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UV Radiation and Primary Production in the Antarctic Waters

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Abstract

A profiling underwater radiometer was used for the first time in the waters around Indian Antarctic Station (70°46'S & 1 l°44'E) in the summer of 1994. The profiles include natural fluorescence (upwelled radiance at 683 nm), scalar irradiance (photosynthetically active radiation (PAR), computed primary production (pp), diffuse attenuation coefficient, and UVB (308 and 320 nm) and UVA (340 and 380 nm) radiation and ocean temperature all measured as a function of depth from 21/1/94 to 673/94. Fifteen stations in the Antarctic waters (69°53' to 70°02'S) and 6 *en route* (64°53' to 30°01'S) were analysed. The average values for surface chlorophyll *a* and pp were higher for temperate than for Antarctic waters (1.68 mg/m^3 and 216.56 mgC/m^3/d respectively). The values for column chlorophyll (22.48 mg/m^2) and primary productivity (1023.79 mgC/m^2 /d) in the Antarctic waters however, were 2.14 and 1.5 times higher than those in temperate waters. Interestingly, significant positive correlations were observed between primary productivity and PAR, UVA, UVB in the Antarctic and Temperate surface waters. Significant *r* values were obtained between pp and the above parameters in the Antarctic sub-surface waters determined at discrete depths of 10, 20, 30 and 40 m. However, when the primary productivity values were normalised for PAR, a more negative effect was noticed at the Antarctic surface waters. This response in the photosynthetic parameters could be due to the varied effect of UVA and UVB on phytoplankton.

Introduction

Though the ozone hole was observed in the late 70s it is now a predictable springtime event (Mc Minn *et al,* 1994). It is an effect resulting from air pollution, polar vortex and other characteristics of the polar stratosphere. The subsequent negative effect on the Antarctic phytoplanktop in not totally un-equivocal. Just as there are enough evidences to show amply the deleterious effect of UVB and UVA on the phytoplankton and other living 1989, community, (Roberts, 1989; Karenz, 1991) there are other studies to show that there is enough photoadaptibility to overcome the deleterious effects (Marchant *et al.,*

1991; Helbling *et al.*, 1992; Mc Minn *et al*, 1994). It is pointed out that any changes that the spectrum of light had to bring, have already taken place and that future changes in the relative composition of the diatom community are likely to be insignificant (Mc Minn *et al.*, 1994). This is further supported by the observation that the Shannon diversity index shows that the UVB radiation had little effect on the planktonic community. However, the studies of UVB and phy toplankton growth are difficult to generalize in a consistent, quantitative framework. (Neal, 1987; Stride and Anderson, 1994). The weight of the results indicate that environmental UV can inhibit the growth of many phytoplankton and sensitivities differ between species and strains. The potential UVB stress is broad scale and the response of marine ecosystems involves many spatial and temporal scales and also involves subtle changes that may be difficult to decipher (Marchant *et al.*, 1991). Thus the effects range from cellular level damage to physiological impairment and reduced reproduction and mortality. UVB penetration into the sea, varies with turbidity, concentration of DOM, absorption by plants and other factors. In spite of the variance in UVB attenuation in space and time, the global concern revolves around the ecological impacts upon the biologically active surface layers. However, the Antarctic waters are extremely transparent owing to the low concentration of cells, particulates and dissolved substances, resulting in maximum UV penetration (Romenkevich and Peresypkin, 1993). Phytoplankton respond to this stress by shifting pigment content of cells by producing photoprotective mycosporine amino acids (Carreto *et al*, 1990; Karentz *et al.* 1991). In the light of the above divided opinion on the net effect of UV light on Antarctic primary productivity (pp), it was relevant to check what results would come forth from the under-water profiling radiometer that not only gives the *in situ* data on the UV penetration (308,320,340 and 380 m) but also computed values of pp in relation to depth. The present paper compares the chlorophyll (chl *a)* and pp values of an anchored station in Antarctica (69°57'S & 11°55'E) with that of a few temperate stations *en route* and discusses the effect of UV light on the pp in those waters in that season.

Materials and Methods

A profiling underwater radiometer (Biospherical Instruments Inc. San Diego, CA, USA) was used to procure data on chlorophyll a (chl a) derived from natural fluorescence (upwelled radiance at 683 nm, scalar irradiance-PAR (photosynthetically available radiation), diffuse attenuation coefficient (K), computed primary production (pp), UVB and UVA radiation as function of depth from 15 stations in the Antarctic waters (69°53' to 70°02'S) and 6 stations

from Temperate waters (64°53S to 30°01'S). The instrument enables to assess the effect of sub-surface transmission of UVR in aquatic environments.

Results and Discussion

Photosynthesising plants are not only dependent on the incoming radiation, but also emit a light of their own. Natural fluorescence is the solar stimulated fluorescence of chlorophyll in the phytoplankton community. Measurements of natural fluorescence is a new optical method of assessing both gross photosynthetic rate and chlorophyll concentration within the water column and is a cost effective, rapid non-invasive technique (Chamberlain 1990; *et aL,* Chamberlain and Marra 1992; Keifer et al, 1989). Increased UVB during astral spring ozone hole decreased primary production by 6-12% in the marginal *ice* zone (Smith *et aL,* 1990). Many organisms are under UV stress depending upon the geographical position and also the time of the year (Gerber and Hader, 1994). The metabolic machinery keep adjusting to changes in irradiance (Lewis eral, 1984).

It has been thus possible to measure this net effect on chlorophyll values and primary productivity for the first time in these waters using the under water radiometer. Fig. 1 shows a typical profile taken on the 3rd of February 1994 in the anchored station. The depth of penetration of different wavelengths is seen with UVB at 308 nm penetrating upto 8.5 m and UVA at 380 nm upto 60 m.

Figs 2 and 3 show the monthwise variation in the column chl *a* and pp values at anchored station. February recorded the maximum for chl *a* and pp with a mean of 42.05 mg/m^2 and 1551.82 mgC/m^2 respectively followed by January with a mean of 12.17 mg/m^2 and 798.28 mgC/m^2. A column productivity of greater than 2000 mcg/m^{-2} /d^{-1} has been noticed in this study in a profi le taken on the 28 of February. Earlier studies have shown that the coastal waters of the ice shelf zone showed higher values than the off shore waters.

The mean of the column chlorophyll *a* content in the euphotic zone for the period 1 st Jan to 29th Feb 1984 was 39.15 mg m^{-2} and this value is much higher than the offshore value of 9.6 mg m^{-2}. In the ice edge the Jan value of 45.0 mg m^{-2} had been recorded. Production was not consistently high though values as high as 1.8 g.C m^{-2} d^{-1} have been encountered in Jan and Feb (Pant 1986). Matondkar and Qasim have reported primary productivity values ranging from 0.021- 9.95 mgCm^{-3} d^{-1} (1983). Verlencar and Parulekar (1987) have shown that *a* mean chl a value of 1.72 ± 1.0 µgl^{-1} and pp 1.27 ± 1.0 mgcm^{-3} hr^{-1} in the ice shelf zone to be more productive than offshore Oceanic waters where the corresponding mean values were 0.28 ± 1µgl^{-1} and 0.31 ±0.1 mgCm^{-3} hr^{-1} Primary productivity in the range of 0.39 - 2.02 g/m^{2} /d^{-1} have been reported

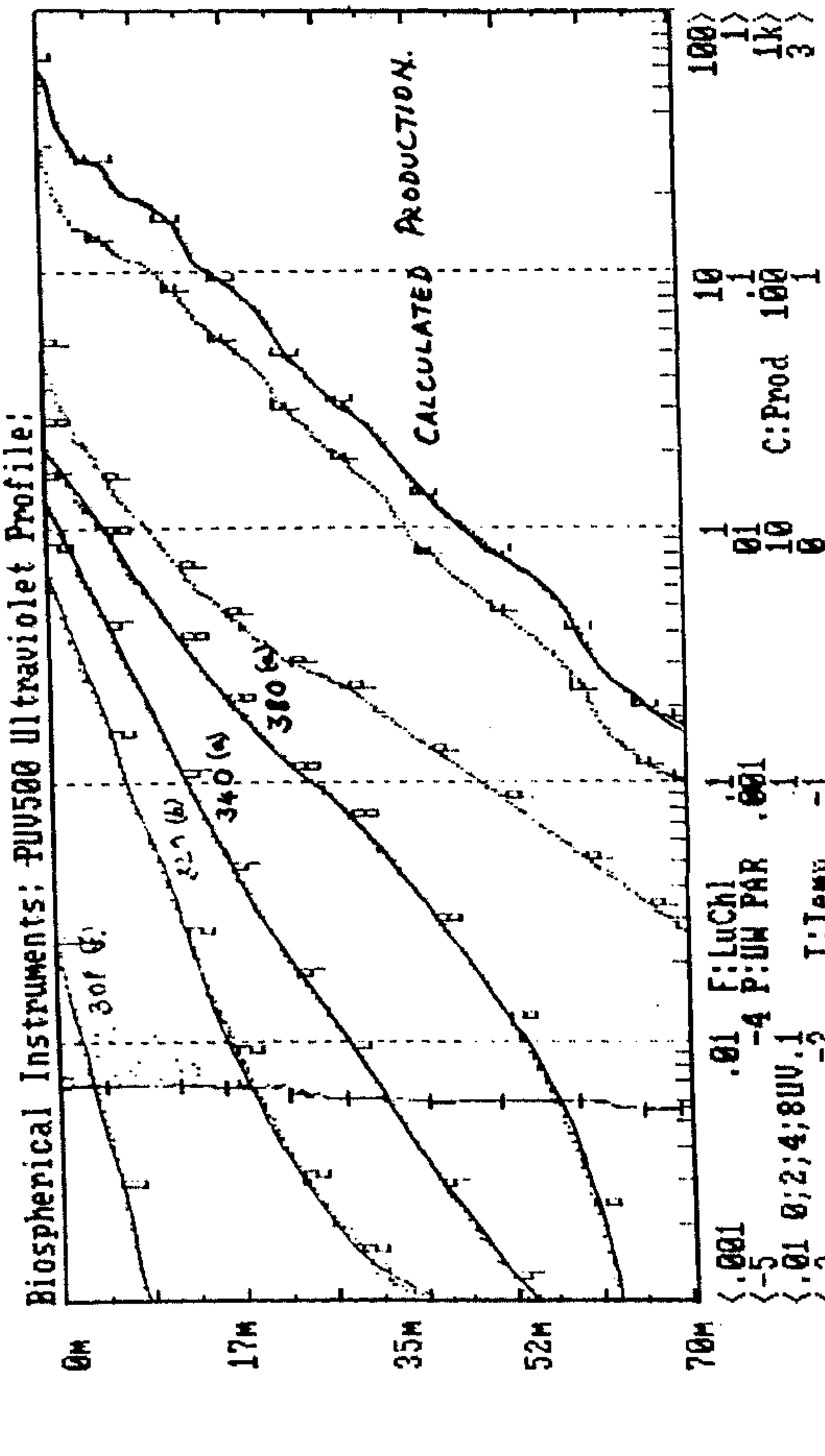
Biospherical Instruments: PUV500 Ultraviolet Profile!
0M
17M
35M
52M
70M
F:LuChl
P:UW PAR
T:Temp
C:Prod
CALCULATED PRODUCTION.
340 (n)
380 (n)

Fig.1

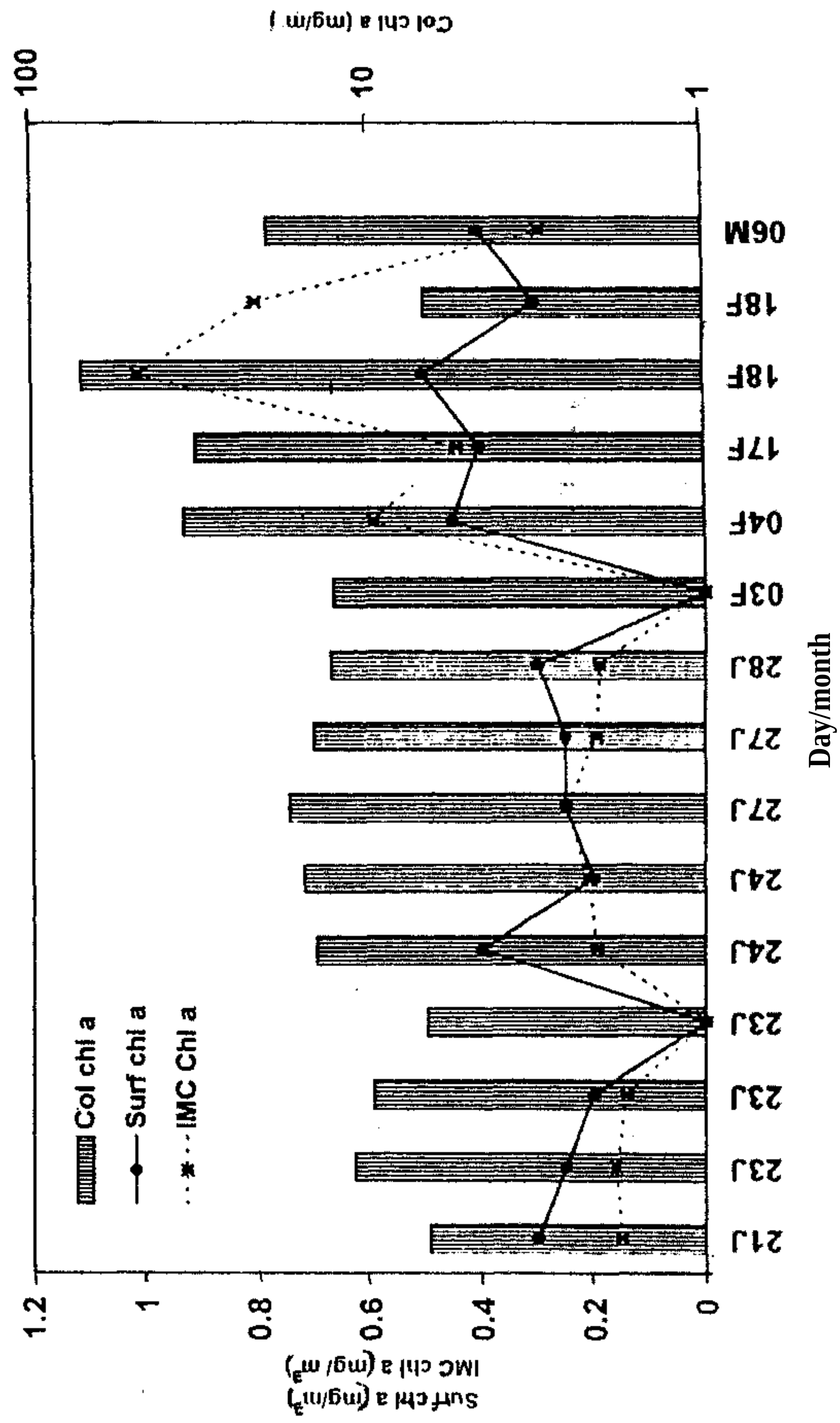

Fig.2 : Surface (mg/m^3, column (mg/m^2) & IMC chlorophyll values at the anchored station (69°57'S & 11°55' E)

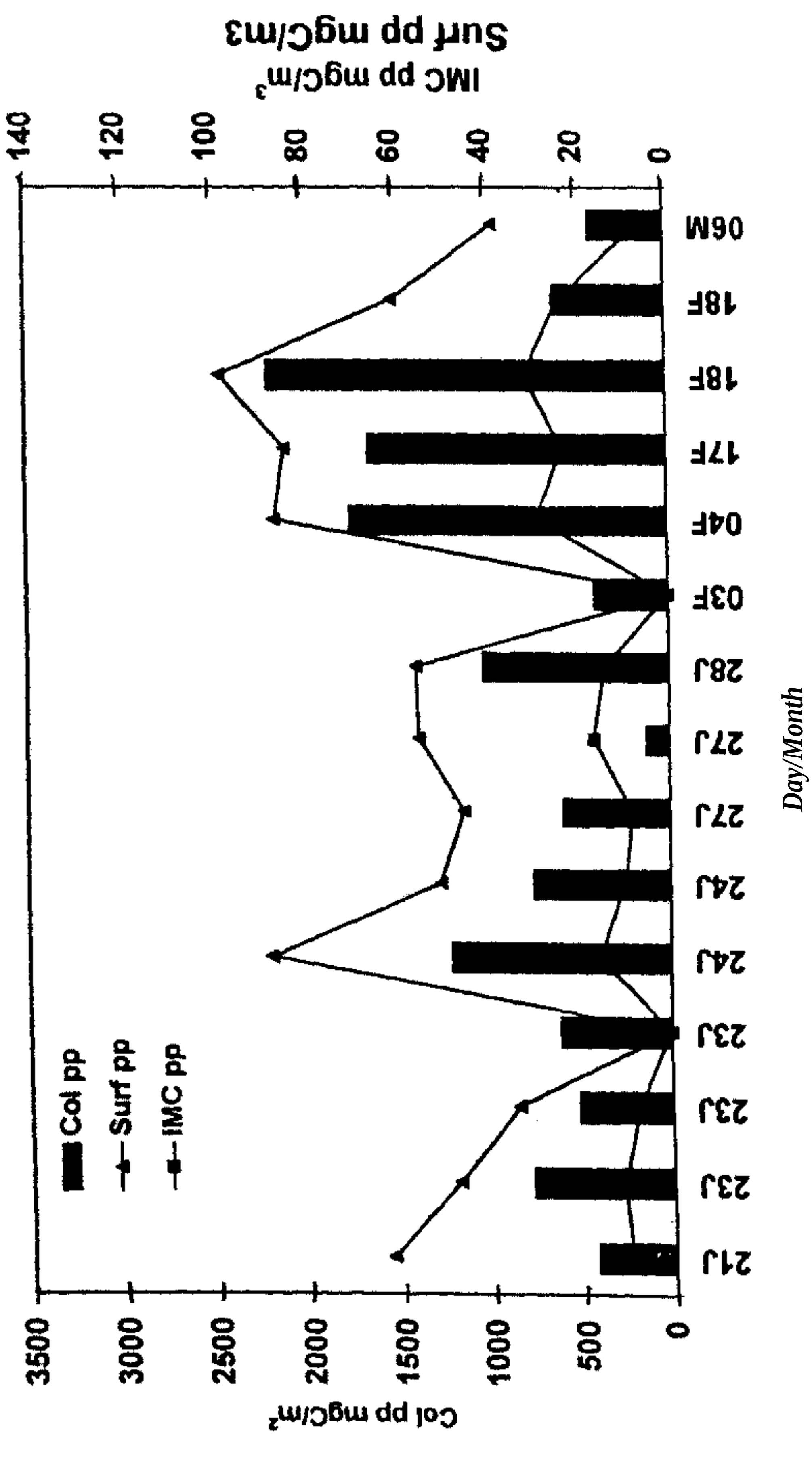

Fig.3 : Surface (mgC/m³/d), column (mgC/m²/d) & IM productivity values at the anchored station (69°57' S & 11° 55'E)

forMcMurdo sound by Barry (1988). Our values measured with the underwater radiometer near the ice edge fall close to the values reported.

Tests on analysis of variance (ANOVA) on monthwise variation in chl and pp at anchored stations revealed highly significant differences in pp at 0.1% level P<0.001; f 17.45 (2.12) and in Chl at 1% level P<0.01; f 7.59 (2.12).

Figures 4 and 5 represent latitudinal variation in column chl and pp. A major peak in chl and pp was observed at 69°S and a minor one at 54°S.

Depthwise variation in column productivity was found significant at 0.1 % level (P<0.001; f=29.47 df=6.92). Maximum production was recorded at 0-10 m depth (av. 444.37 mgC/m^2 /d^1).

Table 1 presents the minimum, maximum, mean and standard deviation values. It can be seen that though the surface chl is higher in the temperate stations, the column and IM values were higher in the Antarctica. Though the surface and IM values for pp were higher in the temperate regions the average column values were higher in the Antarctic by 1.4 times. The depth of light penetration being greater accounts for the higher column chl and pp values in the latter.

Regression analysis on surface & column chl and pp with their respective integrated mean concentration at Antarctic and Temperate waters indicated significant relationship between surface chl, pp and IM values. This could indicate that the high column also meant high surface values. The level of

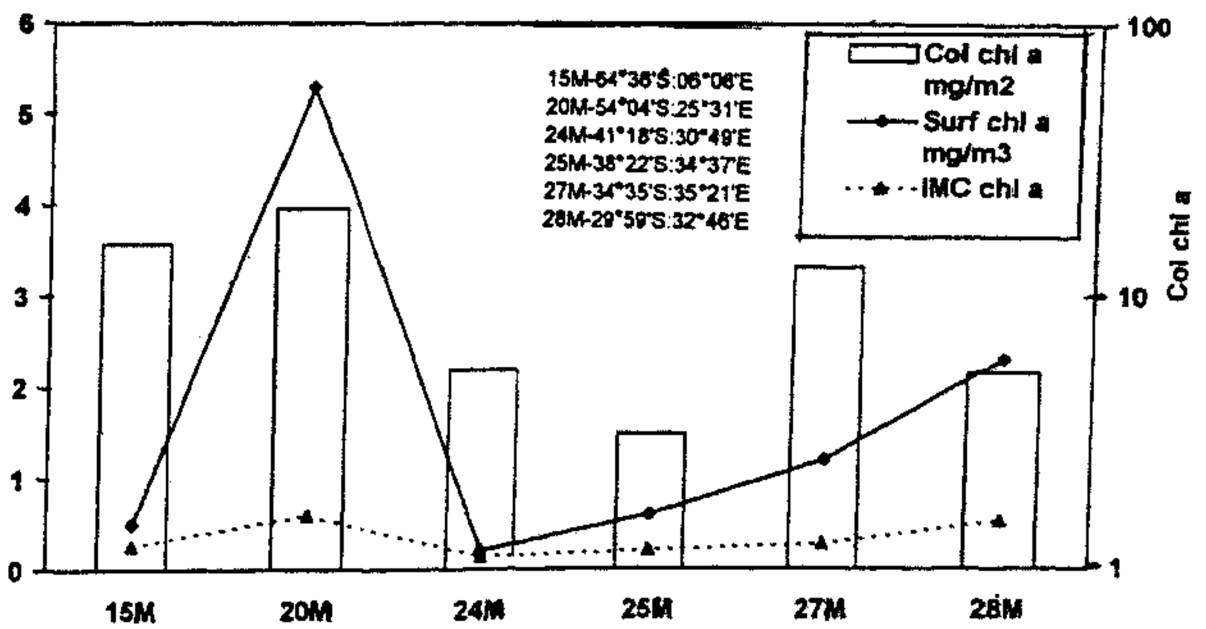

Fig.4: Concentration of chlorophyll at the surface & in the column along with their integrated means in the temperate waters

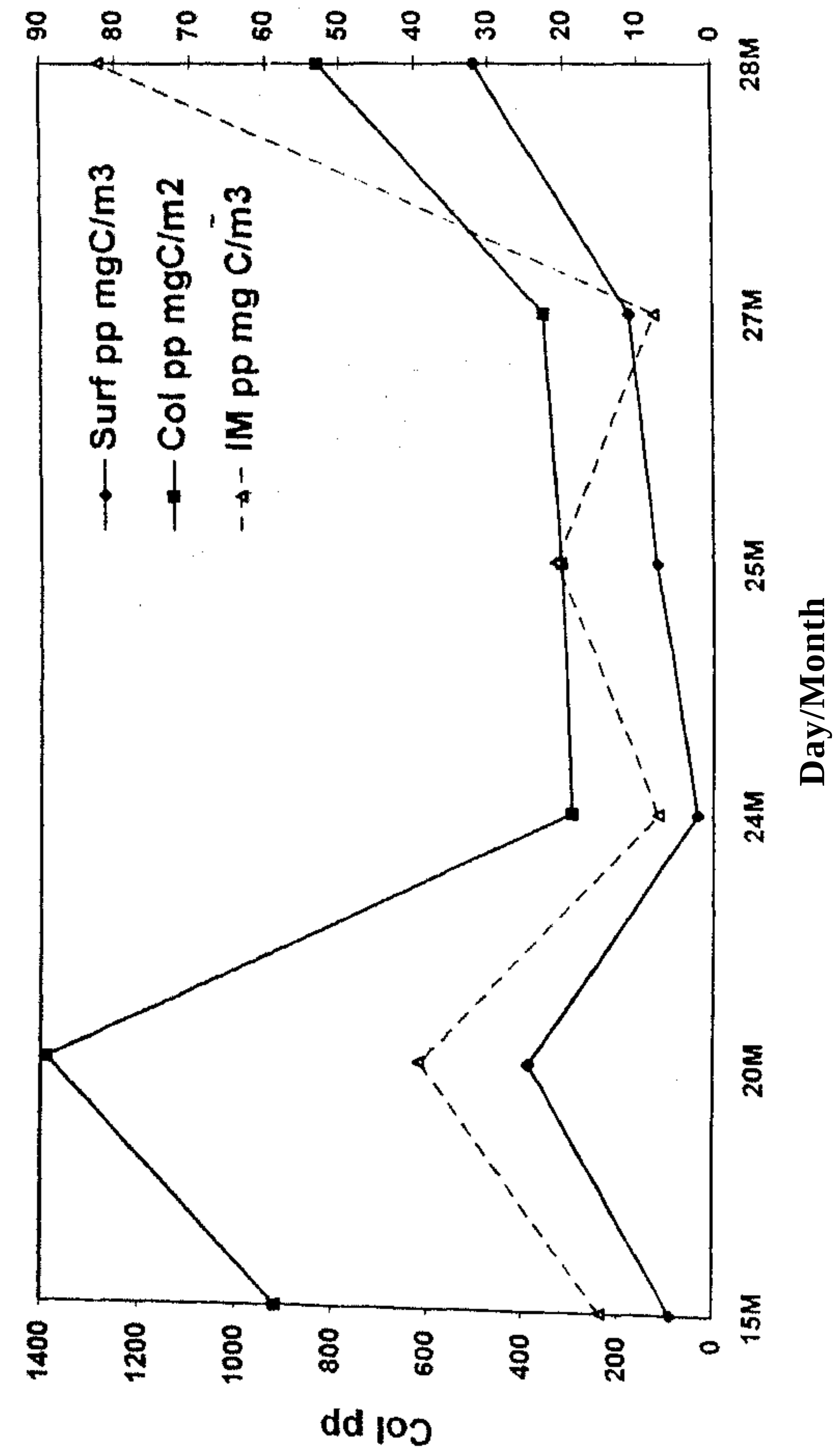

Fig.5 : Surface, column & IM productivity values in the temperate waters

significance was comparatively higher at Antarctic waters (r= 0.78,P<0.001, for chl & IMC and r=0.85, P<0.001, for pp and IM values). At Temperate waters the significance was only at 1% level (P<0.01, r=0.91) for both chl and pp.

Table 2 presents some of the regression values obtained between the UV light (UVB—308 and 320 nm; UVA — 340 and 380 nm) and productivity in these waters. Intriguingly positive correlation was observed between pp, PAR, UVA and UVB in surface and subsurface waters at Antarctic and Temperate waters with highly significant positive correlation at Antarctic waters. How-

Table 1: A Comparison of the Chlorophyll and Primary Productivity Values in the Temperate and Antarctic Waters

	Surface Chl		Column Chl		IM Values	
	Temp	Ant	Temp	Ant	Temp	Ant
Min	0.2	0.2	3.13	6.75	0.14	0.14
Max	5.3	0.5	21.00	71.00	0.60	1.01
Mean	1.68	0.32	10.5	19.18	0.34	0.36
STD	±1.92	±0.1	±7.05	±16.65	±0.19	±0.28
	Surface pp		Column pp		IM values	
Min	32.68	33.86	296.93	410.13	7.43	5.91
Max	497.13	97.93	1388.06	2192.23	82.26	31.32
Mean	216.56	61.97	683.13	953.74	28.97	15.97
STD	±184.27	±20.67	±437.91	±563.54	±28.66	±18.45

Table 2: Relationship between PP, UVA & UVB before and after Normalization with PAR at Temperate and Antarctic Surface and Sub-surface Waters

	Surface			
	Temperate		Antarctic	
	PP	PP/PAR	PP	PP/PAR
	0.542	-0.347	0.491**	-0.776**
UVA[1]	0.495	-0.388	0.438	-0.774
	0.594	-0.175	0.456**	-0.675**
UVB[2]	0.702	-0.303	0.523	-0.768
PAR	0.321	—	0.641**	—
	Subsurface			
	0.170	-0.047	0.416*	-0.195
UVA	0.183	-0.063	0.420	-0.187
	0.041	-0.468*	0.408*	-0.158
UVB	0.147			-0.177
PAR	0.075	—	0.542**	—

*P<0.01; **P< 0.001

1 — 340,380 nm; 2–308,320 nm

ever, when the pp values were normalised for PAR, the relationships between PP/PAR, UVA and UVB were found to be negative at both surface and subsurface waters of Antarctic and Temperate region with more negative impact in Antarctic surface waters (P).

It is inferred that intense UV light tends to reduce chl synthesis at the surface. Secondly though the UV light gets attenuated at the surface, light penetration is more in these clearer waters. Therefore column pp is higher in the Antarctic station.

It has been pointed out that the photochemical conversion of DOM is important for the turnover of Carbon (Mopper et al, 1991). The reactive transient species due to UVB influenced production could have important biological consequences. (Mopper and Zhen, 1990). Hence the significance of relating UVB related effects to photochemistry is slightly stressed (Cullen and Neale, 1994). UVB suppresses bacterial activity and promotes photolytic cleavage of macromolecules thus substituting bacterial enzymatic activity (Herndl et al, 1993). It has been pointed out by Bhattathiri (1990) that in a 24 hour observation in one of the stations in the Polynya the surface value of chlorophyll and productivity was almost equal to the coastal waters of the continent. It was further observed that despite the abundant nutrient and sufficient light energy the population was patchy and the density as low as perhaps the oligotrophic waters. Karentz and Lutz (1990) showed that UVB can be transmitted to a depth of 10M and that biological effects could be detected up to 20-30 m. In our studies the profiles showed that UVB can penetrate up to 35 m and UVA up to 60 m. A column productivity of greater than 2000 $mgC/m^{-2}/d^{-1}$ has been noticed in this study in the 28F profile. Primary-productivity in the range of 0.39-2.02 $g/m^{2}/d^{-1}$ have been reported for Mc Murdo sound by Barry (1988). Our values fall within this range. However, use of different biological weighting functions could give varied insight of the influence of UVR on column productivity.

Conclusion

As surface irradiance is deleterious, damage due to UVA is greater than that due to UVB in the Antarctic surface and sub-surface waters. This effect is also seen in the surface waters of the temperate region. Though the shorter wave length UVB (280 to 320 nm) is absorbed faster and therefore more damaging the longer UVA (320 to 400 nm) could be still more damaging, if not by its energy at least by its extensive reach i.e. its greater flux (Cullen and Neale, 1994). It is therefore concluded that the greater productivity in the Antarctic

waters is due to higher quantum of light received. However when this is normalised for PAR, the negative influence of UV is discernible.

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