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Ozone hole and its correlation with the characteristic UV-absorbing substance in marine algae

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Calculations have indicated that a 10 percent depletion of the stratospheric ozone layer gives an increase in UV-irradiation in the tropics and subtropics of ca. 19.0 and 10.9 percent respectively. In this connection, determination of the characteristic UV-absorbing substance in tropical marine algae was carried out in 1989 and the result was compared with that obtained from corresponding algal samples investigated in 1975. Such astonishing increases were observed in the order of 5.67–6.20 fold for Cyanophyta, 1.78–10.93 fold for Rhodophyta, 4.44–28.38 fold for Phaeophyta and 1.53–7.31 fold for Chlorophyta. This at least suggests that the substance must be produced by the algae in response to the increasing UV-radiant energy penetrating the ozone hole formed at the stratospheric ozone layer.

Key Index Words: ozone hole—tropical marine algae—UV-absorbing substance.

In 1985 the journal, British Antarctic Survey Scientist, reported a completely unexpected finding that springtime ozone levels in the atmosphere over Halley Bay (76°S 27°W), Antartica, had depleted by more than 40 percent between 1977 and 1984 (STOLARSKI, 1988), i.e. from 300 to ca. 180 Dobson Units (1 DU$=10^{-3}$atm. cm). This depletion is most significant at McMurdo Station (78°S), Antarctica, and ranges at heights between 10–17 km of the stratosphere (HOFMANN 1989). Furthermore, according to the Nimbus 7 Total Ozone Mapping Spectrometer Scan this is extending to over at 15° in latitude (MCELROY *et al.* 1986). Data from Chubachi with regard to the Syowa Station (69°S 39°E), Antarctica, over the years from 1966 until 1982 had also transpired such closely related information (SOLOMON *et al.* 1986). Similar tendencies of ozone depletion have also been observed at Thule (76.5°N), Arctic, in 1988 (MOUNT *et al.* 1988) with values ranging between 325 and 400 Dobson Units. The lower comparable effects in the Northern Hemisphere to that in the Southern Hemisphere, which is one third its size, could be attributed to the fact that the winter polar stratospheric vortex is less cold and less stable than its southern counterpart. This represents a close relationship in the generation of polar stratospheric clouds (=PSCs) which occur in the stratosphere when temperature prevail below ca. −80°C.

The causative agent for the depletion of the ozone layer is strongly proven to be in the increase of atmospheric chlorofluorocarbons (=CFCs) due to anthropogenic releases in combination with heterogeneous chemistry involving particles in the clouds (=PSCs), which form during polar nights. The odd nitrogen chain (NO, NO_2) is also believed to be intimately regulating the O_3 level in the atmosphere. Nevertheless, at stratospheric temperatures, C10 reacts with O six times faster than NO_2. Bromine is also believed to be involved in a similar related process. The increase in production and use of CH_3Br, a fumigant, and CF_3Br and CF_2ClBr, employed extensively as fire extinguishers, should also be borne in mind as one of the culprits.

Based on the foregoing, as a consequence of the increase in UV-irradiation, it is anticipated that more sunburns (i.e. UV solar irradiation of 293.7 nm) and skin cancer, i.e. 8,000 new cases in the USA (WOODS 1988), of mankind will transpire as the consequence of augmenting UV-light energy amounting to nearly 6% of the total strength from the sun by the depleting ozone layer shield. Plants have been proven to be unable to photosynthesize as efficiently when exposed to UV-irradiation and as a result yield smaller amounts of seeds or fruits (WOODS 1988).

Marine life does also depend directly on the level of UV-irradiation which is deleterious in relation to their photosynthetic capacity. The limit of their tolerance for far UV solar irradiation is not yet well illustrated. It is apprehended that near UV (i.e. 300–400 nm) penetrates seawater relatively easily, whereas extreme UV (i.e. shorter than 200 nm) would not penetrate at all and far UV is intermedeiate. Organisms thriving at a depth of 5 m in clear water will receive a maximum of ca. 75% of incident surface UV-irradiation in the band from 320–400 nm, 60% at 320 nm and 50% at 300 nm. On this basis ca. half of all marine fishes, all nearshore flora and fauna (including coral reefs) and much of the biota of estuaries, lagoons and freshwater ecosystems could be at risk. As these organisms are already exposed to some UV it can be assumed they possess strategies to cope with at least this level of radiation; but whether these are enough to cope with any increase in UV radiation is another question (WOODS 1988). In this regard, an Australian researcher Bill WOOD of the University of Sydney has just initiated studies on UV penetration in Antarctic waters, measuring the effects of UV on planktonic algae which constitutes the base of the Antarctic food chain (WOODS 1988).

Notwithstanding the foregoing TSUJINO and SAITO (1961) and YABE *et al.* (1965, 1966) had reported of a characteristic UV-absorbing substance from 5 species of red algae, viz. *Neodilsea yendoana, Chondrus ocellatus, Chondrus crassicaulis, Laurencia glandifera* and *Trichocarpus crinitus*. However, these substances appeared different in some properties from the UV-absorbing substances reported by KALLE (1938), FOGG and BOALCH (1958), HANG and LARSEN (1958), CRAGGIE and MCLACHLAN (1964), YENTSCH and REICHERT (1962) and KROES (1970). SIVALINGAM *et al.* (1974 a, b, c) had indicated that the compound existed ubiquitously in all the algal groups and the level of content of the compound fluctuates with depth of their habitat in correlation to the levels of chlorophyll and phycoerythrin. OKAICHI *et al.* (1974) extracted a substance resembling this compound from 2 species of *Noctiluca* harvested from water blooms and they postulated that it is of phenolic nature.

In 1976 SIVALINGAM *et al.* (1976a, b) isolated the compound from the red alga, *Porphyra yezoensis*, and investigated its physicochemical properties. It was concluded at the time that this substance seems to play a role in the photosynthetic pathway as a metabolic regulator or a temporal energy transferring substance in the form of fluorescence energy relay SIVALINGAM *et al.* (1976a). Prior to this, SHIBATA (1969) had reported that the similar UV-absorbing substance is present in corals and a blue-green alga. Then, he had hypothetically suggested it as possibly playing the role of an UV-solar radiation biofilter similar to that of the flavonoids.

Comparative studies on the content of the UV-absorbing substance from tropical algae had been reported by SIVALINGAM *et al.* (1976c). With the advent of the ozone hole problem a study was undertaken in a similar manner to elucidate whether the increase in UV-solar irradiation penetration through the ozone layer would have exerted any effect on the content of the UV-absorbing substance so as to it acting as a biofilter in the algal body. Furthermore, we estimated the possible increase in the penetration of UV-solar irradiation at different areas the world over when depletion of the stratospheric ozone layer attained a level of 10% of the total.

Materials and methods

The increase in ultraviolet radiation at various localities the world over was calculated based on data reported by ILYAS (1990), being due to 10 percent depletion in the ozone layer.

The algal samples employed for the comparative evaluation of the UV-absorbing substance were harvested mostly from 0.5 to 1 m in depth at Batu Ferringhi, Sungai Dua and Batu Maung shores of Penang Island, West Malaysia, in the season between February and April 1989. The ambient seawater temperature was around 28°C. After careful elimination of the microscopic epiphytes and other contaminating material, the algal thalli were homogenized in 80% ethanol in a mortar and centrifuged at 4,000 × g for 20 min. The supernatant was analyzed for the UV-absorbing substance 334, employing an automatic Beckmann ACTA 111 spectrophotometer. The precise procedure had been reported previously by SIVALINGAM *et al.* (1974a, b, c, 1976b). Two grams of thalli of each algal species in triplicates were employed in the investigations. The results thus obtained were compared with those reported from the same area by SIVALINGAM *et al.* (1976c).

Results

Table 1 indicates the percentage increase in UV-radiation intensity the world over, using the value of 10% depletion in stratospheric ozone layer. Evidently, areas in the tropics, viz. Kuala Lumpur and Brazil, are the most extremely exposed to UV-radiation in the region of ca. 19% followed by those in the subtropics, viz. Adelaide and Washington D.C., to the tune of 11.3% while lowest in the regions closest to the Northern Hemisphere, viz. London and Oslo, to the tune of 10.9%.

In relation to such fluctuation in UV-radiation exposure at the various regions of the world concomitantly with the recent advent of the ozone hole in both polar regions, Table 2 illustrates the increment in content of the characteristic UV-absorbing substance in tropical marine algae currently as compared to those values evaluated in 1975 in the same species collected from nearly the same

Table 1. Calculated percentage increase in UV-radiation intensity in various areas the world over with 10% depletion of stratospheric ozone layer.

Areas/Towns	% Increase in UV-radiation
London	10.9
Oslo	10.9
Washington D.C.	11.3
Adelaide	11.5
Brazil	18.8
Kuala Lumpur (Malaysia)	19.0

habitats in the same months.

It is evident that increments in content of the UV-absorbing substance are astonishing, ranging from 5.67–6.20 fold for Cyanophyta, 1.08–10.93 fold for Rhodophyta, 2.10–28.38 fold for Phaeophyta and 1.53–7.31 fold for Chlorophyta. Out of the 19 species of tropical algae investigated, it is obvious that *Padina* sp., the intermediate tidal level zone species, in the Phaeophyta has the highest increment in content, i.e. 28.38 fold, followed by *Acanthophora specifera* and *Jania* sp., i.e. 10.93 and 6.40 fold respectively, in the Rhodophyta and *Lyngbya* sp., i.e. 6.20 fold, in the Cyanophyta.

Discussion

The current results on the investigation of the levels of the UV-absorbing substance in tropical marine algae at present as compared to those evaluated in 1975 are substantially significant, whereby it is apprehensible that the increase is in the range of 5.67–6.20 fold for Cyanophyta, 1.78–10.93 for Rhodophyta, 4.44–28.38 for Phaeophyta and 1.53–7.31 for Chlorophyta.

Regarding this UV-absorbing substance, it had been proposed on the basis of precise experiments (SIVALINGAM *et al.* 1976c) that the substance interacts physiologically in the photosynthetic pathway as the possible metabolic regulator or temporal energy transfer in the form of fluorescence energy relay. Similarly, it had also been proposed by the same authors (1976a) that the

Table 2. Increment in content of the UV-absorbing substance in tropical marine algae as compared to those measured during 1975.

Algal species	UV-absorption maxima (nm)	OD Subst./100 mg wet weight thalli		OD increase in percentage
		1975	1989	
Cyanophyta				
Species growing at HTL*				
Lyngbya sp.	330	0.98	6.08	620
Oscillatoria sp.	330	1.08	6.12	567
Rhodophyta				
Species growing at HTL				
Gracilaria sp.	329	0.81	3.69	456
Species growing at ITL**				
Jania sp.	331	0.30	1.92	640
Acanthophora specifera	325	0.44	4.81	1093
Gracilaria sp.	323	1.20	3.17	264
Laurencia sp. 1	325–330	0.20	1.45	725
Laurencia sp. 2	333	0.36	2.11	586
Gelidiopsis sp.	316	2.82	5.01	178
Gracilaria sp.	331	1.98	2.14	108
Species growing at LTL***				
Laurencia sp. 2	328	0.18	0.97	539
Phaeophyta				
Species growing at HTL				
Chnospore minima	331	0.92	4.08	444
Species growing at ITL				
Dictyota bartayresii	331	0.54	4.83	894
Sargassum sp.	325	0.25	1.32	528
Sphaceria furcigera	321	0.90	1.89	210
Padina sp.	316	0.28	7.94	2838
Chlorophyta				
Species growing at HTL				
Enteromorpha flexuosa	332	0.42	0.64	153
Species growing at ITL				
Valoniopsis pachynema	331	0.22	0.89	405
Cladophora sp.	330	0.13	0.95	731

* HTL, High Tidal Level; ** ITL, Intermediate Tidal Level; *** LTL, Low Tidal Level.

substance further interacts in the algal photosynthetic pathway at PS I having the potentiality of reducing site specifically NADP. Indirectly, SHIBATA (1969) had hypothetically suggested that the substance might possibly be playing the role of also an UV-solar radiation biofilter similar to those of the flavonoid pigments based on his findings of its existence in corals and a blue-green alga in waters of the Great Barrier Reef. It may, therefore, be evident that the algal UV-absorbing substance plays a regulatory role for radiant energy in photosynthesis. Such drastic increase in this physiologically important substance of tropical marine algae may be none other than the reflection of enhancing UV-irradiation in the marine environment.

Lately TEVINI (1990), WELLMANN (1990) and CALDWELL (1990) have indicated the existence of new protective pigments in terresterial plants against increased UV-β radiation other than the flavonoids. Such pigments have also been indicated to be lesser in content in conifer plants found in higher latitudes as compared to those in the tropics and subtropics. Under this context, thus, it should be brought into focus that in order to protect against the gradual expansion of the ozone hole in the stratospheric ozone layer culminating in the increase in penetration of UV-radiation into marine organisms a combat mechanism of biofilter has been generated in marine algae similar to terrestrial plants. This is verified by the tremendous increase in levels of the UV-absorbing substance in marine tropical algae over the span of the last 14 years.

It is concluded that the characteristic UV-absorbing substance in marine algae besides playing the roles of energy transfer and fluorescence energy relay in the photosynthetic pathway functions additionally as a biofilter of solar UV-β radiation. At this juncture, it is extremely pertinent to state that there is an imperative need in the near future to delve on the biosynthetic pathway culminating in the formation of such a biochemical mechanism and the genetic codes leading to a phenomenon of this nature. It should also be borne in mind that this is eventually the first report clarifying the prevalence of a UV-β radiation biofilter substance in marine algae eliminating the counter argument of such rays being detrimental adversely to the primary productivity of the oceans.

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P. M. SIVALINGAM*・西澤一俊**：オゾンホールと海藻の紫外部吸光物質との相関

成層圏のオゾン層が10%減少すると，熱帯では19.0%，亜熱帯では10.9%紫外線が増加することが示された。このことと関連して，1989年に熱帯域の海藻の紫外部吸光物質を定量し，その結果を1975年に同海域の海藻で得られている値と比較した。海藻の紫外部吸光物質は，藍藻では5.67–6.20倍に，紅藻では1.78–10.93倍に，褐藻では4.44–28.38倍に，緑藻では1.53–7.31倍に増加していることが明らかとなった。このことは，少なくとも，この物質が成層圏オゾン層にできたオゾンホールを通して透入してくる紫外線の増加に反応して海藻によって生産されていることを示唆するものである。(*School of Biological Sciences, The University of Sciences Malaysia, Minden, 11800 Penang, Malaysia; **154 東京都世田谷区下馬3-34-1 日本大学農獣医学部水産学科)