurements of the solar UVB, UVA and PAR irradiance. Surface irradiance measurements were obtained in August 1995 using three sharp band sensors (Grbel, Ettlingen) for PAR, UVA and UVB calibrated against a 752 Optronic spectroradiometer. The signals from the sensors were amplified, digitized and stored in a dedicated computer (Visual Basic program 'Windose' written by Michael Lebert, University of Erlangen).

RESULTS

Biomass

Correlation with UV treatment. On 1/9/94, 3 weeks after placing the mesocosms in the sea, productivity of the PAR + UVA + UVB treatment (Fig. 1A, black bars) at 0.5 m was significantly lower ($P < 0.05$) than the productivity of the PAR + UVA treatment (white bars). No statistically significant differences were found at 1.0 and 1.5 m throughout the experiment (Fig. 1B,C).

Correlation with depth. The productivity of the PAR + UVA + UVB treatment is lowest at 0.5 m on 1/9/94 and 15/9/94, that is after 3 and 5 weeks of growth (Fig. 2A). The difference was statistically significant only on 15/9/94 between 0.5 m and 1.0 m. After 7 weeks, this trend is no longer observed. No significant differences were observed between different depths within the PAR + UVA or the PAR treatment (Figs. 2B,C).

Community analysis

The large majority of photosynthetic organisms encountered were pennate diatoms. The occurrence of nonpennate forms was scarce and most likely due to occasional sedimentation of phytoplankton on the tiles.

Clustering and ordination. Figure 3 summarizes the results of nearest-neighbor clustering using the Bray–Curtis index of similarity, while Fig. 4 is the outcome of hierarchical ordination. After 5 weeks of growth (15/9), replicate assemblages show a high degree of similarity (Fig. 3, top), while adequate separation of the different UV treatments occurs (Fig. 4, top). On 29/9 grouping of the UV treatments is clear (Fig. 4, middle), with a high similarity between replicates (Fig. 3, middle). At the end of 9 weeks, there is no clear pattern in the grouping of depths within the same UV treatment or in the similarity between replicate assemblages (Figs. 3, bottom and 4, bottom).

Solar radiation at the sea surface and in the water column

Daily doses at sea surface ranged between 48 and 58 kJ/m^2 in the UVB, 1450–1700 kJ/m^2 in the UVA and 1000–1200 klx in the PAR. Due to cloudless sky the daily irradiances were symmetric with respect to local noon.

Based on measurements in the water column the investigated waters are classified as type "Oceanic III" in the Jerlov system. They show, in fact, a typically high transparency especially in the short wavelength band due to small concentrations of the yellow substance, seston and chlorophyll *a*. Vertical changes of the attenuation coefficient on the order of a factor of 2 were found, caused by inhomogeneous vertical distributions of absorbing and attenuating additions. Thus, the 0.1% depths of solar irradiance changed between 6 and 12 m at 300 nm and between 15 and 50 m at 400 nm. The maximal transmission of the water was observed at 420 nm with 0.1% depth of about 200 m.

DISCUSSION

Coastal ecosystems, support a wide variety of organisms and account for a major part of oceanic productivity (21), thus being of great ecological and economic importance (23,24). Solar UV radiation is a factor known to affect the growth and development of photosynthetic organisms. In the present study, the role of solar UV was investigated on periphytic diatom assemblages, an important photosynthetic component of coastal ecosystems. Productivity inhibition and shifts in species composition caused by UVB were observed during the early stages of community development. Similar observations were made in another study conducted in laboratory mesocosms and in a nearby tropical coral reef (20), where exposure to solar UVB resulted in 40% lower biomass production during the first month of community development, but this productivity inhibition did not persist thereafter.

The importance of marine ecosystems in regulating global gas cycles is widely recognized (25,26). A reduction in oceanic primary production will result in greater atmospheric CO_2 concentrations and thus enhance the greenhouse effect. However, the findings of the present study suggest that periphytic communities occurring at the upper layers of the euphotic zone may be capable of adjusting to changes in environmental stresses such as by increased solar UVB irradiance. This may be due to physiological adaptation at the organism level, or to structural shifts at the community level. Thus, a thorough understanding of the role of solar UVB as well as long-term field experiments are required before predicting the extent of its interaction with the greenhouse effect.

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