Solar UV Effects in Algal Assemblages of the Caribbean and the Mediterranean Seas

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ABSTRACT

Medium- and long-term effects of solar UV on primary succession have been investigated in laboratory microcosms, and in the natural marine environment (Caribbean, Mediterranean seas). Exposure to increased UV-B irradiance in the laboratory caused shifts in species dominance, communitiy composition, and decreased primary productivity. In the field, the productivity of assemblages protected from UV-B, was up to 40% higher than the productivity of assemblages exposed to UV-B (Caribbean). UV-B also caused shifts in community structure in the laboratory. While these UV-B effects are pronounced during early community development, they gradually diminish as succession progresses. Differences in community productivity and structure were not measurable 6-8 weeks after the establishment of the assemblages. Exposure to UV-A did not produce significant differences in productivity or community composition.

INTRODUCTION

Incident UV levels at the earth's surface have been increasing due to atmospheric ozone destruction by CFC's. Ultraviolet radiation represents about 7% of the total solar radiation striking the earth's atmosphere and an even smaller proportion of the radiation penetrating to sea surface levels (Caldwell 1979). Wavelengths shorter than 286nm do not reach the surface of the earth (Bener 1969). UV-B radiation (280-320nm) has adverse effects on biological systems (Häder 1993, Iwanzik *et al.* 1983, Murphy 1983, Elkind and Han 1978). UV-A is less damaging and in some cases beneficial to aquatic primary producers (Halldal 1964).

The effects of solar ultraviolet radiation on biomass production and community development were investigated in marine macrophyte assemblages in the laboratory and in diatom assemblages in the Caribbean and Mediterranean Seas. The waters of the two sites are among the Earth's clearest. UV-B penetration in the East Mediterranean, measured as radiation at 310nm, is reduced by 14% per meter depth (Jerlov 1950), while for UV-A

(at 375nm) the corresponding value is 5%. The band of the solar spectrum with the lowest attenuation rate is blue (3% per meter depth, measured at 465nm), 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). Considering that the absorption rate c UV-B radiation in other areas of the world can be as high as 90% per meter o: more (*e.g.* off the Swedish west coast), UV penetration in the Caribbean and 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 metres.

Physiological UV effects on marine phytoplankton have been the focus of a large number of studies. Due to the initial appearance of the ozone hole over the poles, particular attention has been given to arctic and subarctic organisms. However, the thinning of the ozone layer has expanded over lower geographic latitudes well into the temperate zones. In addition, adverse UV effects are being documented on most primary producers, including marine macrophytes. Despite these facts, literature on UV effects on periphytic organisms at the community level remains scarce. In one of these few studies, Worrest *et al.* (1978) studied the effects of enhanced simulated solar ultraviolet radiation (UV-A and UV-B) on a marine community, recruited in a flow-through apparatus under laboratory conditions. The authors concluded that increased UV exposure depressed chlorophyll α concentrations, reduced biomass, increased autotrophic indice and decreased community diversity. These results were confirmed in subsequent studies (Worrest *et al.* 1981a) utilizing a similar experimental apparatus. Shifts in the species composition of laboratory-grown planktonic assemblages suggest a significant impact of UV radiation on the succession and trophodynamics of natural communities (Worrest *et al.* 1981b).

METHODS AND MATERIALS

The role of UV-A and UV-B radiation on a) algal biomass production and b) species composition and diversity was assessed during primary and secondary succession on artificial substrates in the laboratory and in the field

a. Laboratory mesocosms

The laboratory experiments were carried out at the 3,000 gallon coral reef mesocosm at the Natural History Museum of the Smithsonian Institution in Washinghton D.C. The mesocosm simulates the natural conditions of a typical Caribbean coral reef, thus providing a suitable environment for housing more than 300 species of marine organisms. To maintain a diversified community, the mesocosm is inoculated with wild specimens at

regular intervals. A detailed description of the coral reef mesocosm is given by Adey (1983).

The experiments took place in tray cultures of periphytic algae, (algal turf scrubbers, ATS; Adey 1982) connected to the coral reef mesocosm. Water pumped from the 'lagoon' side of the aquarium flows over a series of ATSs and returns to the 'open ocean' end. Each ATS (fig. 1) is a flow-through tray with a wave generator located at the upstream end of the tray. Plastic lining (polypropylene screening) is used as a surface where algal spores carried by water from the microcosm settle and colonize the ATS (fig. 2). Surge created by the wave generator enhances nutrient uptake by the growing mat of algae.

Photosynthetically active radiation (PAR) was provided by a 400 W metal halide lamp suspended over each ATS. PAR photon flux was set at 700 $\mu Ein/m^2/sec$ -approximately 2/3 of the solar flux of a typical clear day at the field site (latitude 21° N) at a depth of 60 cm below water surface, as measured at noontime in summer. Westinghouse FS-40 sunlamps were used as a UV source. The lamps were suspended along the long side of the trays (fig. 2). The spectrum of these lamps was modified by cellulose acetate filters to achieve the desirable levels of UV exposure over the developing algae.

Biomass data were obtained every seven days by scrape-harvesting the algae; community analysis was carried out in wet mounts of algae samples obtained weekly by randomized sampling.

b. Field experiments

The field experiments were carried out near the island of Grand Turk, Turks and Caicos Islands, lat. 21° 2′ N, long. 71° 3′ W during the periods May-July (experiment 1), and August-October (experiment 2) 1987, and in Saronicos Gulf, near Korinth, Greece (37° 58′ N, 23° 0′ E). In both locations, the experimental appararus was installed over sandy bottom, where reflected and diffuse radiation maximized exposure of the developing communities.

Three UV treatments were established using a combination of UV-absorbing filters and plexiglass:

1. PAR
2. PAR + UV-A
3. PAR + UV-A + UV-B

In both experiments, the growth surfaces were suspended from PVC rafts tied together in tiers of three (fig. 3). Only one end of each raft tier was anchored to allow free swinging of the apparatus with the current.

To prevent fouling, the filters were scraped on a regular basis (2-3 days). Occasionally, the filters were brought to the surface, and their UV transmittance was checked for replacement of defective filters.

Biomass samples were obtained by scrape-harvesting. The collected algal biomass was strained free of salt water, and allowed to dry for 24 hours to constant weight at 80° C. To analyse 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.

RESULTS

a. Laboratory

Biomass

The biomass data are plotted in figure 4. The assemblage exposed to high UV-B had a mean weekly biomass production 55.1% lower than that of the corresponding control, and the lowest biomass production of all treatments. The most dramatic overall difference occurred on the second week of growth, with a productivity value of 3.66 $g/m^2/day$ - 30.2% of the mean productivity of the controls (12.12 $g/m^2/day$). It is worthwhile noticing that the assemblage exposed to UV-A seems to have the highest productivity than all other treatments including the assemblages exposed to PAR only.

After week 6, the UV treatments were reversed over the developing assemblages. Following treatment reversal, no distinct differences in the productivity of all treatments were observed.

Relative Abundance

The relative abundances of the dominant species in the six assemblages are plotted in figures 5-10.

HIGH UV-B TREATMENT (fig. 5): During the first three weeks of sampling (2-4) the dominant species is *Enteromorpha prolifera* (Muell.) J. Ag., while *Cladophora fuliginosa* Kuetz. reaches its maximum abundance in week 4. *Schizothrix calcicola* Druet, present from the beginning of the sampling, becomes increasingly abundant and eventually dominates the assemblage 2 weeks before the treatment reversal. *Ectocarpus rhodochondroides* Borg., present only in minute quantities in weeks 5 and 6, drastically increases in abundance as soon as it is relieved from exposure to UV-B radiation. *Licmophora* sp. is the only subdominant after the treatment reversal.

LOW UV-B TREATMENT (fig. 7): The two species of green algae (*Enteromorpha, Cladophora*) dominate this assemblage in weeks 2 - 4. *Ectocarpus rhodochondroides* appears in week 3, increases in abundance in week 4 to

become dominant two weeks before the reversal of treatments. That point marks the dramatic decline of *Enteromorpha* with the concomitant increase of *Ectocarpus*. *Licmophora* is present in the second half of the experiment, and *Cladophora* persists in significant quantities throughout the duration of the experiment.

UV-A TREATMENT (fig. 9): Week 2 is dominated by the two greens, *Enteromorpha* and *Cladophora*. However, unlike the two previous UV treatments, in the third week *Ectocarpus* has a percentage cover of 80 and remains the dominant species throughout the experiment. Treatment reversal did not have any dramatic effects on this community. The abundance of *Licmophora* fluctuates in an inverse pattern than that of *Ectocarpus*. Towards the end of the experiment *Polysiphonia* sp. appears on the screens, but its abundance never exceeds 10%.

CONTROLS (figs. 6,8,10): Green algae (*Enteromorpha, Cladophora*) dominate these assemblages in the first second week, while *Licmophora* and *Ectocarpus* are already present in significant numbers. In the following weeks, before treatment reversal, *Ectocarpus* becomes abundant, *Licmophora* and *Cladophora* occupy a significant area while *Enteromorpha* virtually disappears by the fourth week. As soon as the community is exposed to high UV-B irradiance *Ectocarpus* is replaced by *Schizothrix calcicola* and *Cladophora*. One week later, however, *Ectocarpus* resumes its dominant role, *Enteromorpha* has a sporadic distribution, wile *Schizothrix* and *Cladophora* are outcompeted by the end of the experiment.

Species Diversity

The weekly species diversity values of the six assemblages are plotted in figures 11-13. Unlike biomass production, species diversity fluctuated widely (especially that of the two UV-B treatments; see high UV-B, weeks 2, 3 vs. weeks 4, 5, 6; low UV-B, week 2 vs. weeks 3-6), and no significant differences were found among the means of the weekly values of the assemblages in either part of the experiment.

ATS 1 (fig. 11): Species diversity was higher in the second and third weeks in the control assemblage of this ATS. In the following three weeks, however, the species diversity of this control is very low, while the assemblage exposed to high UV irradiance shows a higher value of species diversity. Treatment reversal reverses the relation of species diversity of the two communities: the community now exposed to high UV-B irradiance exhibits higher species diversity, while the same parameter declines dramatically for the other assemblage. After week 7 the two communities are characterized by similar species diversity values.

ATS 2 (fig. 12): The low UV-B assemblage has a similar species diversity value to that of the control in weeks 2-4. In weeks 5 and 6, however, the control shows lower species diversity than the low UV treatment; this is

reversed with the treatment reversal, and the diversities of the two assemblages tend to be equal in weeks 8-11.

ATS 3 (fig. 13): There seems to be no distinct difference between the diversities of the two assemblages. In both the UV-A treatment and the control, species diversity progressively decreases with time.

b. Field

Tropical Assemblages (Caribbean)

The productivity of assemblages not exposed to UV radiation was significantly higher (30-40%) than that of the assemblages exposed to the full spectrum until week 4 (fig. 14). After that point the productivity values are not significantly different.

Mediterranean Assemblages (Korinthos)

Standing crop measurements were obtained by scrape-harvesting the biomass of each ceramic tile, followed by oven-drying to constant weight. The biomass results are plotted in figures 15-20.

Figs. 15-17: During the first 3 weeks (10/8/94 - 1/9/94), the communities exposed to UV-B radiation (dark bars) show the lowest productivity values at 0.5m (fig. 15) and 1.0m (fig. 16). During the same time, at the same depths, the communities exposed to UV-A and PAR, but protected from UV-B (white bars) show the highest productivity. The productivity difference between the two UV treatments is statistically significant ($p<0.05$) at 0.5 metres only. This trend is not observed at 1.5m, probably due to a 25% reduction in UV-B irradiance. At this depth, the communities exposed to UV-B and UV-A show a slightly higher productivity, but the difference is not statistically significant. After 5 weeks of growth, the same general trends are repeated at the 3 depths to disappear at all depths after 7 weeks (29/9) and 9 weeks (13/10) of growth.

Figs. 18-20: The productivity of communities exposed to UV-B radiation increases almost linearly with depth after 3 and 5 weeks of growth (fig. 18). After 7 weeks, this trend is no longer observed.

There is no clear correlation between productivity and depth in the PAR+UV-A treatment (fig. 19), while in the PAR treatment (fig. 20) communitiy productivity at 0.5m seems to be lower during the first 7 weeks of growth. This difference, however, is not statistically significant ($p>0.2$).

DISCUSSION

The biomass results of the Caribbean field experiment parallel those of the laboratory. The productivity of the UV-B exposed assemblages in weeks 2, 3, and 4 is substantially higher than that of assemblages protected from UV-B. In addition, exclusion of UV-A radiation did not result in significantly different biomass production. However, the productivity of all treatments in the field did not differ significantly from one another after the fourth week, while in the laboratory, productivity differences between the high UV treatment and the controls persisted throughout the first part of the experiment (*i.e.* for 6 weeks). This discrepancy might be due to two facts: a) the UV/PAR ratio was higher in the laboratory than in the field, and b) the field communities were highly diversified (over 100 species of diatoms), while in the laboratory there were less than 20 species of filamentous algae and diatoms present.

In the Mediterranean, the same productivity trends are observed, but the differences are less pronounced than in the Caribbean. This, however, may be an artifact of the smaller sample area used in the Mediterranean experiment. Exposure to solar UV-B as well as UV-A caused shifts in the species composition of the diatom assemblage during the first few weeks of development. However, as the establishment of the biological community progresses, the structural patterns of the diatom assemblages disappear.

In conclusion, solar UV-B radiation inhibits community productivity and affects community structure during the early stages of primary succession. However, UV-B seems to have no measurable effect on community productivity and structure of already established communities (laboratory and field). The resilience of natural communities suggests that caution should be applied when the results of short-term studies carried out in artificial evironments are extrapolated to a global scale for predicting climatic changes.

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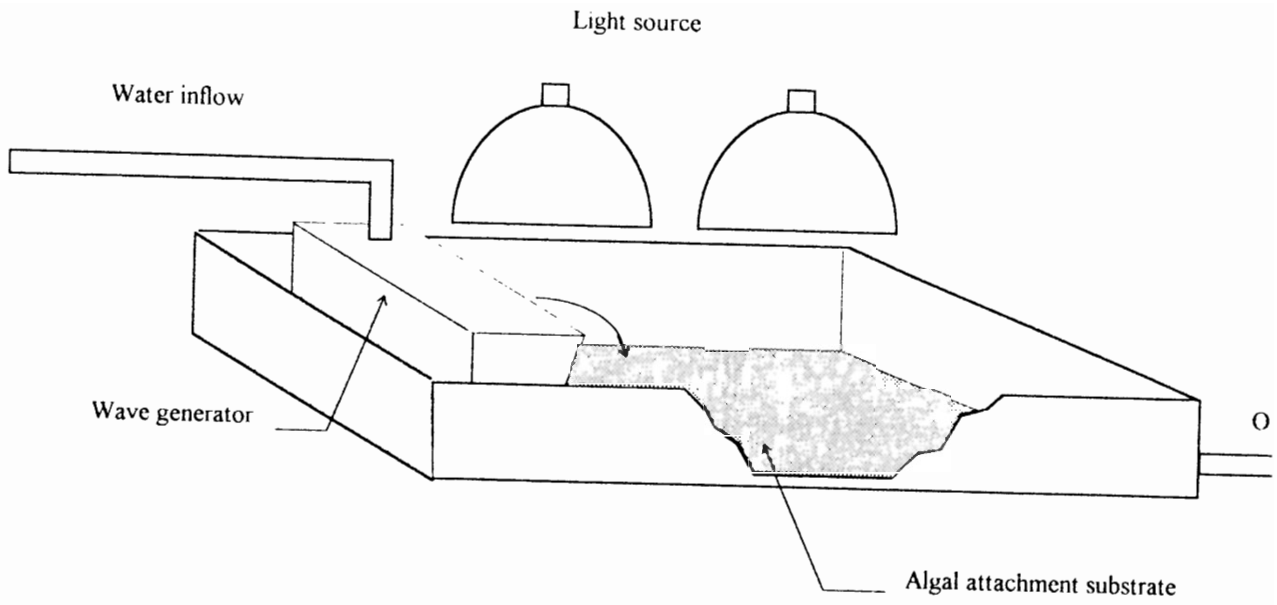


Figure 1: Algal Turf Scrubber (ATS)

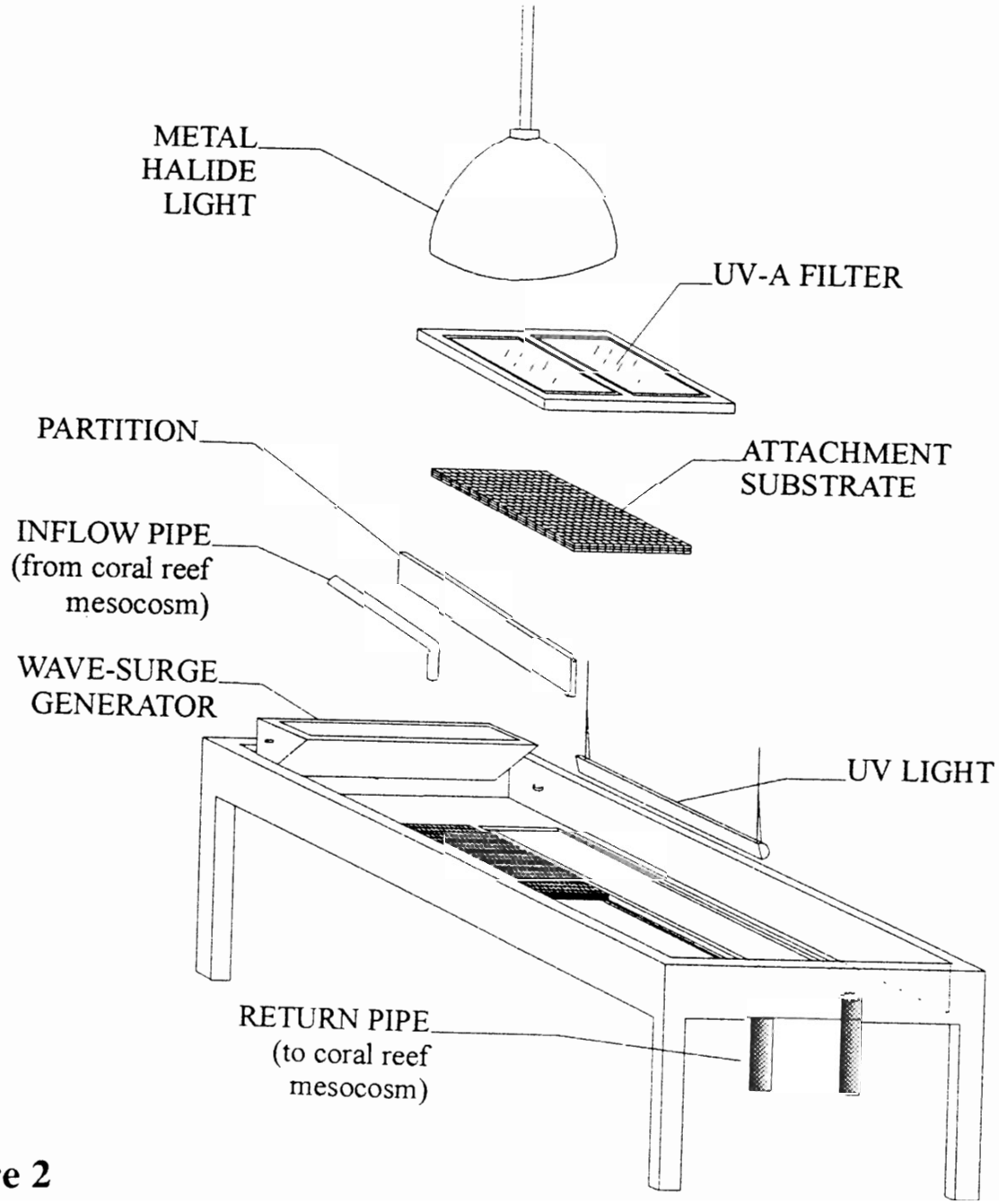
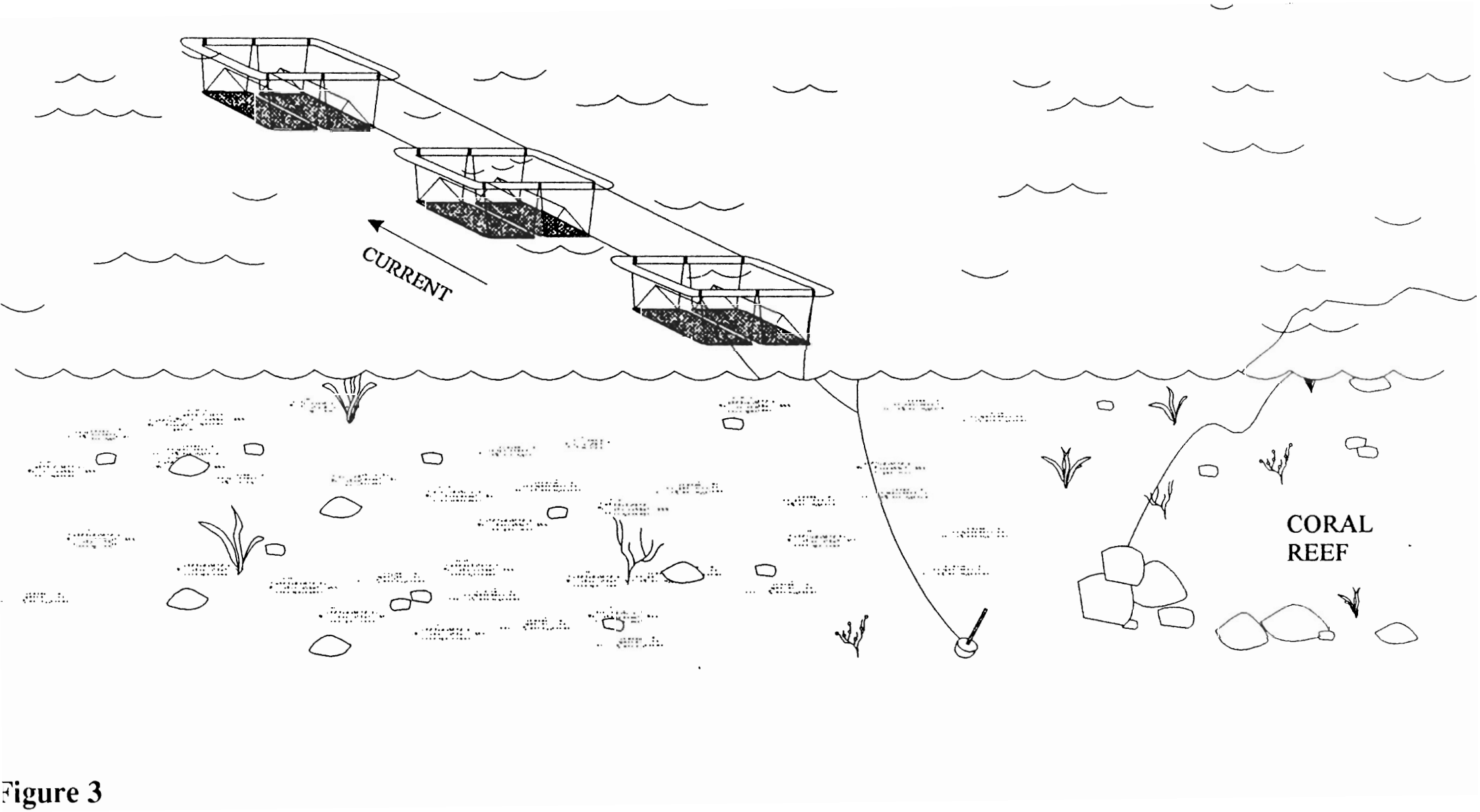


Figure 2



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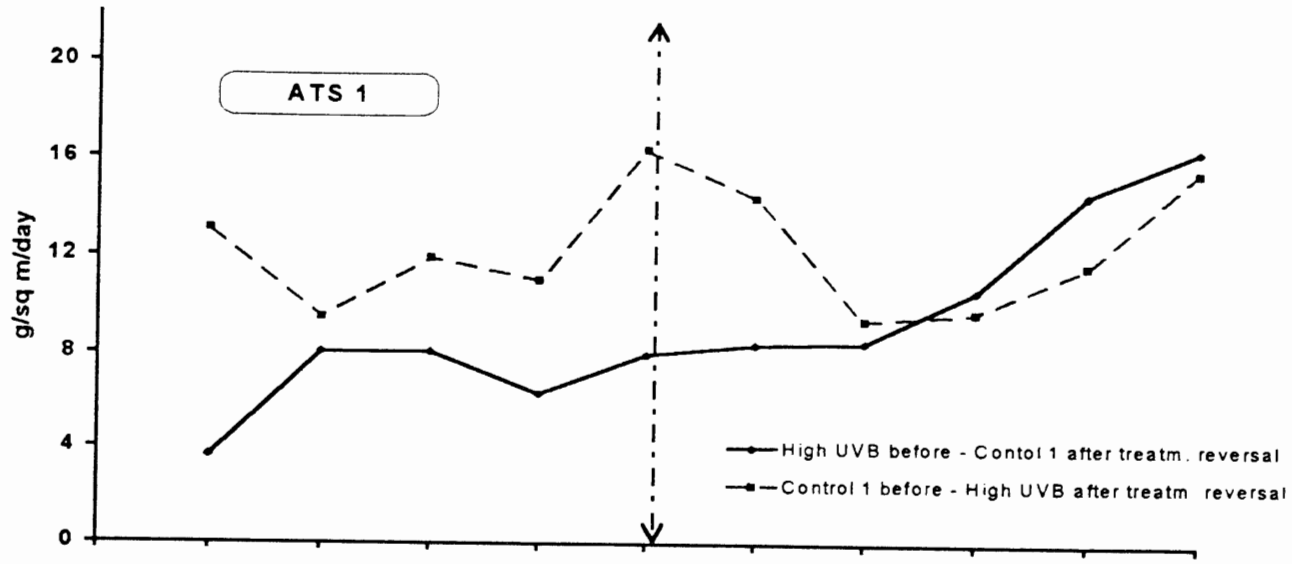


Figure 4a

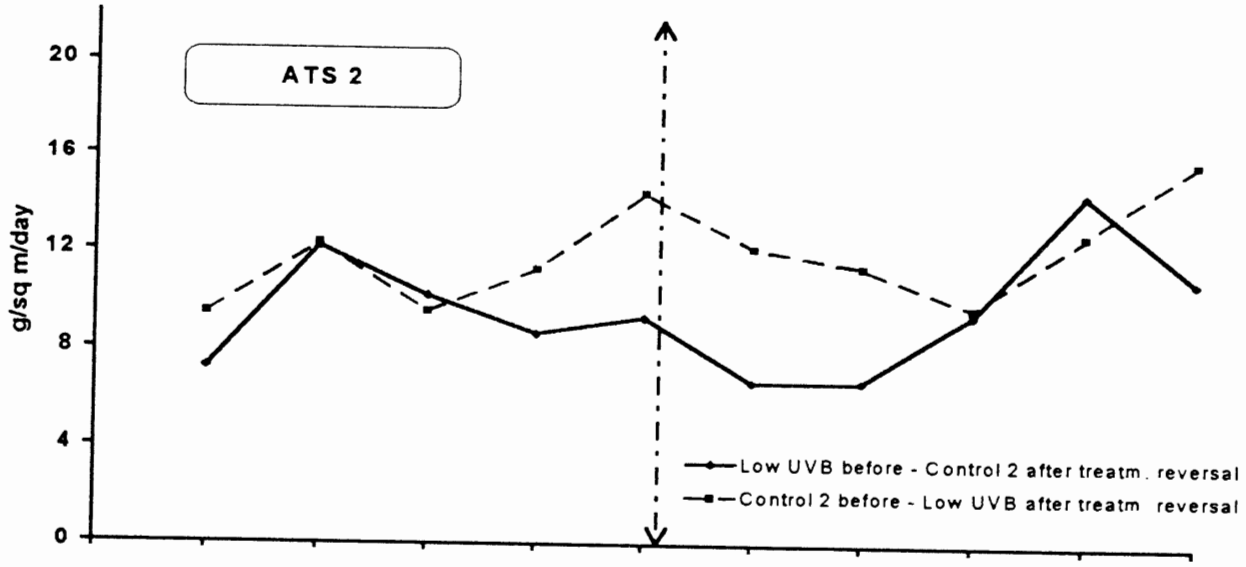
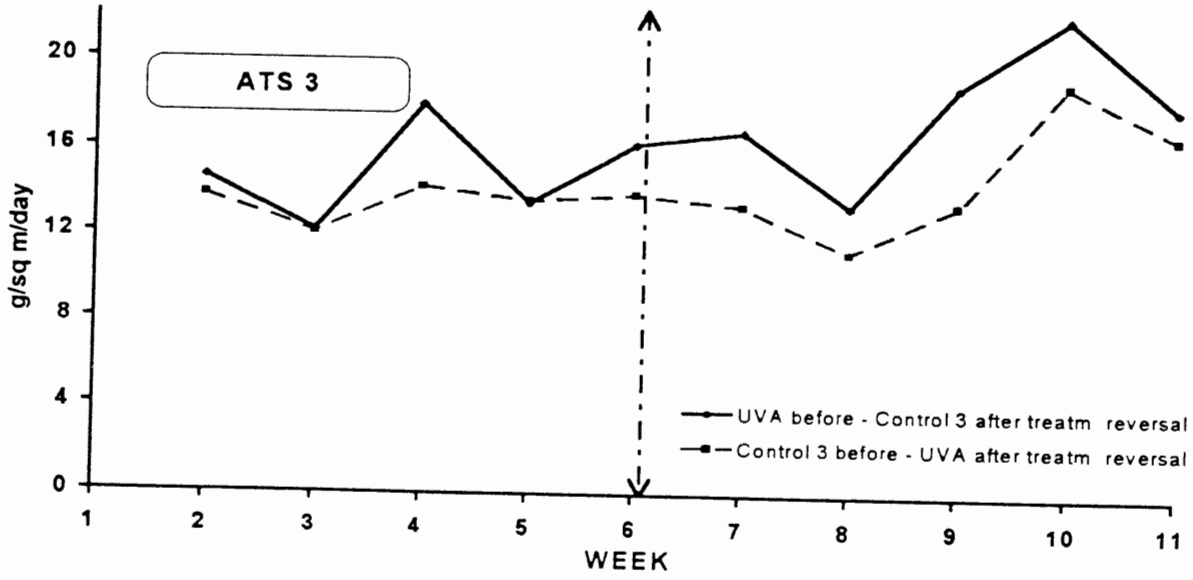


Figure 4b



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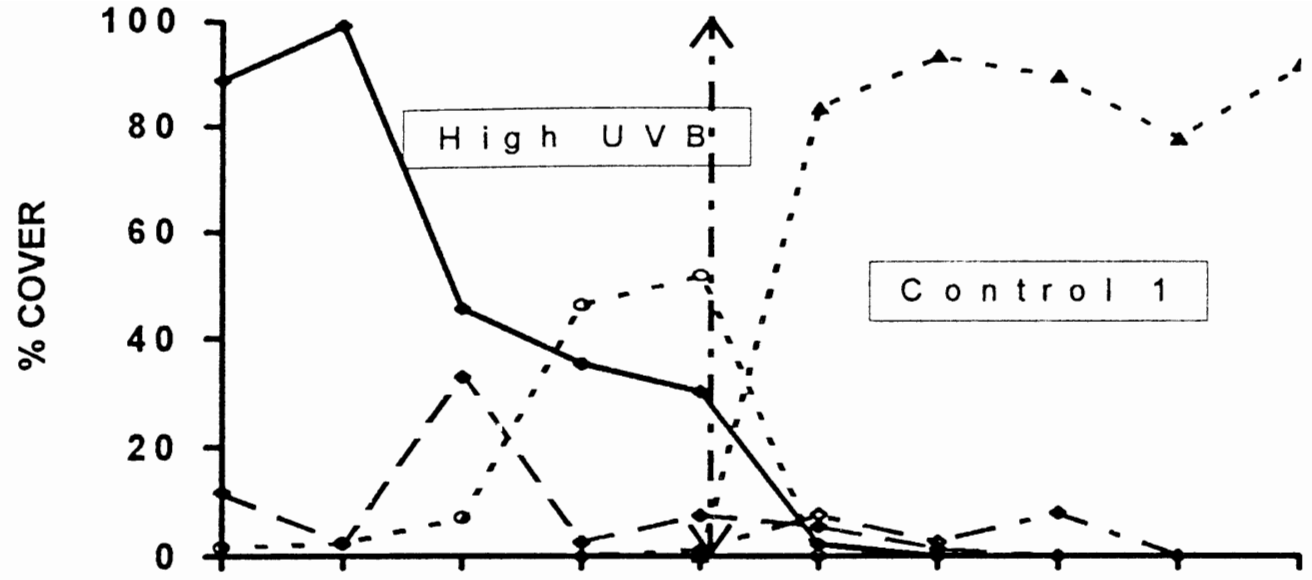

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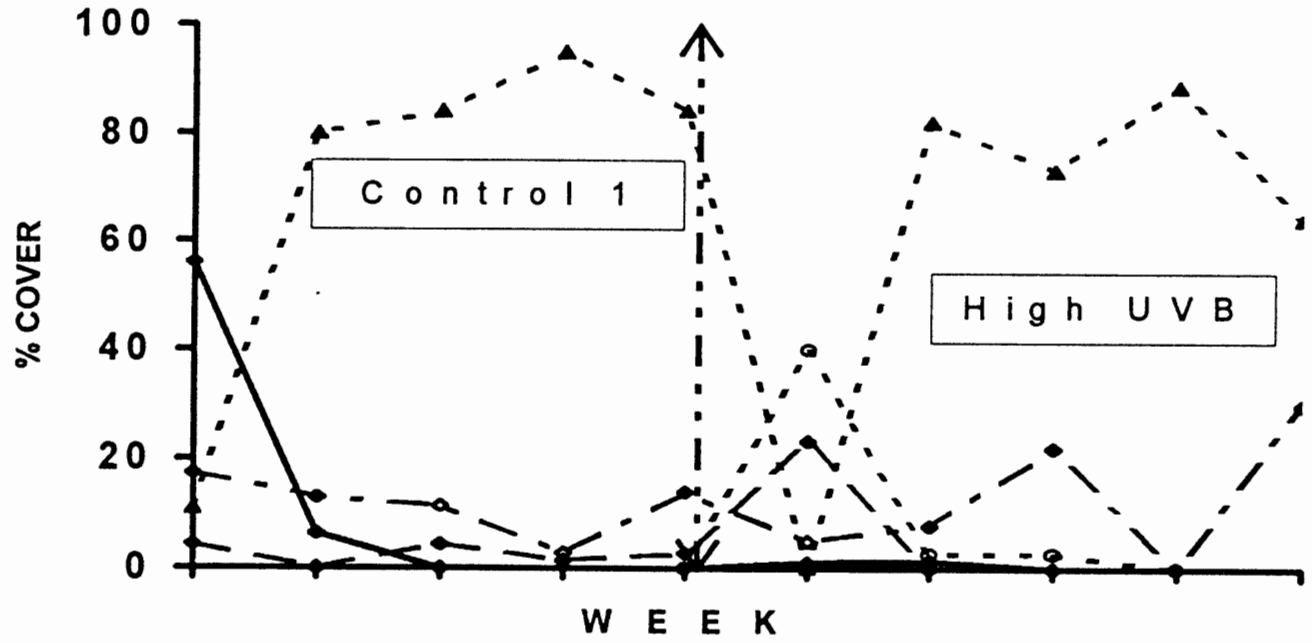

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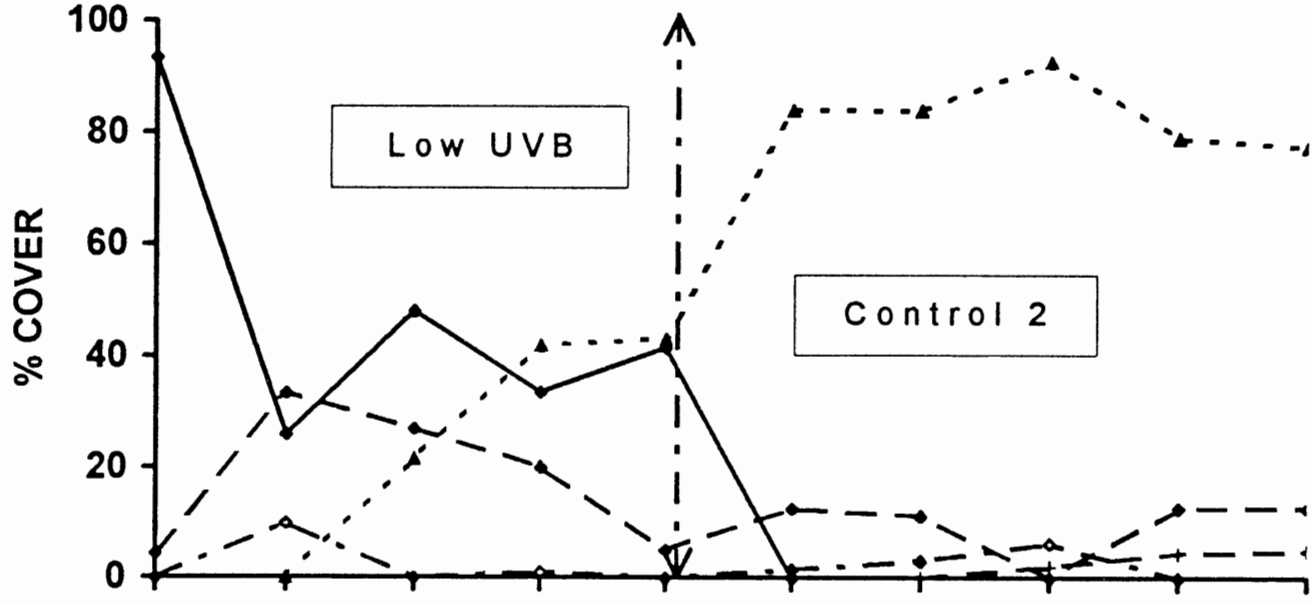
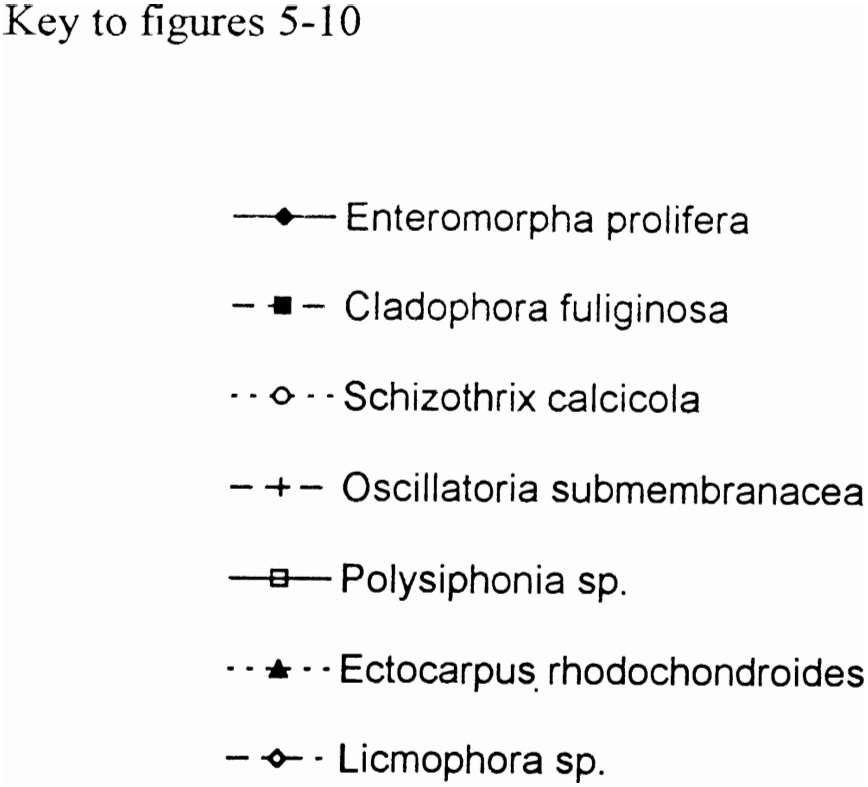
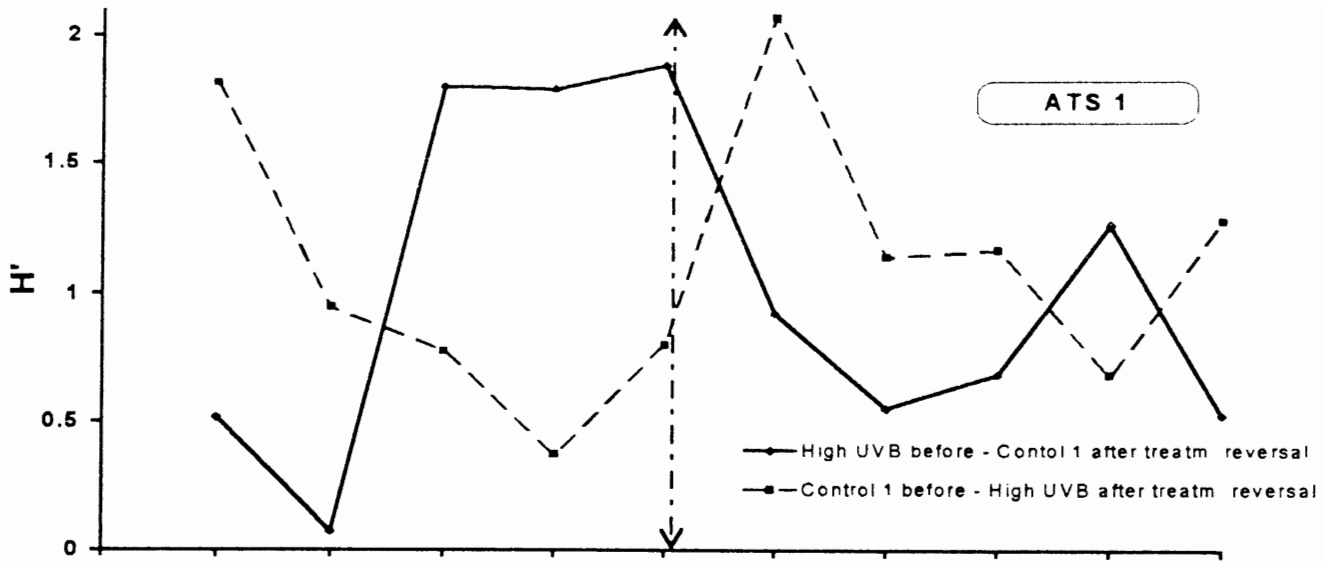


Figure 7

Key to figures 5-10





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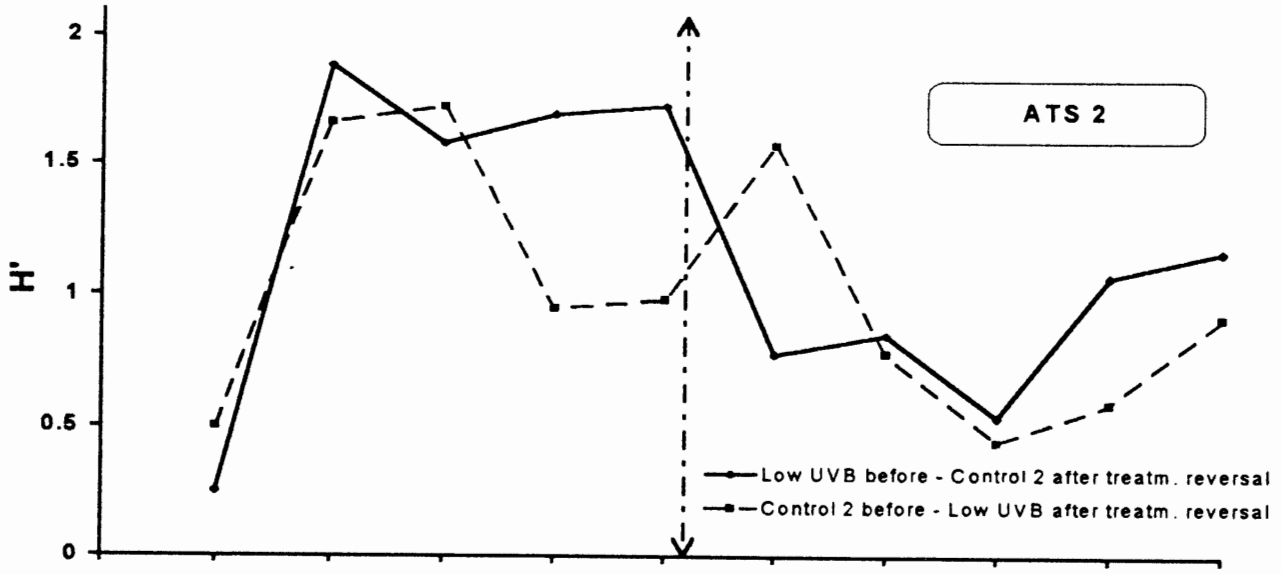

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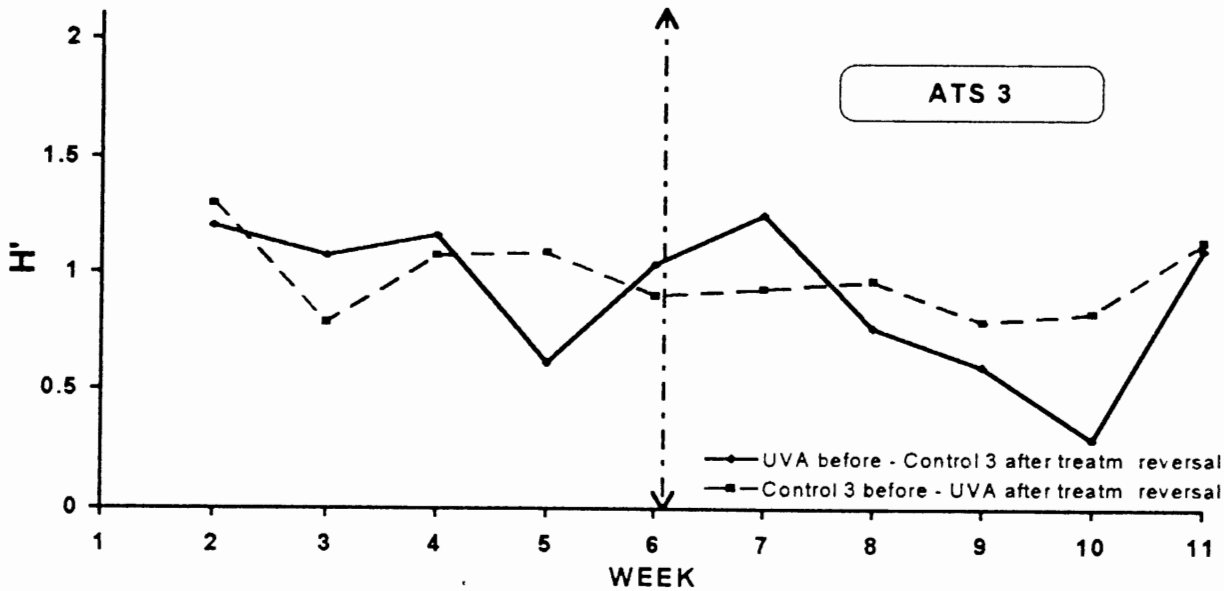

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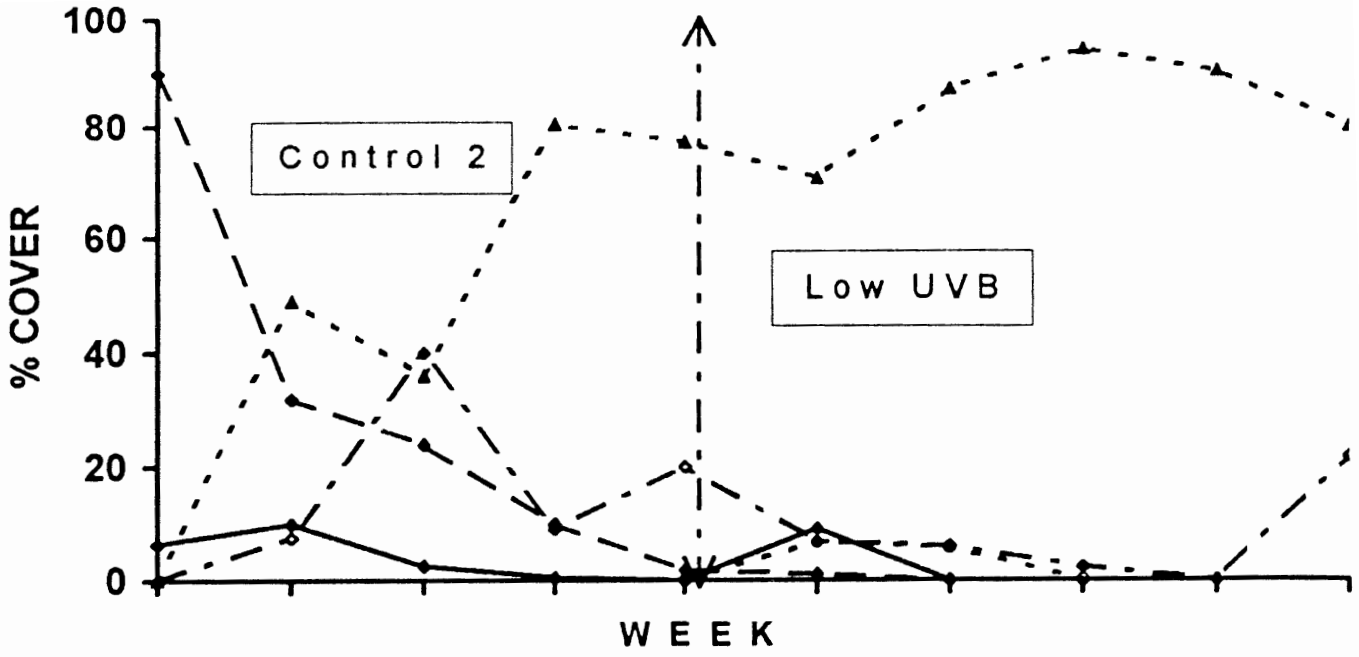

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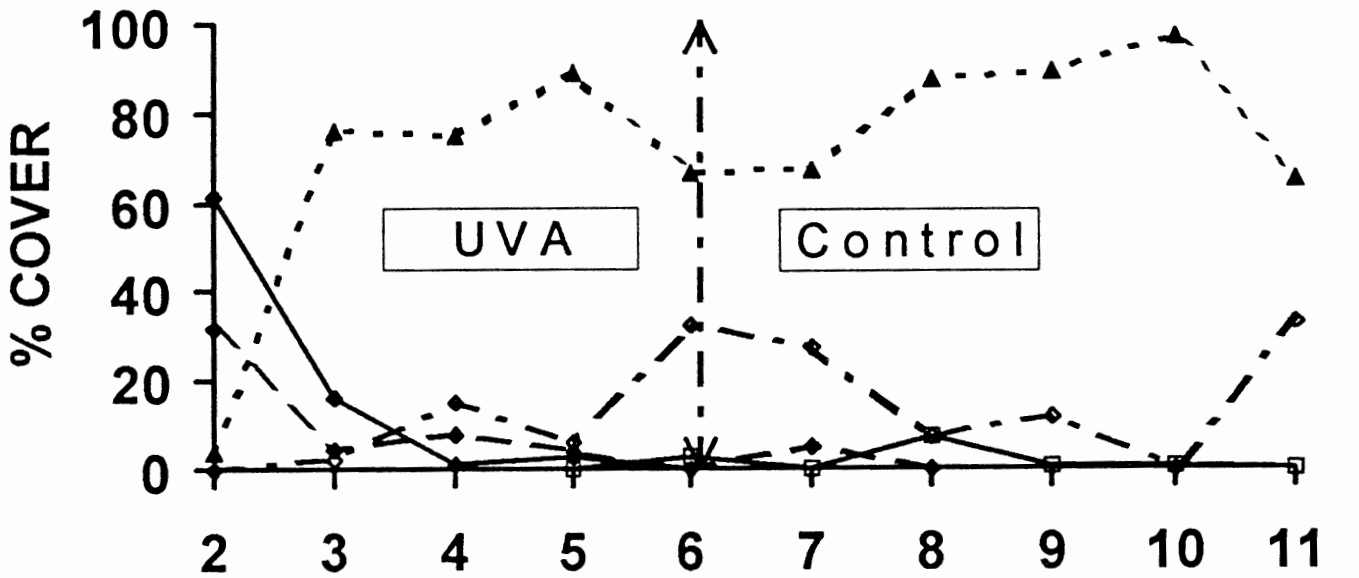

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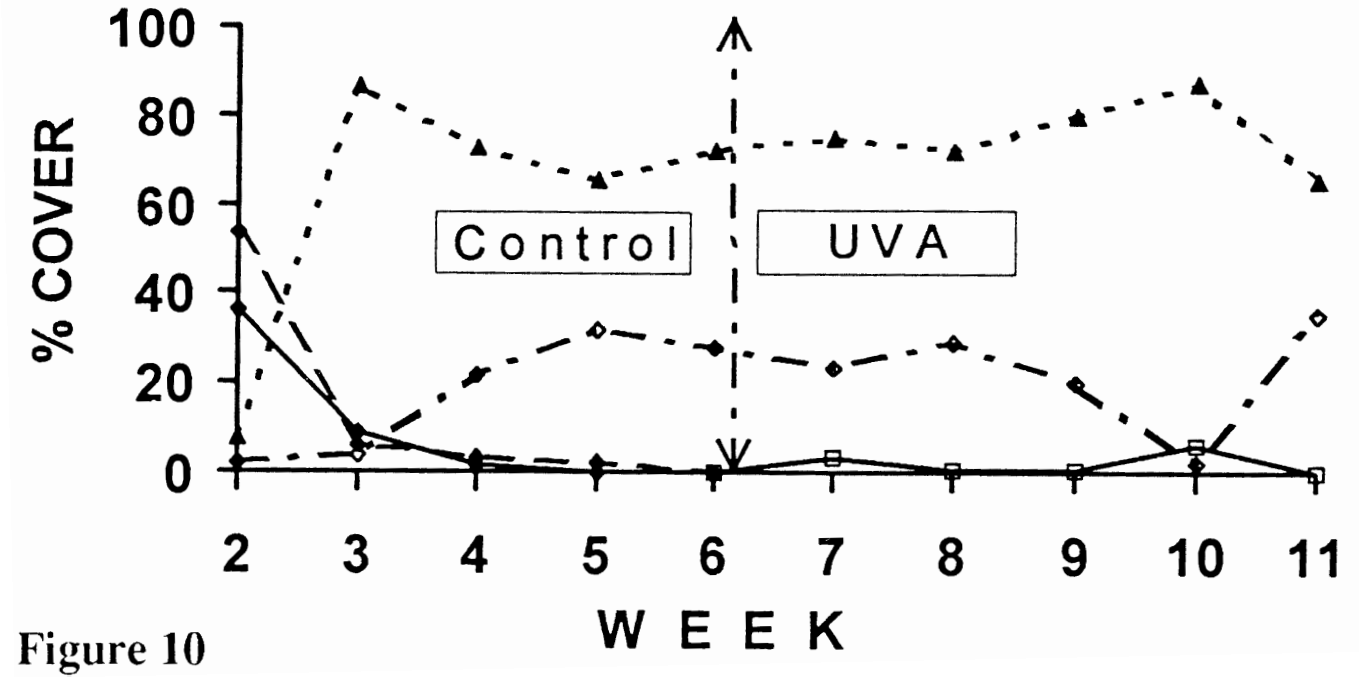

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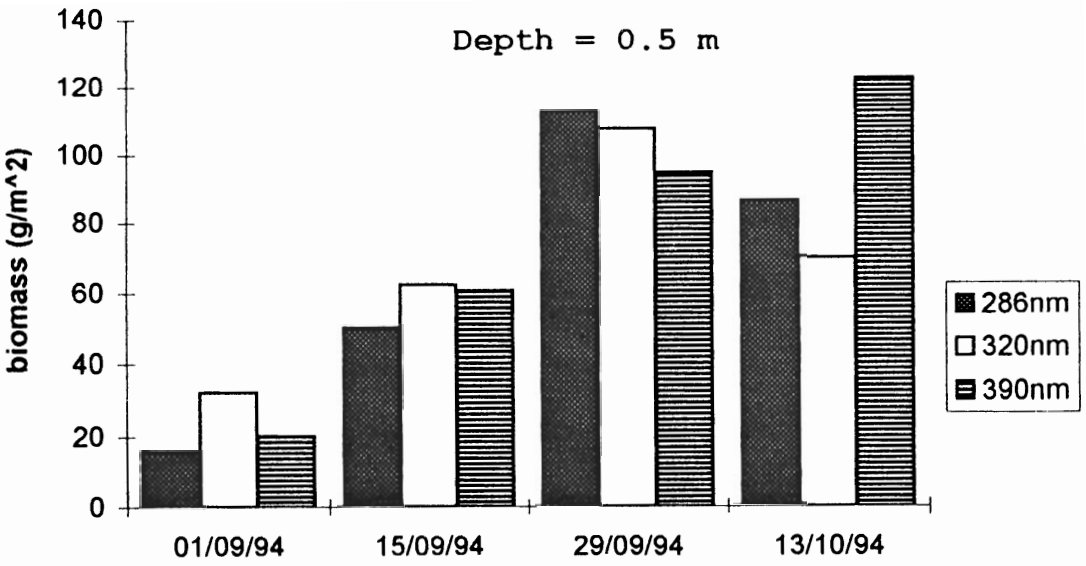

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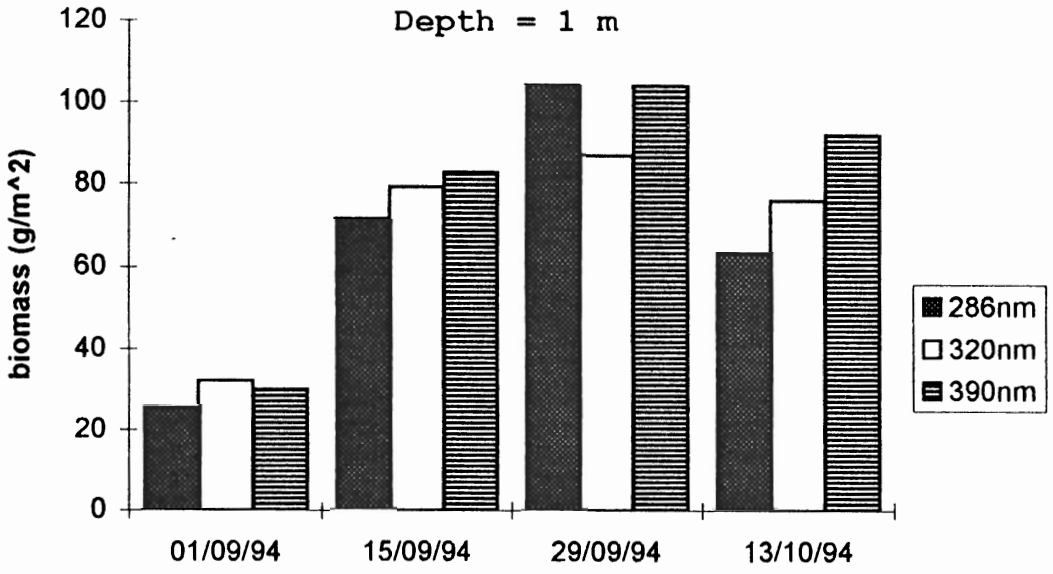

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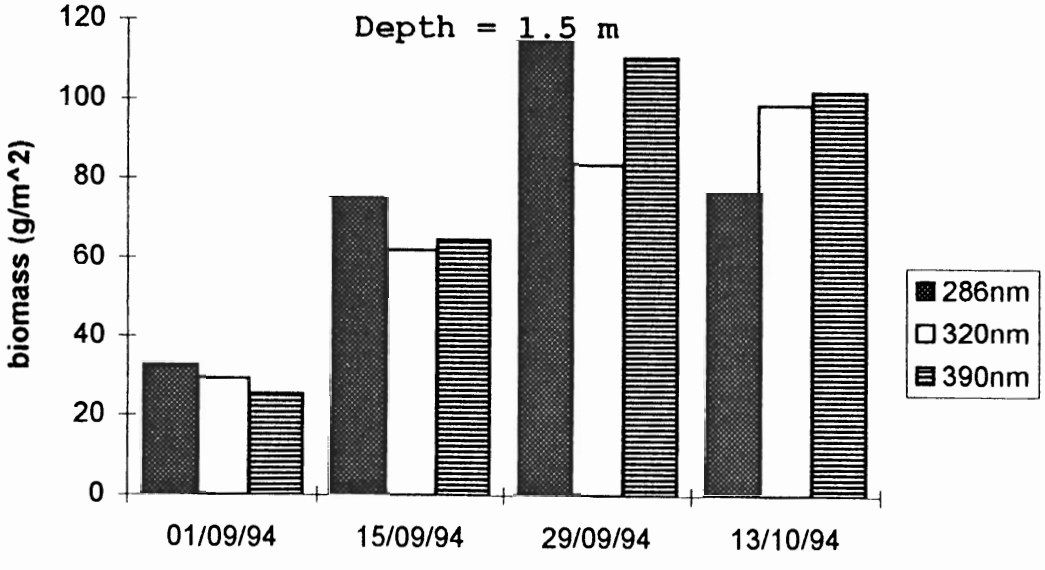

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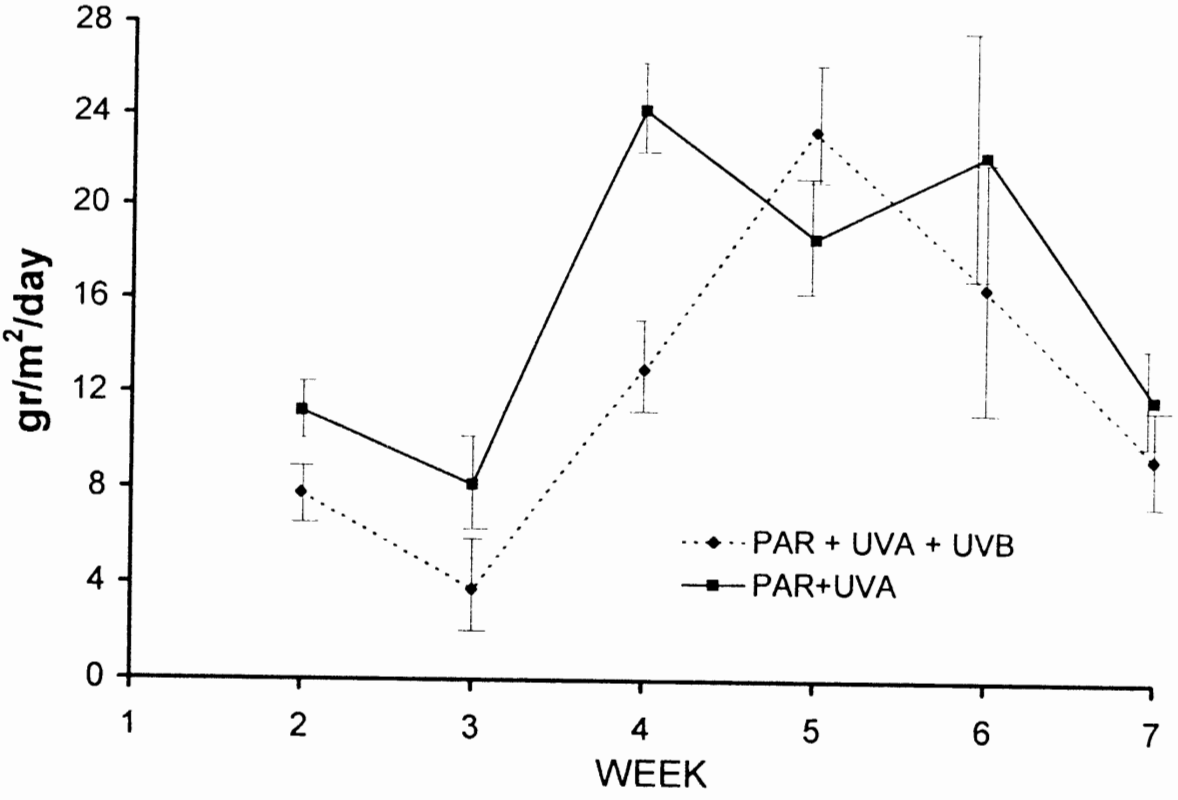
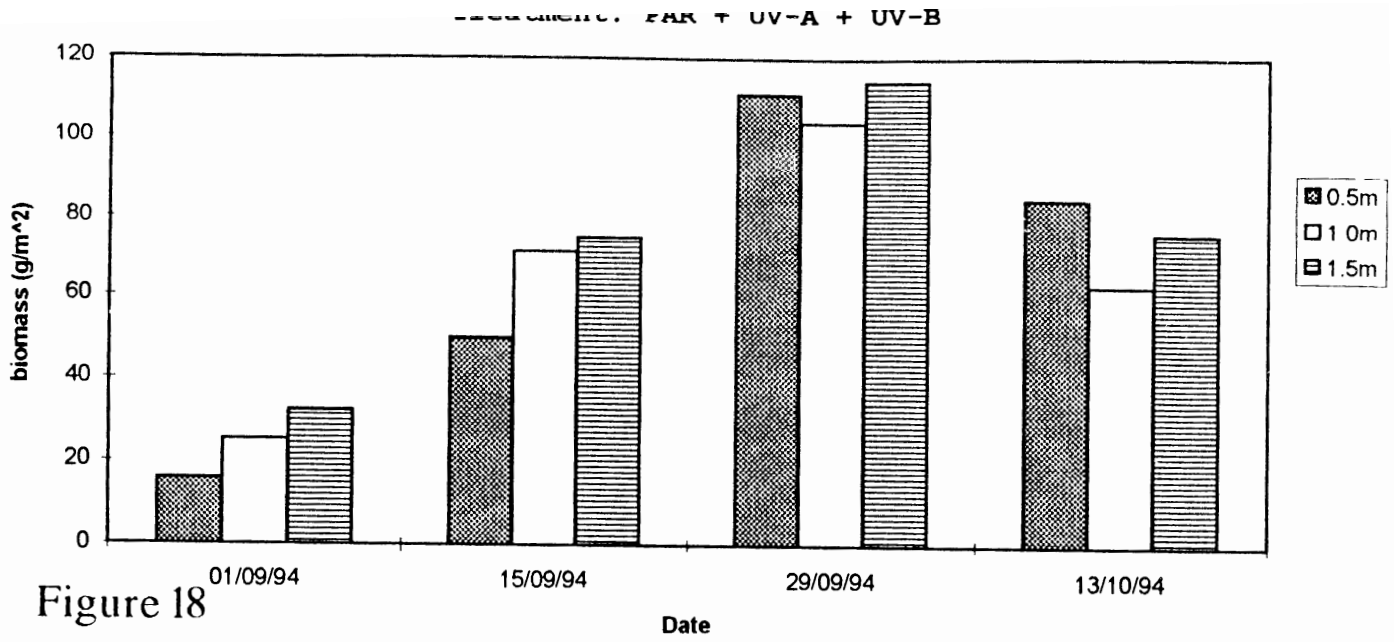


Figure 14: Biomass production (Caribbean experiment)

Figures 15-17: Mean standing crop values of Mediterranean diatom assemblages (n=2). (Figure 15: Assemblages at 0.5 m; Figure 16: Assemblages at 1.0m; Figure 17: Assemblages at 1.5m.) Bars: Just Significant Confidence Intervals ($p<0.05$). A two-way ANOVA indicated that on 1/9/94 at 0.5m the PAR+UVA+UVB treatment had a significantly lower biomass than the PAR+UVA treatment. No other significant differences were observed thereafter.

Figures 18-20: Mean standing crop values of Mediterranean diatom assemblages (n=2). (Figure 18: Assemblages grown under PAR+UVA+UVB; Figure 19: PAR+UVA; Figure 20: PAR.) Bars: Just Significant Confidence Intervals ($p<0.05$). On 15/9/94 under the PAR+UVA+UVB treatment the assemblage grown at 0.5m had a signficantly lower biomass than that at 1.0m. No other significant differences were observed.



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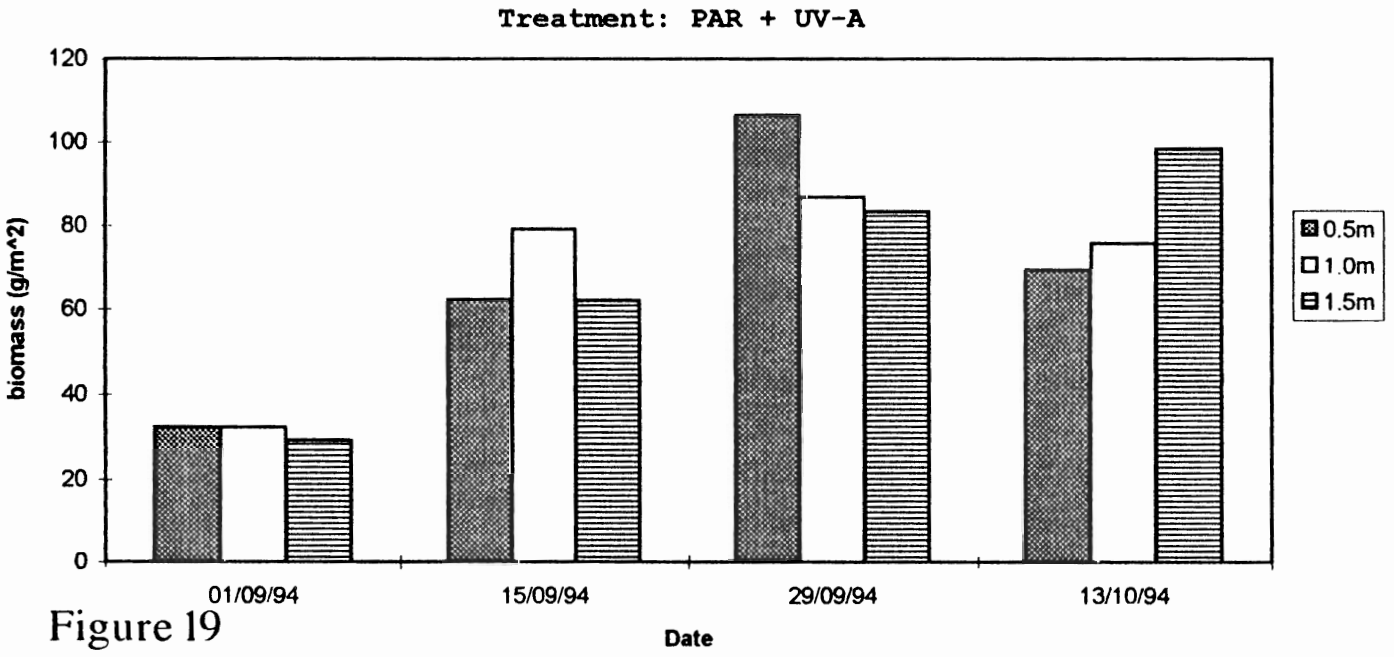

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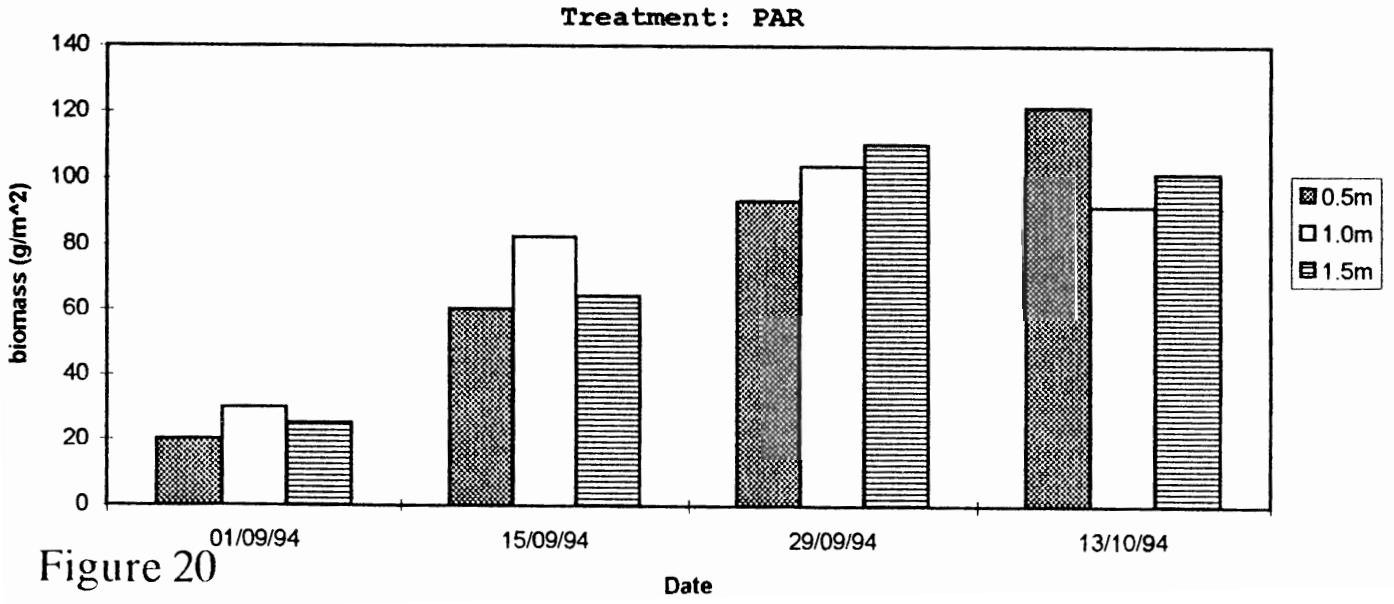

Figure 20